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The Effects of Bicycle Accommodations on Bicycle/Motor Vehicle Safety and Traffic Operations

U.S. Department of Transportation
Federal Highway Administration

Research and Development
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FOREWORD

There is a variety of on- and off-road facilities for bicyclists - each with its own advantages and disadvantages. This report discusses available research and state-of-the-practice information on wide (unmarked) curb lanes, marked bicycle lanes, shoulders used by bicyclists, and pathways and trails.

This report, FHWA-RD-92-069, presents one bicycle planning process, offers an overview of European bicycle facilities, presents the results of preliminary field studies, and describes a methodology (including a set of tables) for use in determining when to apply each type of bicycle facility.

The determination of which facility type to use to accommodate bicyclists is based upon several factors: motor traffic volume, average motor vehicle operating speeds, traffic mix (trucks and recreational vehicles), the presence of on-street parking, and the adequacy of sight distances.

The report also discusses the goals of bicycle programs as being either the accommodation of existing users or the promotion of use by new riders, and the implications of these goals for facility design. The concept of a "design driver" for bicycle facilities is also addressed as it affects facility design.

This report offers documentation for information found in FHWA Report, FHWA-RD-92-073, which is a user manual delineating the methodology for determining the most appropriate type of bicycle facility for a given set of traffic operational conditions.

Sufficient copies of this report are being distributed to provide a minimum of one copy to each Region and Division office and State highway agency. Additional copies for the public are available from the National Technical Information Service (NTIS), Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161. A small charge will be imposed by NTIS.

Lyle Saxton, Director
Office of Safety and Traffic
Operations Research and Development

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16. Abstract

Here are the other two copies of Bike articles

sment of the Federal government's policy goal for types of "design bicyclists." It concludes by ations for selecting roadway design treatments ires of all types of bicyclists.

assumptions regarding policy goals and the types , on the state-of-the-practice, and on professional g, and evaluation is needed to assess and refine

ions, principles, and approaches used to develop model planning process for identifying a network cycle facilities should be provided to accommodate casual adult riders and children); and recommends ions for roadways to serve different types of traffic operational factors.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

(Revised September 1993)

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1. INTRODUCTION AND STUDY APPROACH

The primary objective of this project was to develop a Manual for selecting roadway design treatments to accommodate bicycles. Accomplishing this required consideration of the Federal Government's policy goal for bicycling and a determination of the needs of bicyclists. This report sets forth an approach for selecting roadway design treatments to accommodate a wide range of bicyclists. In so doing, it departs from the thinking that has predominated in bicycle facility planning in the United States for the past 15 years.[1] The report reflects all that has been learned since the bikeway boom of the 1970's and combines this experience with a broader perspective on the type of bicyclist to be served.

PROJECT PURPOSE AND SCOPE

The objectives of this project are to:

- Establish the traffic operational conditions which determine when to provide different types of bicycle facilities.
- Develop a procedure for selecting the most appropriate roadway design which considers the needs of all roadway users.

The scope of work is stated as follows:

> All types of bicycle facilities (both on-road and off-road) are within the scope of this effort. To the maximum extent possible, existing research and operational findings shall be used in conducting this study. Where research or operational practice does not address particular topics, original research may be conducted. Effects on all roadway users shall be considered in the development of recommended bicycle facility treatments. This research shall build upon existing general criteria and should develop specific criteria for the application of the different bicycle facility types.

METHODOLOGY

The project team reviewed a wide variety of domestic and foreign literature to establish the state of the practice in bicycle facility planning and design. Some of the leading practitioners were contacted for their opinions of various approaches. In some cases, draft materials were distributed for comment. Two meetings were held with a panel of representatives from the 12 States that co-funded the project and other bicycle program specialists to present preliminary findings and recommendations for comment. Some field studies were conducted and are reported on in chapter 6. The scope of these studies was limited; therefore, the conclusions are preliminary.

Conclusions in this report are based primarily on the current state of the practice, which is itself based more on experience than on rigorous empirical research. Recommendations are based on the literature reviewed.

