3-72

Synthesis on Lane Widths on Urban and Suburban Arterials

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by

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DISCLAIMER

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SUMMARY

This synthesis presents a review of current literature and state and local highway agency policies and practices related to lane width on urban and suburban arterials. The synthesis documents current knowledge and practice concerning the advantages and disadvantages and the safety and operational tradeoffs of a range of lane widths for urban and suburban arterials, including 2.7-, 3.0-, 3.3-, and 3.6-m (9-, 10-, 11-, and 12-ft) lanes. Lane widths greater than 3.6 m (12 ft) are also evaluated, primarily for shared use by motor vehicles and bicycles. The research included an extensive review of literature and a survey of practice reported by highway agencies in 40 states and 35 cities and counties. The survey of highway practice focused on current design practices for lane width and traffic operational and safety experience with lanes of different widths.

The geometric design practices related to lane width must consider the needs of motor vehicle, pedestrian, and bicycle traffic. The AASHTO *Policy on Geometric Design of Highways and Streets* (*1*), commonly known as the *Green Book*, offers guidelines on the selection of appropriate lane widths on urban and suburban arterials considering primarily the needs of motor vehicle traffic. In Chapter 7 of the *Green Book,* lane widths from 3.0 to 3.6 m (10 to 12 ft) are addressed along with specific circumstances for which each width should be considered. The desirable widths of various auxiliary lanes are covered, along with associated warrants for each, in Chapter 9. The highway agency survey found that some agencies consider using lane widths at midblock and intersection locations outside of the minimum and maximum values set by the *Green Book.* The highway agency survey also identified factors that responding agencies consider when selecting lane widths on urban and suburban arterials.

Pedestrian issues involving lane widths are more prominent at intersections than at midblock locations on urban and suburban arterials. Since pedestrians are more likely to cross a roadway at the intersection, rather than at a midblock location, the majority of pedestrian/vehicle interaction takes place at intersections. It has been established in previous research that excessive crossing distances at intersections can be intimidating for pedestrians. Thus, provision of a shorter crossing distance provides a more pedestrian friendly intersection. Shorter crossing distances can be achieved using a combination of narrower lane widths and smaller curb radii on new designs or by reconstruction and narrowing of existing roadways to provide raised median islands or curb return bulbouts. However, beyond the evident advantages for pedestrians, the potential disadvantages for motor vehicle and bicycle traffic of providing narrower lanes on urban arterials needs to be considered. The highway agency survey identified pedestrian issues that responding agencies considered in determining lane widths on urban and suburban arterials.

The addition of a bicycle facility can have a direct effect on lane width along urban and suburban arterials because of the space required. The types of on-road bicycle facilities that affect lane widths include a shared lane, a wide curb lane, and a bicycle lane. Most bicycle travel takes place on roadways with no dedicated space for bicyclists, or shared lane facilities. When additional width is allocated to the outside vehicle lane for bicycle use, it is termed a wide curb lane (WCL). Bicycle lanes are portions of the roadway, designated by striping, signing, and pavement markings, for the exclusive use of bicycles. Wide curb lanes and bicycle lanes are particularly beneficial in that they offer improved safety and maneuverability for bicyclists and vehicles. Guidelines for accommodating bicycle traffic in most riding environments are presented in the AASHTO *Guide for the Development of Bicycle Facilities* (*2*). Many important bicycle issues were cited by highway agencies that responded to the highway agency survey.

Traffic operational effects of lane width on urban and suburban arterials, including saturation flow rates at intersections, pedestrian signal timing, and running speeds at midblock locations, are discussed. Previous research has identified lane width, among other geometric elements, as a factor that directly affects the saturation flow rate at intersections. Lane width also affects pedestrian crossing times at both intersection and midblock crossings. At signalized intersections, reducing the pedestrian crossing distance can usually improve the signal timing of the intersection. Limited research has been conducted to evaluate the effect of lane width on vehicle running speeds at midblock locations.

A number of past studies have been conducted to determine the traffic safety effects of lane width, but the results of these studies are varied. Despite the extensive research that has been conducted on the effect of lane width on motor vehicle safety, it is difficult to draw any definite conclusions about the relationship. While many countermeasures have been identified to reduce crossing distance at intersections for pedestrians, no studies have documented the effect of lane width on pedestrian safety. Several studies are presented that indirectly addressed bicycle safety issues related to lane width. However, no studies have determined a quantitative relationship between lane width and bicycle safety. Researchers do agree that increasing the space between bicyclists and vehicles should result in increased bicycle safety. A number of methodologies have been established to rate the perceived level of comfort for bicyclists on arterial roadway facilities in urban and suburban settings.

This synthesis summarizes the advantages and disadvantages of using narrower lane widths on urban and suburban arterials. These advantages and disadvantages reflect the current knowledge and experience of highway agencies concerning lane widths. There are many unresolved issues concerning lane widths that indicate a need for further research.

CHAPTER 1.

INTRODUCTION

BACKGROUND

Urban and suburban transportation corridors are becoming increasingly congested. At the same time, adding width to roadways and streets often results in higher running speeds and increased pedestrian crossing distances, which in turn can act to decrease the safety and livability of the communities through which the roadways and streets pass. Further, additional space for roadways and walkways is often extremely limited or simply not available. Therefore, it is important that the roadway width be optimized in terms of safety and operational efficiency. Lane widths of 3.0, 3.3, and 3.6 m (10, 11, and 12 ft) are the most commonly used in these situations. Traditionally, the wider lane has been thought to maximize operational capacity. Recently, questions have been raised concerning whether narrower lanes may have similar capacity capabilities and perhaps enhanced safety characteristics compared with the wider lanes in low-speed applications.

OBJECTIVES AND SCOPE

The objective of this synthesis is to document current knowledge and practice concerning the selection of lane width on urban and suburban arterials. The synthesis addresses the advantages and disadvantages and the safety and operational tradeoffs of a range of lane widths for urban and suburban arterials, including 2.7-, 3.0-, 3.3-, and 3.6-m (9-, 10-, 11-, and 12-ft) lanes. Lane widths greater than 3.6 m (12 ft) are also addressed, primarily for shared use by motor vehicles and bicycles. Effects of lane width on the pedestrian, bicycle, and vehicle modes of travel are presented. The preparation of this synthesis included a critical review of relevant literature and a highway agency survey to determine the current practices of state and local highway agencies.

This synthesis was prepared as part of NCHRP Project 3-72, *Lane Widths, Channelized Right Turns, and Right-Turn Deceleration Lanes* and includes the results of research performed for that project will involve data collection and analysis to better understand the traffic operational and safety effects of different lane widths on urban and suburban arterials. Separate syntheses have been prepared to address channelized right turns and right-turn deceleration lanes on urban and suburban arterials.

ORGANIZATION OF THIS SYNTHESIS

This synthesis is organized as follows. Chapter Two addresses the geometric design of lane widths, based on highway agency policies and practices. Chapter Three summarizes current knowledge concerning traffic operational effects of lane widths, and Chapter Four summarizes current knowledge concerning traffic safety effects of lane widths. Chapter Five presents a summary of the advantages and disadvantages of various lane widths. Appendix A presents the questionnaire used in the highway agency survey, while Appendix B summarizes the survey results concerning lane width.

CHAPTER 2.

GEOMETRIC DESIGN

This chapter presents geometric design issues related to lane width, taking into consideration motor vehicle, pedestrian, and bicycle modes of travel. Survey data from state and local highway agencies concerning lane width design practices and policies as they relate to the three modes of travel are also summarized.

GEOMETRIC DESIGN FOR MOTOR VEHICLES

The AASHTO *Policy on Geometric Design of Highways and Streets* (*1*), commonly known as the *Green Book*, provides guidance on the selection of lane width on urban and suburban arterials primarily to accommodate motor vehicle traffic. Chapter 7 of the *Green Book* addresses the use of lane widths from 3.0 to 3.6 m (10 to 12 ft) and identifies the presence of truck traffic and speed as key factors in the choice of lane width. Chapter 9 addresses the width of auxiliary lanes and median left-turn lanes.

In Chapter 7, the *Green Book* states that 3.0-m (10-ft) lanes should be used in restricted areas with little or no truck traffic; it is also stated that 3.6-m (12-ft) lanes are most desirable and should be used, where practical, on higher-speed arterials. The *Green Book* suggests the use of reduced lane widths in lower speed areas (70 km/h [45 mph] or less) to allow more lanes to be provided in areas with restricted right-of-way and to provide shorter pedestrian crossing distances. It states that lane widths of 3.3-m (11-ft) lanes are used extensively for urban arterial street designs, but no specific criteria are provided. However, the *Green Book* provides specific guidance on the types of lanes for which a reduced width is appropriate:

"A 3.3-m (11-ft) lane width is adequate for through lanes, continuous two-way left-turn lanes, and lanes adjacent to a painted median. Left-turn and combination lanes used for parking during off-peak hours and for traffic during peak hours may be 3.0 m (10 ft) in width."

Where substantial truck traffic is anticipated, additional lane width may be desirable.

In Chapter 9, the *Green Book* states that auxiliary lanes should be at least 3.0 m (10 ft) wide and should, desirably, be equal to the width of the through lanes. A median left-turn lane should be 3.0 to 3.6 m (10 to 12 ft) wide.

GEOMETRIC DESIGN FOR PEDESTRIANS

Pedestrian crossing distance at intersections and midblock crossings is an important factor in the design of urban and suburban arterials. Intersections are often the best and most direct place for pedestrians to cross a roadway and are the most common pedestrian crossing locations (*3*). However, intersection crossings can be intimidating for pedestrians if the crossing distance is excessive.

At the intersection proper, the curb radii significantly affect lane width and crossing distance. The selection of an appropriate curb radius should take into consideration the safety, operations, and convenience for both motorists and pedestrians. Curb radii should be appropriate to accommodate the design vehicle for the intersection, but at the same time, it should be recognized that larger curb radii have disadvantages for pedestrians. In particular, the curb radius significantly impacts the crossing distance for pedestrians. Figure 1 illustrates the effect of curb radius on pedestrian crossing distance. The impact of curb radii on crosswalk distance is also illustrated in Figure 2, based on the assumptions that (a) the sidewalk centerline at a right-angle intersection is in line with the middle of a border and (b) the same curb radius is used at all four corners of the intersection.

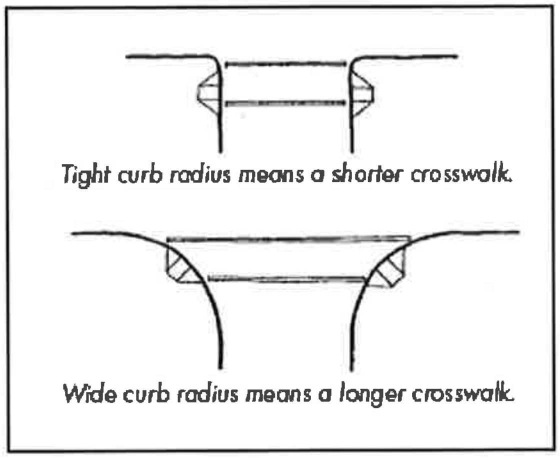
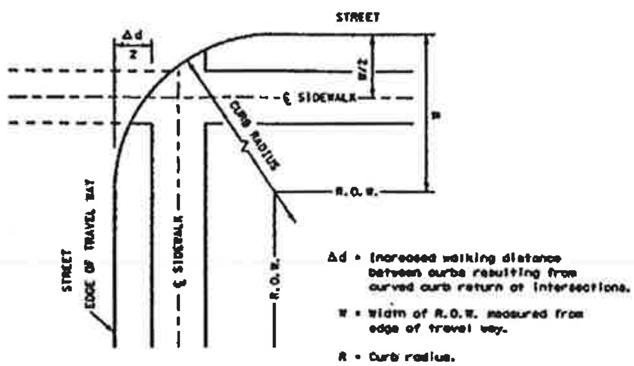


Figure 1. Differences in crossing distances due to tight and wide curb radii (4).



CURB RADIUS, R	ADDED CROSSWALK DISTANCE Δd	
	W = 3m [10 Ft]	W = 6m [20 Ft]
METERS (FEET)	METERS (FEET)	METERS (FEET)
3 [10]	0.8 [3]	0.0 [0]
6 [20]	4.0 [14]	1.6 [5]
9 [30]	8.0 [27]	4.6 [15]
12 [40]	12.4 [42]	8.1 [27]
15 [50]	16.9 [57]	12.0 [40]

Figure 2. Variations in crosswalk lengths due to different curb radii and width of borders (1).

The *Florida Pedestrian Planning and Design Handbook* (*5*) recommends that a median be installed at intersections whenever the crossing distance exceeds 18 m (60 ft) to provide a refuge for slower or late crossing pedestrians. This implies the maximum desirable pedestrian crossing distance is 18 m (60 ft). Pietrucha and Opiela (*6*) recommend that pedestrian refuge islands be provided when crossing distances exceed 23 m (75 ft).

It is more desirable for pedestrians to cross roadways at intersections than at midblock locations because midblock crossings are not generally expected by motorists. However, at specific locations where intersections are spaced relatively far apart or substantial pedestrian generators are located between intersections, midblock crossings may be desirable so pedestrians do not have to make excessive or inconvenient diversions in their travel path to cross at an intersection. At midblock locations where the crossing distance exceeds 18 m (60 ft), AASHTO (*2*) recommends a median or crossing island be considered to help pedestrians cross the roadway in two stages.

GEOMETRIC DESIGN FOR BICYCLISTS

In the design of urban and suburban arterials, it may be desirable to allocate specific areas of the roadway cross section for use by bicyclists. The provision of bicycle facilities, in most cases, directly affects the width of vehicle lanes because part of the roadway cross section intended for vehicle lanes may need to be reallocated to a bicycle lane. The types of on-road bicycle facilities that affect lane widths include a shared lane, a wide curb lane, and a bicycle lane. A shared lane facility is one in which motorists and bicyclists share a standard traffic lane. A wide curb lane is a single lane shared by bicyclists and motorists with an extra amount of space allotted primarily for bicycle use. Bicycle lanes are established within the traveled way using appropriate pavement markings and signing along the roadway. A striped bicycle lane delineates specific portions of the roadway for bicyclists use and for motorized traffic.

Shared Lane

Most bicycle travel in the United States occurs on streets with shared lane facilities, that is, on streets with no special accommodations for bicyclists. In many cases, the existing roadway system and standard travel lane widths are adequate for efficient motor vehicle and bicycle travel. In some cases, simply designating a roadway as a bicycle route through the use of signing is sufficient to indicate to all users that the particular roadway is suitable for bicycle traffic, and that motorists may expect to encounter bicyclists on this designated roadway (*2*).

Wide Curb Lane

A wide curb lane (WCL) is the lane found closest to the curb and is designed wider than the standard lane to allocate extra space for the shared use of motor vehicles and bicycles. WCL advocates feel this shared use arrangement allows for improved safety as bicyclists operate and maneuver more like motor vehicles. This design is relatively simple to implement within an existing roadway by reducing the width of either adjacent through lanes or turn lanes to provide the needed space for the WCL.

The ideal width, recommended by AASHTO (*2*), for WCLs is from 4.0 to 4.6 m (14 to 15 ft); this is an increase from a standard lane width of 3.6 m (12 ft). Research has shown that lane widths narrower than this do not provide enough room for bicycles and motor vehicles to operate adjacent to one another and lead to motor vehicles encroaching upon adjacent lanes. Also, wider lane widths may encourage vehicle drivers to operate side-by-side in a single lane and, therefore, are not recommended (*7*). The selection of a proper lane width must take into account such obstructions as raised drainage grates, raised pavement markers, or on-street parking which can impede on the space used by bicyclists (*2*).

Bicycle Lane

The AASHTO *Guide for the Development of Bicycle Facilities* (2) defines a bicycle lane (BL) as "a portion of a roadway which has been designated by striping, signing, and pavement markings for the preferential or exclusive use of bicyclists." For lanes designed for the exclusive use of bicycles, AASHTO recommends lane widths between 1.2 and 1.5 m (4 and 5 ft) and indicates that BLs should be delineated from other lanes by a 150-mm (6-inch) solid white line. However, there are some local agencies, such as the City of Chicago Department of Transportation, who do not stripe bike lanes any less than 1.5 m (5 ft) (*8*). In some roadway conditions where there is substantial truck traffic or high-speed vehicle traffic, additional width may be desired. In addition, a 3.6-m (12-ft) minimum width is suggested by AASHTO for lanes shared by bicycles and parked cars (*2*). Within the bicycle lane, standard pavement marking symbols should be provided along with a directional arrow to inform bicyclists and motorists of the bicycle lane presence.

Selection of Bicycle Facilities

King (*9*) developed a series of tables/matrices that illustrate different policies used to select a bicycle facility type for a given roadway. The tables/matrices include measures, such as posted speed limit and traffic volume ranges, that are used in selecting the type of bicycle facility. Several of these tables/matrices are provided below. Table 1 illustrates policies established in the Netherlands. Table 2 illustrates policies established by the Federal Highway

Administration (FHWA) in the United States, and Table 3 illustrates the practice of a state department of transportation (Minnesota).

TABLE 1. Matrix for Selecting a Bicycle Facility Based on Vehicle Speed and Traffic Volume (Netherlands) (*9*)

Facility	Vehicle speed (mph)					
	15	20	25	30	35	40
	Traffic volume (veh/day)					
N— Narrow lane	8,000	–	–	–	–	–
W— Wide lane	–	< 9,000	< 6,000	< 4000	< 2,000	–
B— Bike lane or shoulder	–	9,000 – 10,000	6,000 – 9,000	4,000 – 6,500	2,000 – 2,500	–
S— Separate lane or path	–	> 10,000	> 9,000	> 6,500	> 2,500	All

TABLE 2. Matrix for Selecting a Bicycle Facility Based on Vehicle Speed and Traffic Volume (FHWA) (*9*)

Facility	Vehicle speed (mph)					
	15	20	25	30	35	40
	Traffic volume (veh/day)					
N— Narrow lane	–	–	–	–	–	–
W— Wide lane	< 10,000	< 10,000	–	–	–	–
B— Bike lane or shoulder	> 10,000	> 10,000	All	All	All	All

NOTE: A separate lane/path is not included in the FHWA matrix.

TABLE 3. Matrix for Selecting a Bicycle Facility Based on Vehicle Speed and Traffic Volume (Minnesota) (*9*)

Facility	Vehicle speed (mph)					
	15	20	25	30	35	40
	Traffic volume (veh/day)					
N— Narrow lane	< 10,000	< 10,000	< 500	< 500	< 500	–
W— Wide lane	–	–	500 – 5,000	500 – 5,000	< 5,000	< 500
B— Bike lane or shoulder	–	–	> 5,000	> 5,000	> 5,000	> 500

NOTE: A separate lane/path is not included in the Minnesota matrix.

The AASHTO *Guide for the Development of Bicycle Facilities* (2) provides information on accommodating bicycle traffic on urban and suburban arterials. While it is not intended to be a design policy, it presents guidelines on designing a roadway that is sensitive to the needs of both bicyclists and other highway users.

SURVEY OF CURRENT HIGHWAY AGENCY PRACTICE

The highway agency survey reported in Appendix B of this synthesis indicates that 16 percent of state and local highway agencies use lane width design policies that are different from the *Green Book*. Approximately 15 percent of state highway agencies and 29 percent of local highway agencies indicated that they use different lane widths for midblock locations and signalized intersection approaches.

The narrowest lane width that responding state highway agencies consider acceptable on urban and suburban arterials ranges between 3.0 and 3.6 m (10 and 12 ft) for both midblock locations and signalized intersection approaches. The narrowest lane width considered by responding local highway agencies ranges between 2.6 and 3.6 m (8.5 and 12 ft) for midblock locations and between 2.4 and 4.2 m (8 and 14 ft) for intersection approaches. The factors that responding highway agencies consider in selecting an appropriate lane width for an urban or suburban arterial include:

- Established geometric design policies
- Potential interference with existing development
- Availability of space for a roadway median
- Availability of space for bicycle facilities
- Level of service considerations at signalized intersections
- Running speeds at midblock locations
- Level of service considerations at midblock locations
- Percent trucks in vehicle traffic mix
- Crossing time/distance for pedestrians
- Cost/right of way
- Availability of space for sidewalk
- Availability of space for left-turn lanes

- Availability of space for parking
- Crash rates

Based on the highway agency survey, many state and local highway agencies consider pedestrian issues in determining lane widths on urban and suburban arterials. The following pedestrian issues were cited as considerations:

- Crossing distance
- Crossing time
- Vehicle speeds
- Pedestrian volume
- Signal timing
- Pedestrian refuge islands
- Sidewalks
- Land use (pedestrian generators)
- Pedestrian safety
- Americans with Disabilities Act (ADA) accommodation
- Aesthetics/appearance to attract pedestrian movement

Many state and local highway agencies also consider bicycle issues in determining lane widths on urban and suburban arterials. The following bicycle issues were cited as considerations:

- Bicycle lane
- Wider curb lane

- Shoulders
- Established bike route
- Vehicle speed
- Bicycle volume
- Parking
- Right of way availability
- Bike paths
- Edge lines
- Vehicle mix
- Curb and gutter
- Surface type/condition
- Traffic volume
- Roadway type

Several highway agencies identified the AASHTO *Guide for the Development of Bicycle Facilities* (*2*) as a key resource for determining lane widths on urban and suburban arterials.

CHAPTER 3.

TRAFFIC OPERATIONS

This chapter discusses the influence of lane width on traffic operations on urban and suburban arterials. An understanding of the relationship between lane width and traffic operations is important in making decisions concerning urban and suburban arterials. Issues related to saturation flow rate at intersections, pedestrian crossing time, and running speeds at midblock locations are addressed.

SATURATION FLOW RATE AT INTERSECTIONS

A number of geometric elements, including lane width, affect the saturation flow rate at an intersection on an urban or suburban arterial. The relationship between each of these elements and saturation flow rate is discussed below.

Lane Width

Several studies have been conducted to evaluate the relationship between lane width and saturation flow rate at intersections. Zegeer (*10*) evaluated the saturation flow rates on approaches with lane widths varying between 2.6 and 4.7 m (8.5 and 15.5 ft). Saturation flow data were collected from 2,733 vehicles on eleven approaches with lane widths varying between 2.6 and 2.9 m (8.5 and 9.5 ft). Four approaches with lane widths varying between 3.9 and 4.7 m (13.0 and 15.5 ft) were also surveyed, with a sample size of 1,568 saturation flow vehicles. All baseline conditions except for lane width were held constant at these locations. The survey results were then compared with those of the baseline condition surveys (with a sample size of 6,687 saturation flow vehicles). The narrower lane widths demonstrated saturation flow rates between 2 and 5 percent less than did those in the baseline surveys, while the wider lane widths demonstrated saturation flow rates 5 percent greater than did those in the baseline surveys. Table 4 illustrates the proposed factors for lane width adjustments.

TABLE 4. Lane Width Adjustment Factors (*10*)

Width (ft)	Adjustment factor
8 – 8.9	0.95
9 – 9.9	0.98
10 – 12.9	1.00
13 – 15.9	1.05

A 1983 study by Agent (*11*) of the effects of lane width on saturation flow indicated that lane width did not have an effect on saturation flow for lane widths of 3.0 m (10 ft) or more. For lane widths between 2.7 and 3.0 m (9 and 10 ft), a 5 percent reduction in saturation flow was found compared to lane widths of 3.0 m (10 ft) or more. No lane widths below 2.7 m (9 ft) were observed. There was a slight unexplained reduction in saturation flow for lane widths greater than 4.5 m (15 ft). A similar analysis was performed with the limited data available for commercial vehicles, and no effect was found even for lane widths below 3.0 m (10 ft). Table 5 illustrates the effect of lane width on saturation flow.

TABLE 5. Effect of Lane Width on Saturation Flow (*11*)

Lane width (ft)	Total headway (sec)	Average headway (sec)	Saturation flow (vphg)[a]
9 – 9.9	858	2.29	1,572
10 – 10.9	2,839	2.16	1,667
11 – 12.9	11,089	2.18	1,651
13 – 14.9	2,454	2.18	1,651
15 or more	680	2.21	1,629
10 – 14.9	16,382	2.18	1,654
10 or more	17,062	2.18	1,653

[a] vphg—vehicles per hour of green time.

Potts et al. (*12*) evaluated saturation flow rates on signalized intersection approaches on urban and suburban arterials with lane widths varying between 2.9 and 4.3 m (9.5 and 14 ft). The sample size was 1,199 average headways, with each average headway based on at least four headway measurements per queue. All baseline conditions except for lane width were held constant at these locations. For analysis purposes, lane widths were grouped into three categories: 2.9 m (9.5 ft), 3.3 to 3.6 m (11 to 12 ft), and 4.0 m (13 ft) and greater. Lane width had a statistically significant effect on average saturation flow rate. The results of the research indicate that using narrow lanes (i.e., 2.9-m [9.5 ft]) on signalized intersection approaches on urban and suburban arteries resulted in an average saturation flow rate that is approximately 80 pc/h/ln, or 4.3 percent, lower than when 3.3- to 3.6-m (11- to 12-ft) lanes were used. Similarly, using wider lanes (i.e., 4.0 m [13 ft] or greater) resulted in an average saturation flow rate that is approximately 81 pc/h/ln, or 4.2 percent, higher than when 3.3- to 3.6-m (11- to 12-ft) lanes were used. The average saturation flow rate for each lane width category was:

Lane width category (ft)	Average saturation flow rate (pc/h/ln)	Standard error (pc/h/ln)
9.5	1,752	15
11 to 12	1,832	11
13+	1,913	19

Previous research (*13*) suggests that discharge headway is a function of a vehicle's position in the queue. To account for this relationship, Potts et al. adjusted the saturation flow rate data to account for the queue position of the last vehicle measured. The adjusted data showed a very similar relationship between lane width and saturation flow rate. That is, the adjusted average saturation flow rate for the 2.9-m (9.5-ft) lane width category was approximately 80 pc/h/ln, or 4.4 percent, lower than that for the 3.3- to 3.6-m (11- to 12-ft) lane width category. The adjusted average saturation flow rate for lane widths of 4.0 m (13 ft) or greater was approximately 82 pc/h/ln, or 4.4 percent, higher than that for the 3.3- to 3.6-m (11-

to 12-ft) lane width category. The average adjusted saturation flow rate for each lane width category was:

Lane width category (ft)	Average adjusted saturation flow rate (pc/h/ln)	Standard error (pc/h/ln)
9.5	1,736	15
11 to 12	1,816	11
13+	1,898	19

Based on the results presented above, the saturation flow rates that can be expected at signalized intersection approaches on urban and suburban arterials, under nearly ideal conditions, can be represented as a range between the *adjusted* and *unadjusted* values. Table 6 presents the average saturation flow rate range for each lane width category.

TABLE 6. Average Saturation Flow Rate Range for Each Lane Width Category

Lane width category (ft)	Average saturation flow rate (pc/h/ln)
9.5	1,736 to 1,752
11 to 12	1,816 to 1,832
13+	1,898 to 1,913

The HCM (*14*) provides saturation flow rate adjustment factors for lane widths that are greater than or less than 12 ft. Table 7 compares the saturation flow rate estimates based on HCM procedures to those measured in the current research. The table shows that the measured saturation flow rate values are generally lower than those obtained from HCM procedures. Furthermore, the percentage difference in saturation flow rate between sites with 2.9- to 3.6-m (9.5 to 12 ft) lanes was found to be about half the value used in the HCM. These findings should be considered as a basis for revisions to the HCM. In particular, there appears to be justification for revising the HCM lane width adjustment factors for lane widths less than 3.6 m (12 ft).

TABLE 7. Comparison of Saturation Flow Rate Values From This Research to HCM Values

	HCM (*14*)		Potts et al. (*12*)	
Lane width (ft)	Adjusted saturation flow rate[a] (pc/h/ln)	Percent difference from value for 12-ft lanes	Adjusted saturation flow rate[b] (pc/h/ln)	Percent difference from values for 12-ft lanes
9.5	1,751	–7.8	1,736	–4.4
11	1,848	–2.7	1,816[c]	–
11.5	1,880	–1.1	1,816[c]	–
12	1,900	0.0	1,816[c]	–
13	1,976	+4.0	1,898[d]	+4.5
14	2,041	+7.4	–	–

[a] The HCM saturation flow rates have been adjusted for lane width.
[b] The saturation flow rates in the research of Potts et al. have been adjusted for queue position.
[c] This value was derived for sites with a range of lane widths from 11 to 12 ft.
[d] This values was derived for sites with a range of lane widths of 13 ft or more.