This report and the accompanying Manual has been prepared for State and local transportation agency personnel, consultants, and private citizens concerned with the selection of appropriate highway design treatments to accommodate bicycle use.

The Manual is intended to be used in conjunction with the 1991 edition of the American Association of State Highway and Transportation Officials' Guide for the Development of Bicycle Facilities (*AASHTO Guide*).[2]

ORGANIZATION OF THE REPORT

The remainder of this chapter discusses two key study premises: the Federal policy goal for bicycle use, and based on this, the group or groups intended to benefit from roadway design treatments to accommodate bicyclists.

Chapters 2, 3, 4, and 5 present a synthesis of the literature and state of the practice related to the four basic design approaches for serving bicyclists: wide curb lanes, bike lanes, shoulders, and separate bicycle pathways. Chapter 6 presents the findings of field studies. Chapter 7 provides an overview of current European approaches to accommodating bicycles, including traffic calming strategies. Chapter 8 is an overview of a bicycle planning approach that can be used to identify/select routes from special bicycle facility treatments. Chapter 9 presents specific recommendations for design treatments to accommodate different types of bicyclists under different sets of traffic operational conditions.

STUDY APPROACH

To address the objectives of this project, it is essential to first consider certain policy and behavioral issues associated with bicycle use. Two questions are key:

1. Is the policy goal to accommodate current use or to increase the number of users?

2. What are the needs of the design bicyclist?

There are two options for a statement of policy regarding bicycle use; each carries significant implications for selecting roadway designs to accommodate bicycling.

- *Accommodating current use.* This policy would focus attention on meeting the needs of only current bicycle users and is consistent with the general approach taken by most bicycle advocates over the past 15 years. These advocates believe bicyclists should have the knowledge and skills needed to operate a bicycle in the traffic conditions typically associated with shared use of streets and highways.

- *Increasing the number of users.* This policy calls for assessing facility needs to determine what would be required to encourage more people to use bicycles. This policy establishes a more demanding performance measure by which to determine the success of any actions, namely that the provisions result in a real increase in bicycle use. Increasing bicycle use means attracting new users and those new users will often not be willing to share roadway lanes with motor vehicles under existing traffic conditions.

NATIONAL POLICY

Over the past 2 years, several policy statements regarding bicycling have been issued by the Congress, by the U.S. Department of Transportation (US DOT), and by the Federal Highway Administration (FHWA).

"Moving America," the statement of national transportation policy issued by the US DOT, says:

> It is Federal transportation policy to: Promote increased use of bicycling, and encourage planners and engineers to accommodate bicycle and pedestrian needs in designing transportation facilities for urban and suburban areas.[3]

The Transportation Appropriations Act of 1991 commends the US DOT on this statement and added the following statement in the section of the bill directing the US DOT to conduct a national walking and bicycling study:

> Opportunities for bicycling and walking must be enhanced if their full potential to reduce pollution, congestion and energy consumption is to be realized and the safety of nonmotorized users is to be enhanced.[4]

One of the stated goals of the study is to "develop a plan for the increased use and enhanced safety of these modes." During 1990, the Federal Highway Administrator, Dr. Thomas Larson, stated, "The FHWA is committed to working with the States to encourage their (nonmotorized modes) use and make them safer."[5] Further, in an FHWA Policy Memo, Larson refers to the National Transportation Policy statement and adds that:

> I strongly support this important element of the National Transportation Policy and request the full support of the field offices in cooperation with the State highway and transportation agencies to achieve these important objectives.
>
> Bicyclists and pedestrians are legitimate users of the transportation system, and FHWA has a responsibility to provide for their transportation needs.
>
> I am specifically asking that the field offices ensure that full consideration is given to the safe accommodation of bicycle and pedestrian traffic on all Federal-aid highway projects.[6]

Many of these themes are carried through into the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and in a series of implementation guidance notes issued by FHWA.[7]

Thus, it may be concluded that current Federal policy is to increase bicycle use, as well as continuing to accommodate existing use.

THE "DESIGN USER"

The traditional approach to highway design uses the concept of a "design vehicle," which details the typical operating characteristics of the vehicle mix as a basis in determining design characteristics. Since most vehicles are driven in such a way as to make their operational performance nearly identical, highway designers are largely free to ignore differences among the ***operators*** of motor vehicles. This is ***not*** the case with bicycles and bicyclists.