Other Factors

The 2000 edition of the *Highway Capacity Manual* (HCM) (*14*) provides a methodology for analyzing the capacity of signalized intersections and considers a wide variety of prevailing conditions, traffic composition, geometric characteristics, and details of signalization. This methodology also examines performance measures and provides adjustment factors to address known or projected conditions. The subsequent paragraphs, excerpted from the HCM, focus primarily on right-turn movements at signalized intersections and the provision of relevant adjustment factors. Table 8 provides a summary of the following HCM adjustment factors related to geometric characteristics:

- Lane width
- Right-turn lanes
- Left-turn lanes
- Lane utilization
- Grade

- Parking
- Bus blockage
- Area type

Table 9 provides a summary of the following adjustment factors related to vehicular characteristics.

- Pedestrian/bicycle blockage
- Heavy vehicles

Lane Width

The lane width adjustment factor, f_W, accounts for the negative impact of narrow lanes on saturation flow rate and allows for an increased flow rate on wide lanes. Standard lane widths are 3.6 m (12 ft). The lane width factor may be calculated with caution for lane widths greater than 4.8 m (16 ft), or an analysis using two narrow lanes may be conducted. The use of two narrow lanes will always result in a higher saturation flow rate than a single, wide lane, but in either case, the analysis should reflect the way in which the width is actually used or expected to be used. In no case should the lane width factor be calculated for widths less than 2.4 m (8.0 ft). Refer to Table 8.

TABLE 8. Geometric Adjustment Factors for Saturation Flow Rate (*14*)

Factor	Formula	Definition of variables	Notes
Lane width	$f_W = 1 + \frac{(W-12)}{30}$	W = lane width (ft)	W ≥ 8.0 (If W > 16, a two-lane analysis may be considered)
Single right-turn lane	Exclusive Lane: $f_{RT} = 0.85$ Shared Lane: $f_{RT} = 1.0\text{-}(0.15)P_{RT}$ Single Lane: $f_{RT} = 1.0\text{-}(0.135)P_{RT}$	P_{RT} = proportion of RTs in lane group	$f_{RT} \geq 0.050$
Single left-turn lane	Protected Phasing: $f_{LT} = 0.95$ Shared Lane: $f_{LT} = \frac{1}{1+0.05P_{LT}}$	P_{LT} = proportion of LTs in lane group	
Lane utilization	$f_{LU} = \frac{v_g}{(v_{g1}N)}$	v_g = unadjusted demand flow rate for the lane group (veh/h) v_{g1} = unadjusted demand flow rate on the single lane in the lane group with the highest volume N = number of lanes in lane group	
Grade	$f_g = 1 - \frac{\%G}{200}$	%G = percent grade on a lane group approach	–6 ≤ %G ≤ +10 Negative is downhill
Parking	$f_p = \frac{N - 0.1 - \frac{18N_m}{3600}}{N}$	N = number of lanes in lane group N_m = number of parking maneuvers per hour	$0 \leq N_m \leq 180$ $f_p \geq 0.050$ $f_p = 1.000$ for no parking
Bus blockage	$f_{bb} = \frac{N - \frac{14.4N_B}{3600}}{N}$	N = number of lanes in lane group N_B = number of buses stopping per hour	$0 \leq N_B \leq 250$ $f_{bb} \geq 0.050$
Area type	$f_a = 0.900$ in CBD $f_a = 1.000$ in all other areas		

TABLE 9. Vehicular Adjustment Factors for Saturation Flow Rate (*14*)

Factor	Formula	Definition of variables	Notes
Pedestrian-bicycle blockage	LT adjustment: $f_{Rpb} = 1.0\text{-}P_{LT}(1\text{-}A_{pbT})\ (1\text{-}P_{LTA})$ RT adjustment: $f_{Rpb} = 1.0\text{-}P_{RT}(1\text{-}A_{pbT})\ (1\text{-}P_{RTA})$	P_{LT} = proportion of LTs in lane group A_{pbT} = permitted phase adjustment P_{LTA} = proportion of LT protected green over total RT green P_{RT} = proportion of RTs in lane group P_{RTA} = proportion of RT protected green over total RT green	
Heavy vehicles	$f_{HV} = \dfrac{100}{100 + \%HV(E_T - 1)}$	%HV = percent heavy vehicles for lane group volume	E_T = 2.0 pc/HV

Right-Turn Lane

The HCM (*14*) provides a right-turn adjustment factor, f_{RT}, to reflect the effect of geometry when determining the saturation flow rate. The right-turn adjustment factor depends on a number of variables, including whether the right turn is made from an exclusive or shared lane and the proportion of right-turning vehicles in the shared lanes. Refer to Table 8.

When right turn on red (RTOR) is permitted, the right-turn volume for analysis can be reduced by the volume of right-turning vehicles moving on the red phase. This reduction is done on the basis of hourly volumes before the conversion to flow rates. The number of vehicles able to turn right on a red phase is a function of several factors, including:

- Approach lane allocation (shared or exclusive right-turn lane)
- Demand for right-turn movements
- Sight distance at the intersection approach

- Degree of saturation of the conflicting through movement
- Arrival patterns over the signal cycle
- Left-turn signal phasing on the conflicting street
- Conflicts with pedestrians

For an existing intersection, it is appropriate to consider the RTORs that actually occur. For both the shared lane and the exclusive right-turn lane conditions, the number of RTORs may be subtracted from the right-turn volume before analysis of lane group capacity or level of service (LOS). At an existing intersection, the number of RTORs should be determined by field observation.

If the analysis is dealing with future conditions or if the RTOR volume is not known from the field data, it is necessary to estimate the number of RTOR vehicles. In the absence of field data, it is preferable for most purposes to utilize the right-turn volumes directly without a reduction for RTOR, except when an exclusive right-turn movement runs concurrent with a protected left-turn phase from the cross street. In this case, the total right-turn volume for analysis can be reduced by the number of shadowed left turners. Free-flowing right turns that are not under signal control should be removed entirely from the analysis.

Left-Turn Lane

The left-turn adjustment factor, f_{LT}, is based on variables similar to those for the right-turn adjustment factor, including:

- Whether left turns are made from exclusive or shared lanes

- Type of phasing (protected, permitted or protected-plus-permitted)
- Proportion of left-turning vehicles using a shared lane group
- Opposing flow rate when permitted left turns are made

Lane Utilization

The lane utilization adjustment factor, f_{LU}, accounts for the unequal distribution of traffic among the lanes in a lane group with more than one lane. The factor provides an adjustment to the base saturation flow rate. The adjustment factor is based on the flow in the lane with the highest volume and is calculated by the equation shown in Table 8. This adjustment is normally applied to account for the variation of traffic flow on the individual lanes in a lane group due to upstream or downstream roadway characteristics, such as changes in the number of lanes available or flow characteristics (i.e., the pre-positioning of traffic within a lane group for heavy turning movements). Actual lane volume distributions observed in the field should be used, if known, in the computation of the lane utilization adjustment factor. A lane utilization factor of 1.0 is used when uniform traffic distribution can be assumed across all lanes in the lane group or when a lane group comprises a single lane.

Grade

The grade factor, f_g, accounts for the effect of grades on the operation of all vehicles. Refer to Table 8 for the equation.

Parking

The parking adjustment factor, f_p, accounts for the frictional effect of a parking lane on flow in an adjacent lane group as well as for the occasional blocking of an adjacent lane by vehicles moving into and out of parking spaces. This factor can play a significant role with regard to saturation flows of right turn lanes adjacent to parking lanes. Each parking maneuver (in or out) is assumed to block traffic in the adjacent lane for an average of 18 seconds. The number of parking maneuvers used is the number of maneuvers per hour in parking areas directly adjacent to the lane group and within 76 m (250 ft) upstream from the stop line. If more than 180 maneuvers per hour exist, a practical limit of 180 should be used. If parking is adjacent to an exclusive turn lane group, the factor only applies to the lane group. On a one-way street with no exclusive turn lanes, the number of maneuvers used is the total for both sides of the lane group. Note that parking conditions with zero maneuvers have a different impact than a no-parking situation. Refer to Table 8 for the equation.

Bus Blockage

As in the case for parking, bus stops and maneuvers may also affect saturation flow rates in adjacent right-turn lanes. The bus blocking factor, f_{bb}, accounts for the impacts of local transit buses that stop to discharge or pick up passengers at a nearside bus stop within 76 m (250 ft) of the stop line (upstream or downstream). This factor should only be used when stopping buses block traffic flow in the subject lane group. Refer to Table 8 for the equation.

Area Type

The area type adjustment factor, f_a, accounts for the relative inefficiency of intersections in business districts in comparison with those in other locations. Application of this adjustment factor is typically appropriate in areas that exhibit central business district (CBD) characteristics; that is, narrow street rights-of-way, frequent parking maneuvers, vehicle blockages, taxi and bus activity, small-radius turns, limited use of exclusive turn lanes, high pedestrian activity, dense populations, and mid-block curb cuts. Use of this factor is on a case-by-case basis; it is neither limited to designated CBD areas nor is it used for all CBD areas. Refer to Table 8 for appropriate values.

Pedestrian/Bicycle Blockage

The proportion of right turns using the protected portion of a protected-plus-permitted phase is needed. This proportion should be determined by field observation, but a gross estimate can be made from the signal timing assuming that the proportion of right-turning vehicles using the protected phase is approximately equal to the proportion of the turning phase that is protected. If $P_{RTA} = 0.00$ (i.e., the right turn is completely protected from conflicting pedestrians), a pedestrian volume of zero should be used. Refer to Table 8 for the equation.

Heavy Vehicles

The effects of heavy vehicles factor, f_{HV}, accounts for the additional space occupied by these vehicles and the difference in operating capabilities of heavy vehicles compared with passenger cars. Refer to for Table 8 for the equation.

Dual Exclusive Turn Lanes

In a 1986 study, Zegeer (*10*) conducted surveys for dual exclusive turn lanes to determine volume distribution. The sample sizes for these surveys were 2,026 and 856 for dual left-turn and dual right-turn lanes, respectively. A total of 55.3 percent of the vehicles surveyed in dual right-turn lanes were in the curb (inside) lane. This was a significantly high use of the curb lane for dual right–turn movements because the right-turning radii varied from 3.0 to 15.2 m (10 to 50 ft). The lane distributions suggest factors of 0.90 for dual right-turn lanes when compared with single exclusive turn lanes.

Combining the single and dual turn lane adjustment factors for protected turn phase operation yields an overall factor that can be applied to the unadjusted turn volumes in dual exclusive turn lanes, yielding one adjustment factor rather than two for each dual turn lane calculation. The recommended overall adjustment factor for a dual right turn lane is 0.76.

Agent (*11*) summarized the difference in saturation flow for single versus multiple left-turn lanes in his 1983 report. The study found that the effect of multiple lanes for left turns was opposite that for through vehicles. Saturation flow was 5 percent higher for single left-turn lanes than for dual left-turn lanes. This effect was not totally unexpected. Drivers were often found to be uncomfortable with dual turning lanes. This type of lane is fairly uncommon, and drivers are sometimes unsure of the proper path to follow. That attitude in driver behavior would tend to increase headways and decrease saturation flow.

From the results of the data analyses, Agent (*11*) identifies factors that significantly influence saturation flow.

$$C_r = 1.00 + F_r\left(\frac{P}{100}\right)$$

Where:

C_r = correction factor for turning radius

P = percentage of traffic affected by radius (affected vehicles are those that turn right or that turn left from one one-way street to another)

F_r = adjustment for turning radius. Equation given is for effect on right-turning vehicles. For left turns from one one-way street to another, switch the terms "right-turning" and "left-turning" in the equation below (*15*).

- –0.60 for turning radius of 0 to 3.0 m (0 to 10 ft)
- –0.40 for turning radius of 3.3 to 6.1 m (11 to 20 ft)
- –0.20 for turning radius of 6.4 to 9.1 m (21 to 30 ft)
- 0.00 for turning radius of 9.4 to 12.2 m (31 to 40 ft)
- 0.20 for turning radius of 12.5 to 15.2 m (41 to 50 ft)
- 0.40 for turning radius greater than 15.2 m (50 ft)

$$F_r = \left(\frac{\%\ \text{through and left-turning vehicles}}{100}\right) + F_{rd}\left(\frac{\%\ \text{right-turning vehicles}}{100}\right)$$

Where: F_{rd} = 0.93 for turning radius less than 7.6 m (25 ft)

= 1.00 for turning radius of 7.6 to 13.4 m (25 to 44 ft)

= 1.03 for turning radius of 13.7 m (45 ft) or more

Agent found that the saturation flow is affected by the amount of "friction" between adjacent lanes, with friction depending on relative speeds and vehicle maneuvers. The single through-only lane has the highest friction, since it is adjacent to turning lanes, opposing traffic, or the roadway edge. Friction is reduced by going to multiple through-only lanes. The lowest friction is for the middle of three through-only lanes (*11*).

PEDESTRIAN CROSSING TIME

Shorter crossing distances can be achieved using a combination of narrower lane widths and smaller curb radii on new designs or by reconstructing and narrowing existing roadways to provide raised median islands or curb return bulbouts. Thus, lane width can affect pedestrian crossing distance, and thus pedestrian crossing time, at both intersection and midblock crossings. Crossing time represents the time during which pedestrians are exposed to traffic while crossing the roadway. Crossing time is a function of walking speeds and crossing distance. Excessive crossing distances not only impact pedestrian crossing time, but may add to vehicle delay. At signalized intersections, reducing the pedestrian crossing distance can usually improve the signal timing of the intersection. In cases where the pedestrian crossing time is the controlling factor, reducing the crossing distance across the major road permits the green time for the major-road traffic to be increased proportionately. Thus, under certain situations, reducing the lane width along the major road at an intersection can actually increase the capacity of the major road.

Selecting a pedestrian walking speed is critical in determining the duration of pedestrian WALK signals. Pedestrian walking speeds range from approximately 0.8 to 1.8 m/sec (2.5 to 6.0 ft/sec) (*1*). Many factors impact pedestrian walking speeds, including pedestrian age. Older pedestrians and pedestrians with physical impairments generally walk at speeds in the lower end of the speed range. Other factors that affect walking speed include grade, air temperature, precipitation (rain, snow, and ice), time of day, and trip purpose.

The *Traffic Engineering Handbook* (*16*) summarizes four studies related to pedestrian walking speeds. Eubanks and Hill (*17*) studied the walking and running speeds of pedestrians of various ages by having them walk and run a specified distance. Table 10 shows the 50th percentile walking and running speeds for pedestrians of varying ages. Table 10, based on sample sizes from 62 to 407, indicates that average walking speeds gradually increase until about the age of 10. From age 10 to 50, average walking speed remains fairly steady, and average walking speeds decrease somewhat for pedestrians over 60.