For the past 15 to 20 years, many bicycle advocates have held the most effective way to accommodate bicycling is to ensure bicyclists can share the roadway with motor vehicles.[(1)] They believe promoting bicycling requires better education and training for the many individuals who occasionally ride bicycles, but who are uncomfortable with the idea of "operating in traffic." This approach can be thought of as a "sales approach." Bicycle advocates have a "product" (training to give casual bicyclists the skills they need to share most roadways with motor vehicles) and have been selling it to the public as something essential. However, apparently the public does not want to buy it. In a Harris poll survey of adult bicyclists, only 1.5 percent of cyclists identified training as a factor that would encourage them to ride more often.[(8)]

Bicycling is still an optional activity for most people and if participation is made too difficult, people simply won't bother with it. To serve this public, a "marketing approach" is called for. Under this approach the needs of intended users are determined and a product or service offered that they will find attractive and use.

This does not mean abandoning all engineering principles and planning processes to give the general bicycling public exactly what it asks for. A complete system of separate bike paths or bike lanes on every street is neither appropriate nor feasible. Specific decisions on the type, location, and design of bicycle accommodations should be made by planners, traffic engineers, and other technically qualified professionals. The important message from casual riders is their description of the conditions they need to use their bicycles more often.

There are close to 100 million people of all ages in the United States who own bicycles.[(9)] The Bicycle Federation of America estimates that less than 5% would qualify as experienced or highly skilled bicyclists. Therefore, as the goal is to increase bicycle use and as new users will be predominantly novice riders, any plans must meet the needs of both experienced and less experienced riders. One solution to resolving this challenge is to develop the concept of a "design bicyclist" and adopt the following classification system for bicycle users:

- Group A: Advanced bicyclists (experienced).
- Group B: Basic bicyclists (casual, novice, occasional).
- Group C: Children (pre-teen).

Each group has different needs that must be recognized in order to determine what type of facility treatment will best accommodate and encourage more bicycle use. Based on the reviews conducted as part of this study, the following criteria emerged:

Group A: Advanced Bicyclists

- Direct access to destinations (usually via existing street and highway system).
- The opportunity to operate at maximum speed with minimum delays.
- Sufficient operating space on the roadway or shoulder so as to eliminate the need for either the bicyclist or the motor vehicle operator to shift position when passing.

Group B: Basic Bicyclists

- Comfortable access to destinations but not necessarily by the most direct route; this might be either a low-volume street or designated bicycle facility.
- Well-defined separation of bicycles and motor vehicles on arterial and collector streets.

Group C: Children

- Access to key destinations surrounding residential areas (schools, recreation facilities, shopping, other residential areas).
- Well-defined separation of bicycles and motor vehicles.
- Residential areas with low motor vehicle speed limits, traffic calming strategies and good sight distances.

Other distinctions could be added to this list, but it is sufficient to suggest combining groups B and C in most situations. Based on this, a "design user" concept is proposed that recognizes two broad classes of bicyclists: group A and group B/C riders.

Generally, group A bicyclists will be best served by:

- Designing all streets and highways to accommodate shared use by bicycles and motor vehicles wherever bicycles are permitted to operate.
- Providing usable roadway shoulders on most rural section roads.
- Applying speed limits to minimize speed differences between bicycles and motor vehicles (as is typical on most neighborhood streets).

Generally, group B/C bicyclists will be best served by:

- Ensuring residential neighborhood streets have low speed limits, effective speed controls (traffic calming), and good sight distances.
- Providing usable roadway shoulders.
- Providing designated bicycle facilities (bike lanes, separate bike paths, or side-street routes) through key travel corridors typically served by arterial and collector streets.

Based on these two design cyclist types, a two-tiered approach to meeting their needs is proposed.