TABLE 10. 50th Percentile Walking and Running Speeds for Pedestrians of Various Ages (*16*)

	Males		Females	
Age (Years)	Walking (ft/sec)	Running (ft/sec)	Walking (ft/sec)	Running (ft/sec)
2	2.8	5.6	3.4	5.7
3	3.5	8.9	3.4	8.1
4	4.1	10.4	4.1	9.8
5	4.6	11.2	4.5	11.0
6	4.8	12.9	5.0	11.7
7	5.0	13.2	5.0	12.6
8	5.0	14.3	5.3	12.6
9	5.1	15.1	5.4	14.3
10	5.5	15.4	5.4	14.3
11	5.2	15.4	5.2	15.7
12	5.8	13.3	5.7	14.1
13	5.3	14.5	5.6	12.8
14	5.1	14.6	5.3	12.3
15	5.6	14.4	5.3	12.5
16	5.2	14.6	5.4	12.3
17	5.2	14.9	5.4	12.7
18	4.9	15.1	–*	–
20s	5.7	–	5.4	–
30s	5.4	–	5.4	–
40s	5.1	–	5.3	–
50s	4.9	–	5.0	–
60+	4.1	–	4.1	–

* Insufficient or no data.

Hauer (*18*) estimated that mean walking speed is approximately 1.3 m/sec (4.3 ft/sec) and that 35 percent of pedestrians walk slower than 1.2 m/sec (4 ft/sec), which is the recommended walking speed given in the *Manual on Uniform Traffic Control Devices* (MUTCD) (*19*).

Dahlstedt (*20*) found that pedestrians aged 70 or older, when asked to cross an intersection very quickly, considered "quickly" to be slower than 1.2 m/sec (4 ft/sec). The 85th percentile for a comfortable walking speed for pedestrians aged 70 or older was 0.67 m/sec (2.2 ft/sec).

Knoblauch et al. (*21*) conducted a large study of walking speed and start-up time. Data were gathered on 7,123 pedestrians, more than one-half of whom were over the age of 65. Observations were made at a variety of urban intersections under a number of conditions. The mean and 15^{th}-percentile walking speeds were 1.46 m/sec (4.79 ft/sec) and 1.21 m/sec (3.97 ft/sec), respectively, for pedestrians under the age of 65. For older pedestrians, the mean and 15^{th}-percentile walking speeds were 1.20 m/sec (3.94 ft/sec) and 0.94 m/sec (3.08 ft/sec), respectively. Walking speeds were slightly higher for those pedestrians who did not comply with the pedestrian signal, when one was present at the location. Compliers were those pedestrians who began crossing the intersection only when the WALK signal was on. Mean start-up time, defined as the time from the start of the WALK signal to the moment the pedestrian steps off the curb and starts to cross, was longer for older pedestrians (2.48 sec) than for younger pedestrians (1.93 sec).

Currently, there is no consensus among design guidelines on recommended walking speeds. As indicated above, the MUTCD (*19*) recommends a normal walking speed of 1.2 m/sec (4 ft/sec). FHWA, in *Designing Sidewalks and Trails for Access (Part II)* (*22*), recommends a crossing speed of 1.07 m/sec (3.5 ft/sec). The U.S. Access Board in their draft *Guidelines for Accessible Public Rights-of-Way* (*23*) recommends pedestrian signal phasing be calculated according to a walking speed of 0.91 m/sec (3.0 ft/sec). The U.S. Access Board believes this rate will accommodate a broader range of pedestrians and offer greater access. In the draft *Guide for the Planning, Design, and Operation of Pedestrian Facilities* (*3*), AASHTO notes the recommended walking speed in the MUTCD but also indicates that at locations where it is apparent pedestrians are having difficulty crossing during the allocated time, the signal timing should be adjusted to account for slower walking speeds. The HCM (*14*) indicates that when less than 20 percent of pedestrians are elderly (i.e., 65 years of age and older), a walking speed of 1.2 m/sec (4 ft/sec) is recommended. If elderly pedestrians constitute more than 20 percent of the pedestrian population, a 1.0-m/sec (3.33-ft/sec) walking speed is recommended. In addition, an upgrade of 10 percent or greater reduces walking speed by 0.1 m/sec (0.33 ft/sec).

Pedestrians with physical impairments are much more mobile in our society today than they were just a few decades ago. As a result, many of the design standards for transportation facilities have been modified to meet their needs. However, many pedestrians with physical impairments walk at considerably slower speeds (*16*). Table 11 shows the average walking speed for pedestrians with various disabilities/assistive devices. Many of these speeds are well below the recommended walking speeds listed above.

VEHICLE RUNNING SPEEDS AT MIDBLOCK LOCATIONS

Fitzpatrick et al. (*24*) evaluated the relationship between lane width and travel speed on suburban arterials. In this study, geometric, roadside, and traffic control device variables that may affect driver behavior on four-lane suburban arterials were investigated. Regression techniques were used to determine how selected variables affect operating speed on horizontal curves and straight sections. As part of the study, a series of analyses were performed without using a posted speed limit. This analysis demonstrated that lane width was a significant variable for straight sections of roadway.

TABLE 11. Average Walking Speeds for Pedestrians With Physical Disabilities (*16*)

Disability/assistive device	Average walking speed m/sec	(ft/sec)
Cane/crutch	0.80	(2.62)
Walker	0.63	(2.07)
Wheel chair	1.08	(3.55)
Immobilized knee	1.07	(3.50)
Below-knee amputee	0.75	(2.46)
Above-knee amputee	0.60	(1.97)
Hip arthritis	0.68 to 1.12	(2.24 to 3.66)
Rheumatoid arthritis (knee)	0.75	(2.46)

Figure 3 illustrates the relationship between lane width and 85th percentile speed. For each 1-m (3.3-ft) increase in lane width, speeds are predicted to increase by 15 km/h (9.4 mph).

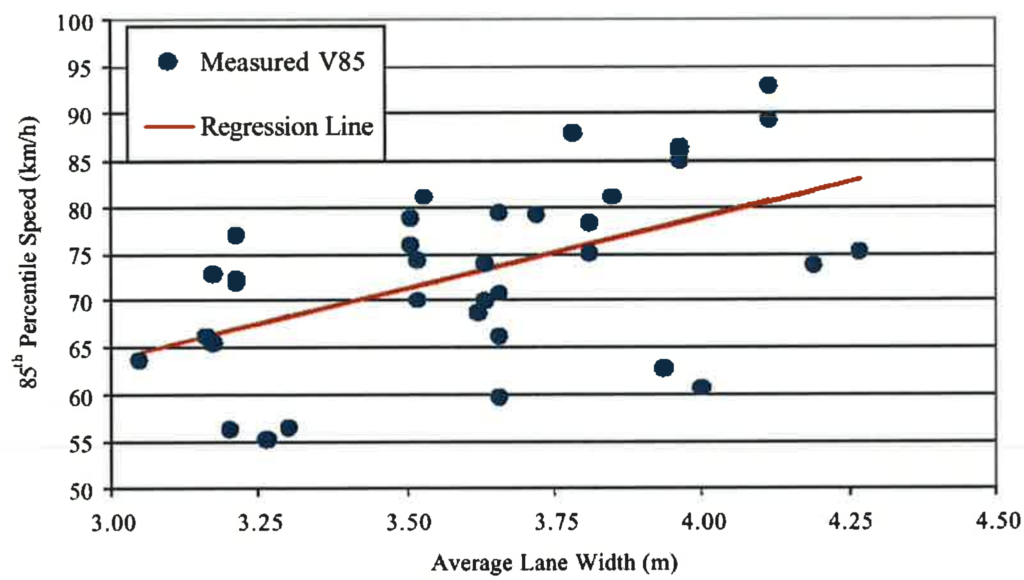


Figure 3. Average lane width versus 85th percentile speed (22).

The study completed by Fitzpatrick et al. (*24*) found that certain variables, such as lane width, could affect operating speeds. This study concluded that additional research into the issues of interaction and combination of variables (i.e., environment, off-road conditions, and driver characteristics) is needed to provide better guidance for developing roadway designs.

Nabti and Ridgeway (*25*) found that the addition of marked bicycle lanes had an effect on motor vehicle speeds. Along roadways with average running speeds above 48 km/h (30 mph), the addition of a bicycle lane had a calming effect on traffic, reducing speeds up to 2.8 percent. Conversely, for roads with speeds less than 48 km/h (30 mph), traffic speeds tended to increase by as much as 3.6 percent with the addition of bicycle lanes.

Potts et al. (*12*) collected speeds data at five urban/suburban arterial locations in the Kansas City metropolitan area where there is a distinct change in lane width. The lane widths for the locations with narrower lanes ranged from 2.9 to 3.1 m (9.4 to 10.3 ft), with an average lane width of 3.0 m (9.8 ft). The lane widths for the locations with wider lanes ranged from 3.6 to 4.1 m (11.9 to 13.3 ft), with an average lane width of 3.8 m (12.5 ft). The average difference in lane width between the locations with narrower and wider lanes was 0.8 m (2.7 ft). In all cases, the number of lanes and the speed limit were the same upstream and downstream of the lane width transition. Speeds of 120 vehicles were collected both upstream and downstream of each lane width transition; the upstream and downstream data collection locations were typically about 0.8 km (0.5 mi) apart.

Table 12 presents a summary of the average speeds found at each site, both for the direction of the narrow-to-wide transition and the direction of the wide-to-narrow transition. At each location, the average speed was higher at the wide-lane location than the narrow-lane location, and all of these differences were statistically significant. Potts et al. concluded that there is a strong indication that lane width influences vehicle speeds on four-lane urban and suburban arterials. When traffic moves from narrow lanes to wider lanes, vehicles tend to speed up by an average of 6 km/h (4 mph). When traffic moves from wide lanes to narrow lanes, vehicles tend to slow down by an average of 6 km/h (4 mph). The average speed difference of 6 km/h (4 mph) was observed for both the narrow-to-wide and wide-to-narrow transitions, providing a clear indication that the observed change in speed does result from the change in lane width. However, the relationship is not sufficiently consistent from site to site that the magnitude of the speed difference can be predicted from the magnitude of the difference in lane width (see Table 13).

TABLE 12. Summary of Speed Data (*12*)

			Average speed (mph)		Difference
Site	Direction	Transition type	Wide	Narrow	(mph)
Bannister Road	WB	Narrow-to-wide	47.1	42.3	4.8
	EB	Wide-to-narrow	47.1	43.9	3.3
Holmes Road	SB	Narrow-to-wide	44.2	39.3	5.0
	NB	Wide-to-narrow	41.7	39.9	1.7
Fourth Street	SB	Narrow-to-wide	37.2	32.5	4.7
	NB	Wide-to-narrow	38.7	31.8	6.9
Truman Road	EB	Narrow-to-wide	40.6	37.7	2.9
	WB	Wide-to-narrow	41.1	36.3	4.8
Wornall Road	SB	Narrow-to-wide	43.8	39.5	4.3
	NB	Wide-to-narrow	44.1	39.5	4.7

TABLE 13. Summary of Speed Difference Versus Lane Width Difference (*12*)

Site	Transition type	Difference in lane width (ft)	Difference in average speed (mph)
Bannister Road	Narrow-to-wide	2.4	4.8
	Wide-to-narrow	2.1	3.3
Holmes Road	Narrow-to-wide	2.5	5.0
	Wide-to-narrow	2.6	1.7
Fourth Street	Narrow-to-wide	2.8	4.7
	Wide-to-narrow	2.9	6.9
Truman Road	Narrow-to-wide	3.0	2.9
	Wide-to-narrow	3.1	4.8
Wornall Road	Narrow-to-wide	2.8	4.3
	Wide-to-narrow	2.5	4.7

The available data strongly suggest that traffic travels at lower speeds on arterial streets with narrower lanes than on arterial streets with wider lanes with an average difference in lane width of 0.8 m (2.7 ft) resulting in an average difference in speed of 6 km/h (4 mph). However, the available data are not sufficient to predict the change in speed as a function of the change in lane width.

Operational Tradeoffs of a Range of Lane Widths

The literature reviewed does not make note of any adjustments for variances, with regard to the effect on running speed, of the following factors:

- Geometric characteristics
  - Approach grade
  - Curb parking
  - Bus stops
  - Area type

- Metro area size
- Length of storage bays

• Traffic control characteristics

- Signal controlled
- Yield control
- Right turn free flow

CHAPTER 4.

TRAFFIC SAFETY

This chapter summarizes current knowledge concerning the safety performance of varying lane width. Safety for motor vehicles, pedestrians, and bicycles are addressed separately.

SAFETY FOR MOTOR VEHICLES

A key aspect of the selection of the appropriate lane width on an urban or suburban arterial is safety. There are many reasons that might lead designers to consider the use of lanes narrower than 3.6 m (12 ft) on urban and suburban arterials. These include the desire to reduce pedestrian crossing distances; the desire to provide space for other roadway features such as medians, bicycle lanes, and curb parking; and the desire to provide space for roadside features such as sidewalks and clear zones and to minimize interference with existing roadside development. The benefits of these other features are substantial, and the decision to use narrower lanes might be an easy one, were it not for concern that provision of lanes narrower than 3.6 m (12 ft) would be accompanied by a reduction in safety. However, in some cases, the safety benefits of an added feature may be greater than any potential reduction in safety associated with narrower through lanes. Therefore, an understanding of the relationship between lane width and safety is central to design decision making concerning urban and suburban arterials.

In a recent review of lane width and safety issues, Hauer (*26*) indicated that there are two principal aspects to the potential link between lane width and safety:

- Wider lanes increase the average separation between vehicles moving in adjacent lanes and, therefore, may provide a wider buffer to accommodate small random deviations from their intended paths.
- Wider lanes may provide more room for correction maneuvers by drivers in near-accident circumstances.

The potential safety effects of each of these relationships are discussed below. The following discussion is adapted from Hauer (*26*), but includes additional insights.

The first potential relationship between lane width and safety is that, as lane width increases, the average separation between vehicles moving in adjacent lanes also increases. This may provide a wider buffer to accommodate the small random deviations of vehicles from their intended paths and the larger deviations that may occur if drivers are inattentive. However, it is also likely that wider lanes induce faster travel speeds, which may increase accident risk and will likely increase accident severity. The 1985 edition of the HCM (*27*) suggested that wider lanes on multilane highways also increase capacity and, therefore, reduce following distances; however, HCM editions since 1985 (*14,28*) have indicated that wider lanes on multilane highways increase free-flow speeds, but do not increase capacity and, therefore, do not reduce vehicle headways.

The second potential relationship between lane width and safety is that wider lanes may provide more room for drivers to make correction maneuvers in near-accident situations related to driver inattention. Specifically, where lanes are wider, vehicles have the opportunity to travel at a greater separation from the edge of the traveled way and, thus, may be less likely to leave the roadway and run onto the roadside. For the driver of a vehicle in a narrow lane, a moment's inattention may result in the vehicle entering an adjacent lane or the roadside. Wider lanes would be expected to reduce the likelihood that inattentive drivers will recover before leaving their lane or entering the roadside. However, the likelihood of a reportable accident resulting from a roadside encroachment is largely a function of the design quality of the roadside. Where a wide paved shoulder is present, a roadside encroachment may have virtually no consequence; where there is a pavement edge dropoff, a poor shoulder, a curb at the edge of the traveled way, or steep slopes or substantial objects exist beyond the edge of the traveled way, a reportable accident, and possibly a severe accident, may result. This indicates that the safety effects of lane width may be difficult to quantify independent of shoulder and roadside design factors.

Hauer (*26*) indicates that the relationships described above are sufficiently complex and that they do not indicate conceptually what the relationship between lane width and safety should be. The review of the safety literature includes a discussion of the relationship between lane width and safety for motor vehicles, followed by discussions of safety-related lane width issues concerning pedestrians and bicyclists.

The relationship between lane width and safety has been studied extensively in the rural environment. An expert panel (*29*) recently reviewed the literature on safety for lane widths on rural two-lane highways for the FHWA Interactive Highway Safety Design Model (IHSDM). This panel concluded that the most credible studies of lane width on rural two-lane highways were those by Griffin and Mak (*30*) for low-volume roads and by Zegeer et al. (*31*) for higher-volume roads. Figure 4 presents the accident modification factors (AMFs) developed by the expert panel (*29*) based on these past studies. AMFs are used in accident prediction algorithms to represent the safety effects of various geometric features (e.g., right-turn lanes). The base value of each AMF is 1.0. Any feature associated with a higher accident experience than the base condition has an AMF with a value greater than 1.0, and any feature associated with lower accident experience than the base condition has an AMF with a value less than 1.0. Another expert panel in a later research study (*32*) concluded that the AMFs for rural two-lane highways shown in Figure 4 are also the best available estimates for rural multilane highways.

Only a few studies have researched the relationship between lane width and safety in the urban environment. Hauer (*33*) developed six statistical models to predict the nonintersection accident frequency of urban four-lane undivided roads. Separate models were developed for "off-the-road" and "on-the-road" property damage only (PDO), injury, and total accidents. From the three statistical models for "off-the-road" accidents, Hauer concluded that if accident frequency is influenced by lane width, it is not discernable. From the three statistical models for "on-the-road" accidents, lane width was found to be associated with PDO accidents but not injury accidents. In the PDO model, wider lanes are associated with higher accident frequencies (**not** lower accident frequencies). However, Hauer notes that the relationship is weak, and lane width is only included in the model because of the traditional interest in this variable.

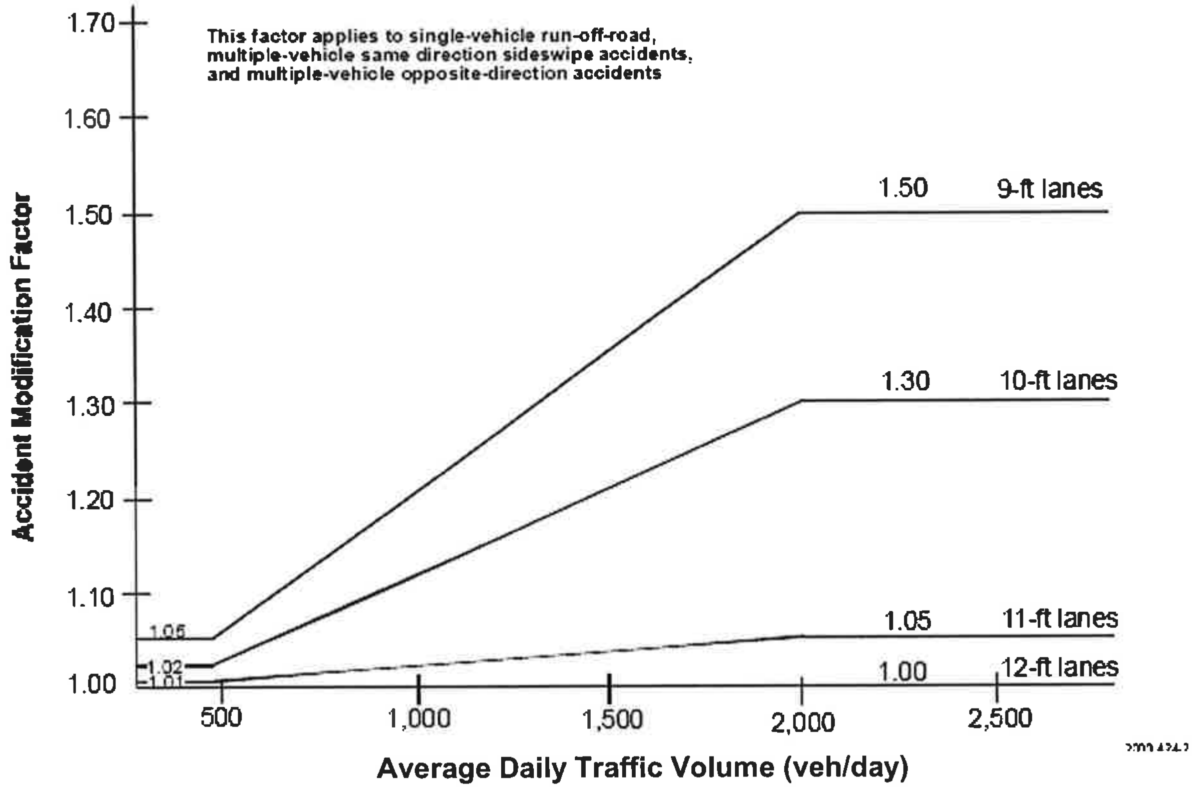


Figure 4. Lane width AMF for two-lane highways from IHSDM crash prediction module (29)

In 2001, Strathman et al. (*34*) analyzed design attributes and crash frequencies on the Oregon state highway system. The analysis differentiated the crash frequencies according to functional classification (freeway vs. nonfreeway) and location (urban vs. nonurban). Strathman et al. did not find any relationship between lane width and accident frequency.

Hadi et al. (*35*) developed negative binomial regression equations to estimate the safety effects of various cross-sectional elements for a number of different highway types. Hadi et al. found significant relationships between lane width and crashes for undivided highways and urban freeways. In general, widening lane widths up to 3.7 m (12 ft) and 4.0 m (13 ft) would be expected to decrease crash rates on two-lane urban roadways and four-lane urban undivided roadways, respectively. Figure 5 shows the benefits of lane widening for four roadway classes, including four-lane urban undivided.

Harwood (*36*) conducted research to determine the effectiveness of various alternative strategies for reallocating the use of street width on urban arterials without changing the total curb-to-curb width. The research addressed urban arterial streets with curb-and-gutter cross sections and speeds of 72 km/h (45 mph) or less. Harwood indicated that the preferred lane width for urban arterial streets under most circumstances is 3.3 or 3.6 m (11 or 12 ft). However, constraints on street widening do not always permit the use of lanes that wide, and under some situations, traffic operational benefits, traffic safety benefits, or both can be obtained from the use of narrower lanes.

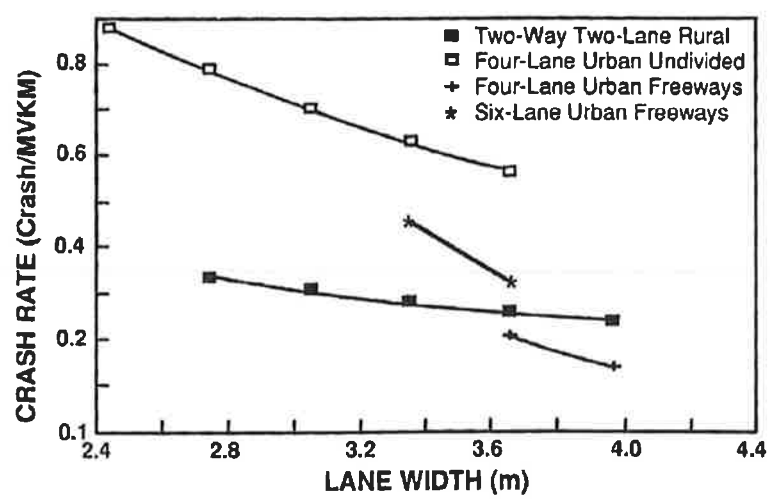


Figure 5. Effect of lane width on midblock crash sites (35).

Commercial buses operate frequently on many urban and suburban arterials. Traffic accidents involving buses result in about 35,000 injuries annually in the United States, as noted by Zegeer et al. (*37*). Zegeer et al. described bus and motor vehicle accident characteristics and recommended several highway improvements to reduce the number and severity of bus-related highway crashes. One of the recommendations concerned lane widths along urban streets. Zegeer et al. note that a primary transit bus accident type involves sideswipe collisions between buses and other motor vehicles. Because of the wider dimensions on buses, it is important that lane widths be adequate to minimize the chance for sideswipe collisions. With narrower lanes, the potential for sideswipe accidents increases. Therefore, Zegeer et al. recommended that along major arterials where buses and other large trucks are likely to operate, consideration should be given to providing lane widths of 3.6 m (12 ft), where possible, or at least 3.3 m (11 ft). This will increase the lateral spacing between buses and other motor vehicles, reducing the potential for accidents.

Potts et al. (*12*) conducted a safety evaluation of lane widths on arterial roadway segments. Analysis of geometric design, traffic volume, and accident data collected by Harwood et al. (*38*) found that, with limited exceptions, there is no consistent, statistically significant relationship between lane width and safety for midblock sections of urban and suburban arterials. There is no indication that the use of 3.0- or 3.3-m (10- or 11-ft lanes), rather than 3.6-m (12-ft) lanes, for arterial midblock segment leads to increases in accident frequency. There are situations in which use of narrower lanes may provide benefits in traffic operations, pedestrian safety and/or reduced interference with surrounding development, and may provide space for geometric features that enhance safety such as medians or turn lanes. The analysis results indicate narrow lanes can generally be used to obtain these benefits without compromising safety.

Two caveats should be considered. First, the data for one of the states analyzed showed an increase in crash rates for four-lane undivided arterials with lane widths of 3.0 m (10 ft) or less, while the data from another state showed an increase in crash rates for four-lane divided arterials with lane widths or 2.7 m (9 ft) or less. While the results from each state were not confirmed in data from the other state, the findings indicate that lane widths of 3.0 m (10 ft) or less on four-lane undivided arterials and lane widths of 2.7-m (9 ft) or less on four-lane divided arterials should be used cautiously unless local experience indicates otherwise. Second, lane widths less than 3.6 m (12 ft) should be used cautiously where substantial volumes of bicyclists share the road with motor vehicles, unless an alternative facility for bicycles such as a wider curb lane, side path, or paved shoulder is provided.

Potts et al. (*12*) also conducted a safety evaluation of lane widths on arterial intersection approaches. Analysis of geometric design, traffic volume, and accident data collected by Harwood et al. (*38*) found that, with limited exceptions, there is no consistent, statistically significant relationship between lane width and safety for approaches to intersections on urban and suburban arterials. There is no indication that the use of 3.0- or 3.3-m (10- or 11-ft lanes), rather than 3.6-m (12-ft) lanes, for arterial intersection approaches leads to increases in accident frequency. There are situations in which use of narrower lanes may provide benefits in traffic operations, pedestrian safety and/or reduced interference with surrounding development, and may provide space for geometric features that enhance safety such as medians or turn lanes. The analysis results indicate narrow lanes can generally be used to obtain these benefits without compromising safety.

Two caveats should be considered. First, the data for one of the states analyzed showed an increase in crash rates for approaches to four-leg unsignalized intersections with lane widths of 3.0 m (10 ft) or less; however, just the opposite was found in the other state. Second, lane widths less than 3.6 m (12 ft) should be used cautiously where substantial volumes of bicyclists share the road with motor vehicles, unless an alternative facility for bicycles is provided.

SAFETY FOR PEDESTRIANS

No studies have been found that have used crash data to document the pedestrian safety implications of lane width. However, it may be reasoned that as crossing distances increase, pedestrian exposure time to motor vehicle traffic increases, particularly at unsignalized intersections, increasing the potential of vehicle-pedestrian conflicts. Thus, lane width can directly affect pedestrian crossing distance.

Many countermeasures designed to improve pedestrian safety involve narrowing lanes to reduce vehicle speeds and enhance pedestrian mobility and safety. For example, curb extensions may be used at intersections to shorten the crossing distance. Curb extensions improve pedestrian safety by reducing pedestrian exposure, increasing pedestrian visibility, and reducing vehicle speeds. Curb extensions are only appropriate where there is an on-street parking lane. Curb extensions extend the sidewalk or curb line out into the parking lane, which reduces the effective street width (Figure 6). Curb extensions should not extend into the travel lanes or bicycle lanes.

Figure 6. Curb extension (39).

Curb extensions may also be used at midblock locations to decrease pedestrian crossing distances and vehicle speeds. Chu and Baltes (*40*) studied midblock crossing difficulty as perceived by pedestrians and found that pedestrians perceive midblock street crossing more difficult with wider crossing distance. Other design features such as raised medians or refuge islands may also be used to reduce lane widths and/or crossing distances for pedestrians at both intersection and midblock crossings. Curb extensions and other traffic calming measures may not be appropriate on major collector and arterial streets.

Zegeer et al. (*41*) performed a recent analysis of safety at marked and unmarked crosswalks, but neither lane width nor crossing distance was considered in that study.