- Group A cyclists will be best served by making every roadway "bicycle-friendly" using design treatments such as wide curb lanes and paved shoulders that accommodate shared use by bicycles and motor vehicles. This provides adequate space for bicycles and motor vehicles to share the roadway with minimum need for changing lanes or lane position. The desired outcome is to have sufficient space to accommodate shared use by bicycles and motor vehicles with minimum delays and maximum comfort (safety).
- Group B/C cyclists will be best served by identifying key travel corridors (typically served by arterial and collector streets) and by providing designated bicycle facilities for these bicyclists on routes through these corridors (see chapter 8).

BASIC PRINCIPLES

The recommendations in this manual follow from five basic principles derived from this two-tiered approach:

1. Two classes of Design Bicyclist are recognized: group A (advanced) and group B/C (basic and child).
2. Given that the stated policy goal is to increase bicycle use, a supply-driven (as opposed to demand-driven) approach of providing special bicycle facilities to increase bicycle use (i.e., "if you build them they will come") is warranted.
3. Every street and highway on which bicycles are permitted is a "bicycle street" and should be designed and maintained so as to accommodate shared use by bicycles and motor vehicles.
4. Providing accommodations to meet the needs of group B/C cyclists involves two steps: (1) a planning process to identify key travel corridors and/or routes along which access is important, and (2) a design decision to identify the most appropriate facility treatment for a route or corridor.

5. Where it is necessary and desirable to provide special facility treatments to accommodate and encourage group B/C bicyclists, these facilities should be treated as *alternatives* or additions to the existing system of streets and highways, and ***not*** as *substitutes* for shared use of the roadway.

2. THE USE OF WIDE OUTSIDE TRAVEL LANES AS A BICYCLE FACILITY

DEFINITION

The Transportation Research Board's *Highway Capacity Manual* (HCM) states that the "ideal conditions for multilane highways include the provision of 12 feet [3.7 m] lanes...."[10] Likewise, the HCM defines ideal conditions for two-lane highways to include "lane widths greater than or equal to 12 feet [3.7 m]...."

The effect of lane widths narrower than 12 ft (3.7 m) is reflected in the HCM's use of roadway capacity adjustment factors for both types of highways. A reduction in lane width from 12 to 10 ft (3.7 to 3 m) can be expected to reduce the carrying capacity of variously configured multilane highways from 9 to 26 percent. A similar reduction in lane width for two-lane highways reduces capacity by 16 to 42 percent. AASHTO's Policy on the Geometric Design of Highways and Streets notes that:

> No feature of a highway has a greater influence on the safety and comfort of driving than the width and condition of the surface....10 to 13 ft [3 to 3.9 m] lane widths are generally used with a 12 ft [3.7 m] lane predominant on most high-type highways....Lane widths of 12 ft [3.7 m] are desirable on both rural and urban facilities....[11]

For these reasons, the term "wide curb lane" or "wide outside lane," as a technique for enhancing the safety and convenience of bicyclists should apply only when the outside through lane width is substantially greater than the 12-ft (3.7 m) width recommended for motor vehicle use.

For low volume streets (e.g., those with less than 1,000 Average Daily Traffic [ADT]) with posted low speed limits (25 mi/h [40 km/h] or less), the shared use of lanes is generally acceptable for all groups of riders. These typically are neighborhood streets.

The *AASHTO Guide* defines wide curb lanes as "highway sections without bicycle lanes [and with] a right lane wider than 12 feet (3.7 m)."[2] As is implied by the name "curb lane," the treatment is usually applied to urban cross-section roads with curb and gutter pan and without a road shoulder. However, in some areas, urban roadways are routinely built without curb or gutter.

In May 1992, the Non-motorized Transportation Committee of the American Society of Civil Engineers formally requested AASHTO revisit the 1991 edition of the *Guide* in relation to the section on wide curb lanes. Specifically, the committee stated:

> The statement on page 14 [of the Guide] that "a right lane wider than 12 ft [3.7 m] can better accommodate both bikes and motor vehicles in the same lane" is misleading and could result in inadequate lane widths.