Lane width may also affect a pedestrian's walking experience along a roadway. The width of travel lanes ultimately impacts the amount of space within the right-of-way for use by other modes (e.g., pedestrians and bicyclists). Space within the right-of-way may be designated for use by different modes of travel, and space may also be allocated as a buffer to separate modes or to provide a recovery for errant vehicles. Landis et al. (*42*) developed a pedestrian level of service model to quantify pedestrians' perception of safety and comfort in the roadside environment. The model quantifies how well roadways accommodate pedestrian travel along the roadway segment. Landis et al. (*42*) found that a pedestrian's sense of safety and comfort is strongly influenced by the presence of a sidewalk and lateral separation relative to the motor vehicle traffic. In general, as the lateral separation increases, the pedestrian's sense of comfort or safety also increases. The elements in the final pedestrian level of service model related to lateral separation include:

- Width of outside lane
- Width of shoulder or bicycle lane
- Presence of on-street parking
- Buffer width (distance between edge of pavement and sidewalk)
- Presence and width of sidewalk

Thus, lane width (and shoulder width) are treated as explicit factors in the assessment of pedestrian safety and comfort. Earlier work by Dixon (*43*) to develop a pedestrian level of service methodology also incorporated lateral separation elements such as buffer space and pedestrian crossing widths.

In ongoing research sponsored by FHWA and being conducted at the Highway Safety Research Center (HSRC) at the University of North Carolina, researchers are developing a hazard index to assess pedestrian and bicycle safety at intersections. A variety of geometric factors including width, turning radius, and auxiliary turn lanes are being investigated to determine how they impact the safety of pedestrians and bicyclists at intersections. The research is scheduled to be completed in September 2006.

SAFETY FOR BICYCLISTS

This section presents those studies that collected explicit data based on surrogate measures to evaluate bicycle safety issues related to lane width. Primarily, three types of surrogate measures have been used, including: lateral positioning of the motor vehicle and bicycle traffic within the cross section of the roadway and/or the separation distance between the two modes of traffic; changes in motor vehicle speed; and encroachment of motor vehicle traffic into the oncoming lane when encountering bicyclists (which is related to lateral positioning). In the absence of accident data, from a theoretical viewpoint, these measures can be used to investigate the safety effects of street width allocations for bicycle treatments, including BLs and WCLs. First, several authors *(44,45)* have reported that the variance of lateral vehicle placement is inversely correlated with accident frequency—as the separate distance between motor vehicles and bicycles increases, the probability of a collision decreases. This suggests that a roadway cross section that provides the maximum separation distance between the two types of road users is the safest. Second, at least from the standpoint of a vulnerable nonmotorized road user, the probability of a pedestrian fatality increases with motor vehicle speed (*3*). Thus, it seems rational to assume that reducing motor vehicle speeds through varying combinations of lane widths and bicycle treatments will at a minimum reduce the severity of bicycle-motor vehicle collisions that may occur and could potentially reduce the probability of such collisions, as well. Third, a positive correlation between centerline encroachment rates and accident experience on horizontal curves has been found *(46)*. Thus, combinations of lane widths and bicycle treatments that minimize the encroachment of motor-vehicle traffic into the oncoming or adjacent lane should also minimize the probability of a motor vehicle-motor vehicle collision. The following paragraphs summarize the results of studies that measured one or more of these surrogate objective measures of safety.

In a study of shared-use facilities, Harkey et al. (*47*) evaluated the impact of WCLs, BLs, and paved shoulders on motor vehicle and bicycle traffic. The research methodology was designed to answer the following questions:

- Which type of bicycle facility (i.e., WCL, BL, or paved shoulder) provides the most comfortable environment for bicyclists and motorists?
- What are the primary differences between the facility types with respect to motor vehicle and bicycle operations?

Observations were made in both rural and urban areas and ranged in motor vehicle speeds, traffic volumes, lane widths, and number of lanes. The measures of effectiveness used in evaluating the different types of facilities were reflective of the risk to both bicyclists and motorists. The measures related to these risks that were collected and analyzed included:

- Lateral placement of the bicycle
- Lateral placement of the motor vehicle
- Separation distance between the bicycle and the motor vehicle
- Encroachments by the motor vehicle and/or bicycle during the passing maneuver

The principal findings included:

1. The separation distance between bicyclists and motorists does not vary significantly by facility type (i.e., WCL, BL, or paved shoulder). On average, motorists positioned their vehicle approximately 2.0 m (6.4 ft) from a bicyclist in a WCL; 1.9 m (6.2 ft) from a bicyclist on a paved shoulder; and approximately 1.8 m (5.9 ft) from a bicyclist in a BL.
2. The distance between the bicyclist and the edge of the roadway was considerably less along WCLs (0.4 m or 1.4 ft) compared to that (0.7 m or 2.4 ft) along facilities with paved shoulders or BLs.
3. Motor vehicles moved to the left about 0.4 m (1.4 ft) further when passing a bicyclist in a WCL than when passing a bicyclist riding on a paved shoulder or BL facility.
4. Encroachment into the adjacent lane to the left by motor vehicles when passing a bicycle was greater on WCLs (22.3 percent) than along BLs or paved shoulders (8.9 percent).
5. Concerning BL widths, taking into consideration the change in lateral position of the motorist and the number of encroachments, BL widths as narrow as 0.9 m (3 ft) can provide sufficient space for motorists and bicyclists to interact safely; however, 1.2-m (4-ft) wide BLs or paved shoulders will optimize operating conditions for motorists and bicyclists while minimizing the paved shoulder and right-of-way required.

McHenry and Wallace *(48)* conducted a study to determine the adequacy of three outside lane widths for bicycle/motor vehicle lane sharing as compared to a traditional BL configuration. In doing so, McHenry and Wallace tried to address the following questions:

- Do travel lane widths wider than 3.6 m (12 ft) offer improved conditions for bicycle/motor vehicle lane sharing?
- Is the above improvement (if any) adequate when compared to BL configurations?
- Can minimum and maximum lane widths be recommended for bicycle/motor vehicle lane sharing?

Observations of motor vehicle traffic and volunteer bicyclists were made at three selected five-lane urban minor arterials with 3.8-, 4.2-, and 5.4-m (12.5-, 13.8-, and 17.6-ft) outside lane width dimensions. A four-lane urban minor arterial with a 3.2-m (10.5-ft) outside lane and 1.2-m (4-ft) wide contiguous BL was also studied. Several measures collected during the study included lateral displacement of motor vehicle traffic towards the highway centerline during the overtaking maneuver, separation distance between the bicycle and motor vehicle traffic during overtaking, and vehicle encroachment into the adjacent lane of traffic during overtaking.

The main conclusions reached by McHenry and Wallace, given the study conditions (i.e., four- and five-lane urban minor arterials), included:

1. For midblock locations, BLs have a positive effect on bicycle and motor tracking patterns. BLs offer the least amount of motor vehicle displacement from original positions. BLs also encourage greater uniformity of the tracking for the motor vehicle and bicycle modes.
2. The standard 3.6-m (12-ft) outside lane does not provide sufficient lane width for mode sharing. On a 3.6-m (12-ft) lane, bicycles act as lateral obstructions,

decreasing operating space by approximately 0.6 m (2 ft). This may affect highway capacity. The extent of the capacity effect depends on both motor vehicle and bicycle volumes. Observation of motor vehicle displacement and speed changes indicated that the effect on capacity will be least at motor vehicle volume extremes, and more significant at mid-range volume levels.

3. The 4.2-m (13.8-ft) curb lane offers some advantages over the 3.6-m (12-ft) lane for shared mode operation. The usefulness of this lane width probably depends on the percent truck traffic (i.e., it tends to decrease in usefulness as the percent truck traffic increases) and average bicyclist experience levels. This lane width was generally perceived by both bicyclists and motorists as too narrow for shared mode operations, but an improvement over the standard lane width.

4. The 5.4-m (17.6-ft) curb lane provides excessive width for mode sharing. While lateral placement of vehicles showed a significant diminishing of the negative effect of bicycles on motor vehicles in the outside lane, vehicle tracking was diffuse. This lane width encouraged use by two motor vehicles at intersections when one vehicle was turning right.

5. The optimum lane width for mode sharing on a major collector or minor arterial highway posted at 64 km/h (40 mph) and not signed specifically for bicycle use is in excess of 4.2 m (13.8 ft) (including a gutter pan) and less than 5.2 m (17 ft) (including gutter pan). An outside lane width of approximately 4.6 m (15 ft) is probably optimum for this type of highway.

6. The existence of a shoulder along the highway rather than a raised curb reduces the optimum lane width necessary for mode sharing, if the shoulder is paved to

the same surface smoothness as the adjacent roadway, and debris is regularly removed from the shoulder surface.

In summary, McHenry and Wallace (*48*) determined that the optimal width for a wide curb lanes was 4.6 m (15 ft) and that BLs had advantages over WCLs such as less vehicle encroachment; lower vehicle displacement when passing a bicycle; and less variation in the lateral position of the vehicle and the bicycle.

Jilla (*49*) evaluated the effects of BLs on the driver and his vehicle in the traffic stream. The interactions of bicycles and motor vehicles when in conflict with each other were evaluated. Jilla collected data on the effects of vehicular speeds and displacements on streets with existing BLs. Data were collected along collector, distributor, and arterial roadways with curb lane widths ranging from 3.3 to 4.6 m (11 to 15 ft) and BL widths ranging from 1.1 to 1.3 m (3.5 to 4.33 ft). Jilla found that cars on narrow roads not only drifted toward the centerline when approaching bicyclists but also that motor vehicle speeds dropped. In addition, on roadways with traffic lanes of 4.3 m (14 ft) or more in width, the presence of a motor vehicle in the opposing lane had only a minor effect on the speed and displacement of the motorist in the lane being studied when no bicyclists were present.

Kroll and Ramey (*50*) investigated the extent to which driver (i.e., motorist) and bicyclist behaviors are affected by the presence of a BL. Observations were made in the field to examine bike and vehicle displacement as functions of speed, lane width, presence of other vehicle, and the presence or absence of a BL. The following measures were collected:

- Separation distance between bicycle and car

- Position of bike and car within the cross section of the roadway
- Incidence of cars crossing centerline while passing a bicycle

In their investigation of the effects of BLs, Kroll and Ramey (*50*) concluded the following:

1. Drivers exhibit decreased variability (i.e., fewer wide swerves or close passes) in passing bicyclists on streets with BLs.
2. The presence of BLs causes no change in mean separation distance between bicycles and cars.
3. Vehicle displacement decreases on streets with BLs.
4. Lateral dispersion of bicycles and cars traveling alone is narrower on streets with BLs.

Based on their findings and conclusions, Kroll and Ramey (*50*) suggested that BLs are desirable on streets where the available travel space (ATS), defined as the distance between bicyclist and roadway centerline, is less than 4.6 m (15 ft) because of fewer centerline violations and because of more wide swerves and close passes found on streets without BLs. Centerline violations reflect a need for greater separation where, in fact, no extra room for separation exists. BLs do not provide extra space on the street; they merely affect the separation continuum. Although the mean separation distance between bicyclist and motorist is the same for roadways with and without BLs, the variability in separation distance decreases with the presence of BLs. Thus, providing a BL appears to lower the likelihood of conflict between the two modes. For example, the spread of vehicles and bikes over a particular street was shown to narrow into bands with considerably less overlap when a BL was provided. Therefore, the likelihood of a conflict is lessened.

Hunter et al. (*51*) conducted a comparative analysis of BLs versus WCLs. Bicyclists were videotaped on the approaches to intersections and through intersections. The midblock area (i.e., the intersection approach) was defined as the area between 89.9 and 150.9 m (295 to 495 ft) from the intersection stop bar location. The videotapes were analyzed to learn more about operational (i.e., vehicle position) and safety (i.e., conflicts) characteristics. In the midblock area, variables that were collected included:

- Motor vehicle encroachment into the adjacent traffic lane
- Distance between the bicycle and the curb face or edge of roadway (or gutter pan seam, if present)
- Distance between the bicycle and the passing motor vehicle

The primary findings and conclusions by Hunter et al. were as follows:

1. Both WCL and BL facilities can improve the safety and operations of bicycle traffic, and where there is adequate width, BLs are preferred.
2. In the midblock area, significantly more motor vehicles passing bicycles on the left encroach into the adjacent traffic lane from WCLs (17 percent) compared with BLs (7 percent). However, encroachments into the adjacent traffic lane rarely resulted in a conflict with another vehicle.
3. When bicycles were not being passed by motor vehicles, the average distance from the curb (or gutter pan seam, when present) was less for BL widths of 1.6 m (5.2 ft) or less than for WCLs having the same traffic volume. For BLs over 1.6 m (5.2 ft) in width, the average bicycle distance from the curb was greater than for WCLs having the same traffic volume.

4. Under comparable speed and traffic conditions, the distance from the bicycle to the passing motor vehicle was a direct function of total width (defined as the BL width plus the width of the adjacent traffic lane or simply the width of the WCL when no bicycle lane was present), regardless of whether the primary bicycle facility was a BL or a WCL.

The objective of a study conducted by Hunter and Feaganes (*52*) was to examine the operational effects of converting 4.3-m (14-ft) WCLs to a 3.3-m (11-ft) travel lane with a 0.9-m (3-ft) undesignated lane. The lane was referred to as an "undesignated lane" because it did not meet current BL standards in terms of lane width, signing, and marking; however, it should be noted that the lane was intended primarily for bicycle usage. Conversions were made along 6 arterial and/or collector streets with 1.2- and 1.8-m (4- and 6-ft) lanes, traffic volumes ranging from 9,700 to 45,000 vpd, and speed limits of 64 or 72 km/h (40 or 45 mph). Interactions between motorists and bicyclists were evaluated before and after the conversions. Primarily, Hunter and Feaganes (*52*) were interested in determining the impact of striping on the:

- positioning of bicycles on the roadway
- positioning of motor vehicles on the roadway
- positioning of each mode as a bicycle was being passed by a motor vehicle

The main findings and conclusions from this study were as follows:

1. The lateral spacing of bicyclists from the gutter pan seam was greater with the stripe as compared to the WCL. The combination 3.3-m (11-ft) travel lane and 0.9-m (3-ft) undesignated lane affected lateral spacing differently for different

sites. On average, bicycles rode 18 to 23 cm (7 to 9 in) farther away from the gutter pan seam at three sites where the stripe was added. This would provide a greater margin of safety for bicyclists.

2. The lateral spacing of motor vehicles from the gutter pan seam was greater with the stripe than without the stripe. This would be expected with the shift of the travel lane by 0.9 m (3 ft) with the addition of the stripe.

3. Overall, the lateral spacing between bicycles and motor vehicles was greater with the stripe than without the stripe; however, the effect was not as clear as for the other two measures above. The addition of the stripe affected lateral spacing differently for different sites. On average, passing motor vehicles were driven 8 to 13 cm (3 to 5 in) closer to bicycles at three of the newly striped sites. This could possibly be indicative of increased comfort level for both road users, where motorists believe bicyclists will ride within the striped area, and bicyclists believe motorists will not cross into their space in the undesignated lane. Conversely, passing motor vehicles were driven 10 to 15 cm (4 to 6 in) farther away from bicycles at the comparison sites where the stripe had already been in place.

4. The addition of the stripe reduced the number of motor vehicle encroachments into the adjacent lane on these multilane roads. The effect varied by site. On average, encroachments were reduced by about 15 to 40 percent at sites were a stripe was newly added.

Several studies have been conducted, and different models developed, to measure the level of service that individual roads provide to bicyclists. A primary difference in the level of service concept as applied to bicyclists (and pedestrians) compared to motor vehicle traffic is that the models are based on bicyclists' perceived level of safety and comfort, and not necessarily on operational measures.

An early attempt to develop a bicycle level of service methodology was made by Davis in 1987 at Auburn University (*53*). In this methodology, each road segment and adjoining intersections were evaluated using a bicycle safety index rating (BSIR). The BSIR was determined by calculating weighted averages of the following indexes:

- Roadway Segment Index (RSI)
  - ADT
  - Number of lanes
  - Speed limit
  - Width of outside traffic lane
  - Pavement factors
  - Location factors
- Intersection Evaluation Index (IEI)
  - Cross street volume
  - Traffic volume on route being indexed
  - Geometric factors
  - Signalization factor

Several counties in the state of Florida have taken the Davis model, or variations of it, when rating the roads within their jurisdiction for bicycle LOS. It was this effort that led to Florida's roadway condition index (RCI).

Dixon (*43*) created a methodology to establish a point system by which Gainesville, Florida, could measure the LOS of the city's bicycle facilities. The factors incorporated into this approach included:

- Type of bicycle facility being provided
- Amount of conflicts experienced by the bicyclist on the road
- Speed differential between bicyclist and motorist
- Motor vehicle LOS
- Maintenance problems of the road
- Availability of multimodal support for bicyclists

Landis et al. (*54*) focused on creating a transferable model to determine bicycle level of service (BLOS) that could be applied in any metropolitan area. The BLOS is not a measure of capacity or level of operational service but is instead a measure of the comfort of the user within the roadway. The results are based exclusively on human reactions to measurable traffic stimuli. In an effort to mathematically express the traffic conditions that affect bicyclist's perceptions, a model was created using the following variables:

- Per-lane traffic volume
- Traffic speed
- Traffic mix
- Cross-traffic generation
- Pavement surface condition
- Available roadway width for bicycling

Another measure of the suitability of roadways is the Bicycle Compatibility Index (BCI), developed for FHWA by Harkey et al. (*55*). The BCI is emerging as a useful measure for rating roadways with various types of bicycle facilities because of its broad applicability to a variety of locations and situations. It is intended to evaluate both urban and suburban roadways on their ability to accommodate motorists and bicyclists. The BCI model, presented in Table 14, incorporates a specific factor for curb lane width. King (*9*) prepared a methodology in which the BCI is presented in tabular matrix form. Table 15 provides a series of speed-volume illustrations for given bicycle facilities at LOS D. This table is indicative of the format used by King for each level of service.

One of the drawbacks of the BCI is its inability to take into effect the presence of a major intersection, but Landis et al. (*56*) have developed an intersection LOS model for bicycle through movements. The model indicates that roadway traffic volume, total width of the outside through lane, and the intersection (cross street) crossing distance are primary factors in the intersection LOS for bicycle through movements.

Based on the studies reviewed, the following summary observations can be made concerning bicycle safety issues as they relate to lane width:

1. Assuming that a standard 3.6-m (12-ft) lane without an adjacent BL is the baseline condition, all evidence suggests that providing additional width along the outside curb lane would improve safety for both bicyclists and motorists. Along a 3.6-m (12-ft) lane, bicyclists act as lateral obstructions. A 3.6-m (12-ft) lane does not allow for sufficient separation distance between bicyclists and motorists and

results suggest that a standard 3.6-m (12-ft) lane will likely cause a high number of vehicle encroachments into the adjacent lane when encountering bicyclists. Additional width could be provided by delineating a BL or paved shoulder for use by bicycle traffic or simply widening the curb lane to allow more space for joint use by bicyclists and motorists.

TABLE 14. Bicycle Compatibility Index (BCI) Model (*55*)

$$BCI = 3.67 - 0.966BL - 0.125BLW - 0.152CLW + 0.002CLV + 0.0004OLV + 0.035\,SPD + 0.506PKG - 0.264AREA + AF$$

where:

BL = presence of a bicycle lane or paved shoulder ≥ 3.0 ft
no = 0
yes = 1

BLW = bicycle lane for paved shoulder width
ft (to the nearest tenth)

CLW = curb lane width
ft (to the nearest tenth)

CLV = curb lane volume
Vph in one direction

OLV = other lane(s) volume – same direction
Vph

SPD = 85th percentile speed of traffic
mi/h

PKG = presence of a parking lane with more than 30 percent occupancy
no = 0
yes = 1

AREA = type of roadside development
residential = 1
other type = 0

$AF = f_t + f_p + f_{rt}$

where:

f_t = adjustment factor for truck volumes (see below)

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 [1]	f_t	Parking Time Limit (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 [2]	f_{rt}
≥ 270	0.1
< 270	0.0

[1] Large trucks are defined as all vehicles with six or more tires.
[2] Includes total number of right turns into driveways or minor intersections along a roadway segment.

TABLE 15. Bicycle Compatibility Index—LOS D Matrix (*9*)

Facility	Vehicle speed (mph)			
	25	30	35	40
	Traffic volume (veh/day)			
N—Narrow lane	1,800 – 6,500	1,800 – 5,250	1,800 – 4,250	1,800 – 3,250
W—Wide lane	6,500 – 10,500	5,250 – 9,000	4,250 – 7,500	3,250 – 6,000
B—Bike lane or shoulder	10,500 – 18,000	9,000 – 18,000	7,500 – 17,000	6,000 – 15,250
S—Separated lane or path	–	–	17,000 – 18,000	15,250 – 18,000

NOTE: Not applicable for speeds below 25 mph.

2. Generally, a 4.3- to 4.6-m (14- to 15-ft) wide space appears to be the ideal width to maximize safety conditions for both motorists and bicyclists. Whether this space is provided as a WCL without additional pavement markings to delineate space or whether this 4.3- to 4.6-m (14- to 15-ft) wide space is divided into designated lanes for motor vehicles and bicycles, the additional space of 0.6- to 0.9-m (2- to 3-ft) above the baseline condition of 3.6-m (12-ft) lanes will improve the safety of the facility for both motorists and bicyclists. Overall, both WCLs and BLs can improve the safety and operations of bicycle and motor vehicle traffic, and, where there is adequate width, BLs are preferred.

3. As stated above, in general wider lanes (space) are safer for both bicyclists and motorists. Wider lanes allow for better vehicle positioning and fewer vehicle encroachments. However, there is a limitation on wider being better. Once lane widths get too wide, and 5.2 m (17 ft) seems to be the limit, the excessive width results in diffuse vehicle tracking which negatively impacts safety for both types of road users.

4. Overall, both WCLs and BLs can improve the safety and operations of bicycle and motor vehicle traffic. Whether a WCL is provided or a BL is marked along the facility, there is minimal effect on separation distance between bicyclist and motorist. Although the separation distance between motor vehicle and bicycle

seems to be unaffected by BL markings, BL markings affect the variability of the separation distance; drivers exhibit fewer wide swerves or close passes when passing bicyclists on roadways with marked BLs. Thus, BLs are preferred because this reduced variability should minimize the probability of an incident between a bicycle and motor vehicle.

5. The type of facility (i.e., WCL, BL, or paved shoulder) affects the position of the bicyclist relative to the edge of roadway. Typically, bicyclists are positioned further from the edge of the roadway in a BL than in a WCL. This allows more room for error in tracking by the bicyclist. This also allows more escape room for the bicyclist in the event that a motor vehicle encroaches into the BL. Given that the separation distance between bicyclists and motorists is essentially the same for WCLs and BLs, this additional room for recovery and escape is another reason BLs are preferred over WCLs.

6. The type of facility (i.e., WCL, BL, or paved shoulder) affects the rate of motor vehicle encroachment into the adjacent lane to the left when passing bicyclists. As noted above, the separation distance does not necessarily change with the different bicycle treatments, but the variability in separation increases with WCLs. This results in a higher number of vehicle encroachments for WCL compared BLs (or paved shoulders). This is another reason BLs are preferred over WCLs.

7. A 0.9-m (3-ft) BL can provide sufficient space for motorists and bicyclists to interact safely. Although additional space is preferred [i.e., 1.5-m (5-ft) wide BLs or wider], 1.2-m (4-ft) wide BL (or paved shoulder) will optimize operating

conditions for motorists and bicyclists while minimizing the right-of-way required.

8. The two most widely used bicycle indices for urban and suburban arterials, the BLOS and the BCI, are directly sensitive to curb lane width. Neither the BCI nor the BLOS purport to represent a direct relationship to accident frequency.

CHAPTER 5.

SUMMARY OF ADVANTAGES AND DISADVANTAGES OF NARROWER LANE WIDTHS

This chapter summarizes the advantages and disadvantages of using narrower lane widths on urban and suburban arterials that have been noted in Chapters One through Four. It is evident that narrower lane widths on urban and suburban arterials are considered to be favorable to pedestrians, because the crossing distances for pedestrians may be reduced at both intersection and midblock locations. However, there are other advantages and disadvantages—for pedestrians and for other travel modes—that should be considered in determining an appropriate lane width. These advantages and disadvantages, identified in Table 15, include geometric design, traffic operational, traffic safety, and environmental issues. While these advantages and disadvantages reflect the current knowledge and experience of highway agencies concerning selection of lane width, there is very little quantitative data on the safety effects of using narrower lane widths. There are many unresolved issues concerning the use of narrower lane widths that indicate a need for further research.

TABLE 16. Summary of Advantages and Disadvantages of Narrower Lane Widths on Urban and Suburban Arterials

Advantages	Disadvantages
Motor Vehicles	
• May provide additional space for added travel lane and/or bicycle facility • May provide additional space for median, shoulders, or curb parking • May provide larger turning radii to facilitate comfortable turning movements without affecting pedestrians • Reduce right-of-way acquisition costs for new facilities • Increase capacity at signalized intersections due to decreased allowance for pedestrian	• Reduce driver comfort, particularly on higher-speed facilities • Reduce midblock running speeds • Decrease vehicle maneuverability within lane, particularly for trucks and buses • Lane widths of 3.0 m (10 ft) or less on four-lane undivided arterials and lane widths of 2.7 m (9 ft) or less on four-lane divided arterials should be used cautiously unless local experience indicates otherwise • Lane widths less than 3.6 m (12 ft) should be

TABLE 16. Summary of Advantages and Disadvantages of Narrower Lane Widths (Continued)

Advantages	Disadvantages
crossing time in the signal cycle • Construction of roadways in areas with limited right-of-way is more feasible • No decrease in safety with narrower lanes except in limited cases	used cautiously where substantial volumes of bicyclists share the road with motor vehicles, unless an alternative facility for bicycles is provided • Reduce saturation flow rates and, therefore, increase delay to motor vehicles at intersections
Pedestrians	
• Provide shorter crossing distance and, therefore, less pedestrian exposure to vehicle traffic at intersections, particularly at unsignalized intersections • Serve as potential vehicle traffic calming measure resulting in reduced vehicle speeds in areas adjacent to pedestrians • May provide additional roadside space for sidewalks and clear zones	• For pedestrian facilities on or along side the roadway at midblock locations, perception of safety is lowered by smaller lateral separation between pedestrians and adjacent motor-vehicle traffic • For locations where newly allocated roadway space is available, introducing curb parking creates a potential visibility restriction in that motorists may have difficulty seeing pedestrians
Bicyclists	
• Serve as potential vehicle traffic calming measure resulting in reduced vehicle speeds in areas adjacent to bicyclists • May provide additional space for wide curb lane or bicycle lane • May provide additional roadside space for separate bicycle path	• For shared-lane facilities, reduce space for vehicles and bicyclists to occupy the lane adjacent to one another • Even where wide curb lanes are present, reduce amount of separation between vehicles and bicyclists • Even where bicycle lanes are present, reduce amount of separation between vehicles and bicyclists • Force bicyclists toward edge of traveled way, where raised drainage grates, raised reflectors, or on-street parking may be present

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Appendix A

Survey Questionnaire

National Cooperative Highway Research Program
Project 3-72

"Lane Widths, Channelized Right Turns, and Right-Turn Deceleration Lanes in Urban and Suburban Areas"

The following survey on lane widths, right-turn deceleration lanes, and channelized right turns on urban and suburban arterials is being conducted as part of the National Cooperative Highway Research Program (NCHRP), which is sponsored by the American Association of State Highway and Transportation Officials (AASHTO) in cooperation with the Federal Highway Administration (FHWA). Your responses to the following questions concerning your agency's geometric design policies and practices regarding lane widths, right-turn deceleration lanes, and channelized right turns on urban and suburban arterials would be greatly appreciated.

SURVEY QUESTIONNAIRE

*(Please return by **August 15, 2003**)*

1. What type of highway agency do you represent?

    ___ State highway agency
    ___ County highway agency
    ___ City/municipal highway agency
    ___ Metropolitan planning organization
    ___ Other: ____

AGENCY DESIGN GUIDELINES

2. Does your agency use lane width criteria that differ from the AASHTO *Green Book*?
    .... ☐Yes ☐No

    Does your agency use design guidelines for right-turn deceleration lanes that differ from the AASHTO *Green Book*? .... ☐Yes ☐No

    Does your agency use design guidelines for channelized right turns that differ from the AASHTO *Green Book*?
    .... ☐Yes ☐No

    If YES, to any of the questions above, please attach a copy of your guidelines.