> Lane widths between 15 and 16 feet [4.6 m and 4.9 m] often work very well and are arguably safer under a variety of conditions that the 12 to 14 feet [3.7 to 4.3 m] (with 14 feet [4.3 m] as a maximum) recommended on page 15 of the Guide.(12)

Therefore, in the following discussion "wide curb lane" or "wide outside lane" refers to the use of outside through lanes equal to or greater than 14 ft (4.3 m) in width on road sections without a bicycle lane or road shoulder, regardless of whether the road has a curb (urban section) or open edge (rural section).

MEASUREMENT OF LANE WIDTH

Many planners and engineers concerned with bicycle use differentiate between the measured width of a lane and the "usable" or "available" lane width. The *AASHTO Guide* comments that:

> ...usable width would normally be from curb face to lane stripe, or from edge line to lane stripe, but adjustments need to be made for drainage grates, parking, and longitudinal ridges between pavement and gutter section.(2)

In a study presented to the Minnesota State Trail Council, Erickson found that longitudinal obstacles located on the right edge of the roadway can reduce the usable width of the outside lane by 1.5 to 2.5 ft (0.5 to 0.8 m).(13) The accumulation of dirt and debris along the curb face of urban cross-section roads can present similar problems. For this reason, a measurement of outside lane width from the lane stripe to the edge of the gutter pan, as opposed to the curb face, is to be preferred.

ADVANTAGES OF WIDE CURB LANES

The State of Florida's *Roadway Plans Preparation Manual* lists several advantages of widened outside lanes:

> In addition to the safety benefits for bicyclists, wide curb lanes provide benefits that will improve traffic flow, add to the capacity of the roadway, and enhance overall highway safety. Some of those benefits are:
>
> - Assist a vehicle in turning right into driveways and narrow connecting streets without encroachment into the adjacent lane.
> - Assist a vehicle in entering the roadway from an intersecting roadway or driveway without encroachment into the adjacent lane.
> - Allow a motorist to pass a bicyclist without delay.
> - Reduce the need for vehicles to change lanes because of a bicyclist.
> - Improve drainage in constricted areas.(14)

As far as bicycle operation is concerned, there are three widely accepted advantages of wide curb lanes:

- They can accommodate shared bicycle/motor vehicle use without reducing the motor vehicle capacity of the roadway.
- They can minimize both real and perceived operating conflicts between bicycles and motor vehicles.
- They increase roadway capacity by the number of bicyclists that can be accommodated.

EFFECTS OF WIDE CURB LANES ON ROAD CAPACITY

Wide outside lanes enhance the capacity of a roadway by allowing a motor vehicle to overtake a bicycle without encroaching into the adjacent lane. Such a characteristic is known as "lane sharing" or "mode sharing." A Maryland study undertaken by McHenry and Wallace concluded that a 12-ft (3.7 m) outside lane is insufficient to accommodate lane sharing:

> The standard 12 ft [3.7 m] outside lane under the study conditions does not provide sufficient lane width for mode sharing. Under study conditions, on a 12 ft [3.7 m] lane, bicycles act as a lateral obstruction, decreasing operating space by approximately 2 ft [0.6 m] with corresponding negative effects on highway capacity. The extent of the capacity effect depends on motor vehicle volumes and bicycle volumes. The effect on capacity will be least at capacity extremes and more significant in the mid-levels of capacity.[15]

The study conditions referred to above are for multilane, urban arterials with a posted speed of 40 mi/h (64 km/h). The greater effects of bicycle operation at mid-levels of capacity are frequently noted by bicyclists. At level of service C (roughly 70 percent of a road's design capacity) or less, motor vehicle speeds are often significantly reduced and the solid line of traffic moves in a regular flow around the bicyclist.[15]

At very low volume levels, it is easier for the overtaking motorist to find an acceptable gap in the adjacent lane. Forester noted that capacity effects are also more pronounced on two-lane facilities.