3. Is your agency considering any changes in your policies concerning lane widths, right-turn deceleration lanes, or channelized right turns on urban and suburban arterials? .... ☐Yes ☐No

    If YES, please elaborate: ____

LANE WIDTHS

4. Does your agency use different lane widths for midblock locations and signalized intersection approaches on urban and suburban arterials? .... ☐Yes ☐No

5. What is the narrowest lane width that your agency considers will perform acceptably for urban and suburban arterials?

   ___ft (for midblock locations)
   ___ft (for signalized intersection approaches)

6. Has your agency used lanes narrower than 11 ft on urban or suburban arterials?

   ___ YES, at midblock locations only
   ___ YES, on signalized intersection approaches only
   ___ YES, at both midblock locations and signalized intersections
   ___ NO

7. What factors does your agency consider in selecting an appropriate lane width for an urban or suburban arterial? (Check all that apply)

   ___ Established geometric design policies
   ___ Level of service considerations at midblock locations
   ___ Level of service considerations at signalized intersections
   ___ Running speeds at midblock locations
   ___ Availability of space for a roadway median
   ___ Availability of space for bicycle facilities
   ___ Crossing time/distance for pedestrians
   ___ Potential interference with existing development
   ___ Other (Please describe:____)

8. What pedestrian issues (i.e., crossing distance, vehicle speeds adjacent to pedestrian areas, etc.) does your agency consider when determining lane widths on urban and suburban arterials?

   ____
   ____

9. What bicycle issues (i.e., bicycle lane, wider curb lane, shoulders, etc) does your agency consider when determining lane widths on urban and suburban arterials?

   ____
   ____

10. Has your agency evaluated the traffic operational or safety effects of using narrower lanes on urban and suburban arterials? .... ☐Yes ☐No

    If YES, please describe the results or attach a copy of the evaluation report.

11. Has your agency implemented projects within the last 5 to 7 years in which an existing urban or suburban arterial was:

    Restriped with narrower lanes (i.e., to accommodate an auxiliary lane, bicycle lane, median or wider median, etc)? .... ☐Yes ☐No

    Restriped to provide wider lanes? .... ☐Yes ☐No

    Would any of these projects be suitable for evaluation as part of this research? .... ☐Yes ☐No

RIGHT-TURN DECELERATION LANES

12. Does your agency use right-turn deceleration lanes at intersections or driveways on urban and suburban arterials? .... ☐Yes ☐No

    Does your agency have volume warrants for right-turn deceleration lanes at intersections or driveways on urban and suburban arterials? .... ☐Yes ☐No

    If YES, please elaborate **(or attach a copy of your warrants)**: ______________________

    ____

13. At what types of locations does your agency use right-turn deceleration lanes on urban and suburban arterials? (Check all that apply)
    - ___ Signalized intersections or driveways
    - ___ Unsignalized intersections
    - ___ Unsignalized major driveways

14. How are bicycle lanes striped along right-turn deceleration lanes?

    ____

    ____

15. Has your agency encountered any traffic operational or safety problems associated with right-turn deceleration lanes on urban and suburban arterials? .... ☐Yes ☐No

    If YES, please elaborate: ______________________

    ____

    Has your agency encountered any traffic operational or safety problems associated with *the lack of* right-turn deceleration lanes on urban and suburban arterials? .... ☐Yes ☐No

    If YES to either question, please elaborate: ______________________

    ____

16. Has your agency implemented projects within the last 5 to 7 years in which a right-turn deceleration lane was installed to accommodate right-turn traffic at an intersection or driveway? .... ☐Yes ☐No

    Would any of these projects be suitable for evaluation as part of this research? .... ☐Yes ☐No

CHANNELIZED RIGHT TURNS

17. Does your agency use channelized right-turn roadways, set off from the through lanes by a triangular island, at intersections on urban and suburban arterials? .... ☐Yes ☐No

18. Where does your agency place pedestrian crosswalks at channelized right-turn roadways?
    - ___ At the upstream end of the channelized roadway
    - ___ In the middle of the channelized roadway
    - ___ At the downstream end of the channelized roadway

19. Does your agency have a formal policy concerning the traffic control for channelized right-turn roadways?? .... ☐Yes ☐No

If YES, please attach a copy of your policy.

20. Does your agency install pedestrian-actuated signals at channelized right-turn roadways on urban and suburban arterials?

____ YES, at all locations
____ YES, at selected locations
____ NO

21. Has your agency developed or used any strategies specifically intended to assist visually impaired pedestrians in crossing channelized right-turn roadways without pedestrian signals? .... ☐Yes ☐No

If YES, please describe: ____

____

22. Are pedestrian considerations a factor in determining the radius and/or width of a channelized right-turn roadway? .... ☐Yes ☐No

If YES, please describe: ____

____

23. Has your agency encountered any safety problems related to pedestrians crossings at channelized right-turn roadways on urban and suburban arterials? .... ☐Yes ☐No

If YES, please describe: ____

____

24. Has your agency implemented any of the following innovative traffic control devices at channelized right-turn roadways?

High-visibility crosswalk markings (to improve conspicuity)? .... ☐Yes ☐No
Fluorescent yellow-green signs at the crosswalk and/or in advance of the crossing location?.. ☐Yes ☐No
Real-time warning device to indicate to the motorist when a pedestrian is present in the area? .... ☐Yes ☐No
Other dynamic message signs?.. ☐Yes ☐No
Other: ____

25. Does your agency use deceleration lanes in advance of channelized right-turn roadways? ...... ☐Yes ☐No

Does your agency use acceleration lanes downstream of channelized right-turn roadways?..... ☐Yes ☐No

26. How are bicycle lanes striped on the approach to and within a channelized right-turn roadway?

____

____

27. Has your agency implemented projects within the last 5 to 7 years in which a conventional intersection has been reconstructed to include a channelized right-turn lane(s)? .... ☐Yes ☐No

    Would any of these projects be suitable for evaluation as part of this research? .... ☐Yes ☐No

28. Do you have any other observations or comments?

____

____

29. May we have the name of an engineer in your agency that we may contact to clarify any aspect of your response or to obtain additional information?

    Contact: ____________________ Title: ____________________

    Agency: ____

    Address: ____

    ____

    Telephone #: ____________________ Fax #: ____________________

    e-mail address: ____

Please return the completed survey by **August 15, 2003**, to:

Ingrid B. Potts, P.E.
Senior Traffic Engineer
Midwest Research Institute
425 Volker Blvd.
Kansas City, MO 64110
ipotts@mriresearch.org

Appendix B

Survey Results Concerning Current Design Policies and Practices of Highway Agencies Related to Lane Widths

This appendix presents a summary of the responses of highway agencies to the questions on the survey questionnaire, which is presented in Appendix A, related to lane widths. The questionnaire presented in Appendix A also addresses highway agency policies concerning channelized right turns and right-turn deceleration lanes; the survey results on these topics are addressed in separate syntheses. Design policies at the national level are based on the AASHTO *Green Book* (*1*). Many states also have their own geometric design manuals and policies, which may differ from the *Green Book* in some particulars.

Survey Recipients

The survey questionnaire was distributed at the Urban Street Symposium, held in Anaheim in July 2003. The questionnaire was also mailed to state and local highway agencies throughout the United States. The mailing list for the survey included:

- 50 state highway agencies
- 125 local highway agencies (99 cities and 26 counties)

Thus, a total of 175 survey questionnaires were mailed.

The questionnaires for state highway agencies were generally sent to the state design engineer. The names and addresses of the design engineers were determined from the membership roster of the AASHTO Subcommittee on Design.

Most of the local highway agency engineers on the mailing list for the questionnaires were city and county traffic engineers. Their addresses were obtained from the ITE directory, city websites, and county websites. The local agencies include approximately two major cities from each state and 26 selected urban or suburban counties. Rural counties were not surveyed because the focus of the study is on urban and suburban arterials.

Response Rate

Table B-1 summarizes the responses to the survey that have been received. A total of 75 responses have been received out of the 175 questionnaires that were mailed. The responses received to date include 40 state agencies, 27 cities, and 8 counties. The overall response rate was 43 percent, including a response rate of 80 percent for state highway agencies and 28 percent for local highway agencies.

TABLE B-1. Response Rate for the Highway Agency Survey

Agency type	Number of questionnaires mailed	Number of responses received	Response rate (%)
State agencies	50	40	80.0
Local agencies	125	35	28.0
Total	175	75	42.9

Agency Design Guidelines

In Question 2, highway agencies were asked whether their design guidelines for lane widths, channelized right turns, and right-turn deceleration lanes differ from the AASHTO *Green Book*. Table B-2 summarizes the responses to this question. The responses indicate that the majority of responding agencies use the *Green Book* as their design guidelines for lane widths, channelized right turns, and right-turn deceleration lanes.

TABLE B-2. Number of Agencies With Design Policies That Differ From the *Green Book*

Type of policy	Number (percentage) of agencies					
	State agencies		Local agencies		Total	
Lane width	2	(5.0)	10	(29.4)	12	(16.0)
Channelized right turns	4	(10.0)	4	(11.8)	8	(10.7)
Right-turn deceleration lanes	8	(20.0)	6	(17.6)	14	(18.7)
Total number of agencies responding	40		35		75	

In Question 3, highway agencies were asked whether they are considering any changes in their policies concerning lane widths, channelized right turns, or right-turn deceleration lanes on urban and suburban arterials. Approximately 20 percent of state highway agencies and 26 percent of local highway agencies are considering changes to their current policies.

LANE WIDTHS

In Question 4, highway agencies were asked whether they use different lane widths for midblock locations and signalized intersection approaches on urban and suburban arterials. Approximately 15 percent of state highway agencies and 29 percent of local highway agencies indicated that they use different lane widths for midblock locations and signalized intersection approaches.

In Question 5, highway agencies were asked to identify the narrowest lane width that is considered acceptable – for midblock locations and for signalized intersection approaches – on urban and suburban arterials. Table B-3 summarizes the responses to Question 5.

TABLE B-3. Narrowest Lane Width Considered for Urban and Suburban Arterials

Lane Width (ft)	Number (percentage) of agencies					
	State agencies		Local agencies		Total	
At midblock locations						
8.5	0	(0.0)	1	(2.9)	1	(1.3)
9	0	(0.0)	5	(14.3)	5	(6.7)
10	9	(22.5)	16	(45.7)	24	(32.0)
11	29	(72.5)	11	(31.4)	42	(56.0)
12	2	(5.0)	2	(5.7)	3	(4.0)
At signalized intersection approaches						
8	0	(0.0)	1	(2.9)	1	(1.3)
8.5	0	(0.0)	1	(2.9)	1	(1.3)
9	0	(0.0)	5	(14.3)	5	(6.7)
10	9	(22.5)	19	(54.3)	28	(37.3)
11	29	(72.5)	7	(20.0)	36	(48.0)
12	2	(5.0)	1	(2.9)	3	(4.0)
14	0	(0.0)	1	(2.9)	1	(1.3)
Total number of agencies responding	40		35		75	

In Question 6, highway agencies were asked whether their agency has used lanes narrower than 11 ft on urban or suburban arterials. Table B-4 summarizes the responses to this question.

TABLE B-4. Locations Where Lane Widths Less Than 11 ft Have Been Used

Response	Number (percentage) of agencies					
	State agencies		Local agencies		Total	
YES, at midblock locations only	0	(0.0)	0	(0.0)	0	(0.0)
YES, on signalized intersection approaches only	6	(15.0)	4	(11.8)	10	(13.5)
YES, at both midblock locations and signalized intersections	14	(35.0)	21	(61.8)	35	(47.3)
NO	20	(50.0)	9	(26.5)	29	(39.2)
Total number of agencies responding	40		34		74	

In Question 7, highway agencies were asked to check, from a list, all of the factors they consider in selecting an appropriate lane width for an urban or suburban arterial. Table B-5 presents the list of factors along with the agencies' responses to the question.

TABLE B-5. Factors Considered in Selecting an Appropriate Lane Width

Factors considered	Number (percentage) of agencies					
	State agencies		Local agencies		Total	
Established geometric design policies	40	(100.0)	29	(82.9)	69	(92.0)
Level of service considerations at midblock locations	12	(30.0)	9	(25.7)	21	(28.0)
Level of service considerations at signalized intersections	20	(50.0)	15	(42.9)	35	(46.7)
Running speeds at midblock locations	10	(25.0)	13	(37.1)	23	(30.7)
Availability of space for a roadway median	24	(60.0)	17	(48.6)	41	(54.7)
Availability of space for bicycle facilities	21	(52.5)	16	(45.7)	37	(49.3)
Crossing time/distance for pedestrians	9	(22.5)	10	(28.6)	19	(25.3)
Potential interference with existing development	23	(57.5)	18	(51.4)	41	(54.7)
Other	13	(32.5)	9	(25.7)	22	(29.3)

NOTE: Columns total to more than 100 percent because of multiple responses.

Questions 8 and 9 addressed pedestrian and bicycle issues that are considered in determining lane widths on urban and suburban arterials. A number of pedestrian and bicycle issues were cited as considerations when determining lane widths on urban and suburban arterials, including:

- Crossing distance
- Crossing time
- Vehicle speeds
- Pedestrian volume
- Signal timing
- Pedestrian refuge islands

- Sidewalks
- Land use (pedestrian generators)
- Pedestrian safety
- ADA accommodation
- Aesthetics/appearance to attract pedestrian movement

The following bicycle issues were cited as considerations in determining lane widths on urban and suburban arterials:

- Bicycle lane
- Wider curb lane
- Shoulders
- Established bike route
- Vehicle speed
- Bicycle volume
- Parking
- Right of way availability
- Bike paths
- Edge lines
- Vehicle mix
- Curb and gutter
- Surface type/condition
- Traffic volume
- Roadway type

Three highway agencies identified the AASHTO *Guide for the Development of Bicycle Facilities* as their primary resource for determining lane widths on urban and suburban arterials.

In Question 10, highway agencies were asked if they have evaluated the traffic operational or safety effects of using narrower lanes on urban and suburban arterials. None of the state highway agencies and only three of the local highway agencies have conducted such an evaluation.

In Question 11, highway agencies were asked if they have implemented projects within the last 5 to 7 years in which an existing urban or suburban arterial was either restriped with narrower lanes or restriped to provide wider lanes. Table B-6 presents the number of state and local highway agencies that have implemented either of these projects.

Of the agencies that have implemented restriping projects, 5 state highway agencies and 12 local highway agencies indicated that their projects may be suitable for evaluation as part of this research.

TABLE B-6. Number of Highway Agencies Implementing Restriping Projects Within the Last 5 to 7 Years

Project	Number (percentage) of agencies					
	State agencies		Local agencies		Total	
Restripe to narrower lanes	21	(52.5)	26	(74.3)	47	(62.7)
Restripe to wider lanes	9	(22.5)	13	(37.1)	22	(29.3)