> If the outside lane is too narrow for lane sharing at the normal traffic speed, then a portion of the motorist delay is attributable to cyclist traffic. This is most severe on a two-lane road, because the overtaking motorist must wait for a gap in oppos-ing traffic. This is much harder and requires a much longer gap than does fitting into a gap or alongside a stream going in the same direction.[16]

While there is general recognition of the capacity-enhancing characteristics of wide curb lanes, a lack of objective data on the effects of different lane widths has resulted in a lack of detailed criteria to evaluate specific alternatives. The HCM concludes:

> There is little existing data or information on the impacts of bicycles on capacity or operating conditions between intersections. Bicycles are not expected to have any impact on flow where curb lanes exceed 14 ft [4.3 m].[10]

On the other hand, the HCM does detail the effects of bicycle traffic on intersection capacity. In many ways, this is more important because the capacity of intersections is the primary determinant of carrying capacity on urban arterial segments. According to the HCM, intersection capacity, in turn:

> ...is based on the concept of saturation flow and saturation flow rates. Saturation flow rate is defined as the maximum rate of flow that can pass through a given intersection approach or lane group under prevailing traffic and roadway conditions....[It] is expressed in units of vehicles per hour.[10]

The HCM measures the effect of bicycle traffic by assigning it a Passenger Car Equivalent, or PCE. A PCE of one means that a bicycle uses up the same available capacity as 1 automobile. A PCE of 0.5 indicates that one bicycle uses the same capacity as half an automobile. The HCM goes on to explain that:

> The equivalent varies with lane width and depends on whether the bicycle movement in question is "opposed" or "unopposed." A bicycle moving straight through an intersection, encountering no significant interference from vehicles or pedestrians, is considered to be unopposed. A left-turning bicycle must cross an opposing vehicular flow on two-way streets, and would be considered to be opposed. Right-turning bicycles may or may not encounter significant pedestrian interference, and could be classified as either opposed or unopposed. Where the conflicting crosswalk flow exceeds 100 peds/hr, it is recommended that right-turning bicycles be considered opposed.[10]

The HCM passenger car equivalents for bicycles are given in table 1.

Table 1. Passenger car equivalents for bicycles in signalized intersections.[10]

Bicycle Movement	Lane Width (feet)		
	< 11	11-14	> 14
Opposed	1.2	0.5	0.0
Unopposed	1.0	0.2	0.0

Based on these HCM values, the provision of wide curb lanes can have a significant positive impact on intersection capacity.

EFFECTS OF WIDE CURB LANES ON BICYCLE/MOTOR VEHICLE OPERATING CONFLICTS

Regardless of the quantitative analysis of roadway capacity, many authors have commented on the ability of wide curb lanes to reduce both the actual and perceived conflicts between motorists and bicyclists. Much of the success of bicycle planning and engineering measures depends on making bicycling both efficient and comfortable. To accomplish this, it is not only important that a bicycle facility actually reduce roadway conflict, but also that it appears to both motorists and bicyclists to reduce conflict.

> Both motorists and bicyclists are happier and more comfortable with each other on roads with wide outside lanes. Wide outside lanes reduce the emotional tension between the parties....Alleviating the tension between motorist and bicyclist encourages cycling in two ways; it makes motorists less intolerant of bicyclists, thus reducing the tendency toward discrimination and bad behavior; and it increases the attractiveness of bicycling.[16]

These sentiments are echoed by the Pima, AZ Area Association of Governments:

> Everyone has at one time or another either encountered a bicyclist on a narrow road, or has been the bicyclist riding on a narrow road being overtaken by traffic. Both the motorist and the bicyclist can act properly and reasonably, and still feel somewhat frustrated, threatened, and/or uncomfortable. The motorist doesn't like having to slow down and then pass (sometimes closely) a bicyclist. The bicyclist, on the other hand, probably has no choice but to use the narrow road, and always must have concern for the few motorists who aren't skilled at judging where the right side of their vehicle is or the correct relative speed of the bicyclist when overtaking and turning right or when turning left from the opposing direction. Narrow roads are unforgiving—there is little, if any, room for operator error, be it motorist or bicyclist.
>
> Outside lanes sized to provide a standard motor vehicle travel lane plus width for bicycles provides a reasonably forgiving roadway environment in terms of lateral distance and clearances, and thus makes the road safer and more convenient for both the motorist and the bicyclist.[17]

DISADVANTAGES OF WIDE CURB LANES

Four points, typically raised against their establishment, argue that wide curb lanes:

- Present the potential problem of being used by motor vehicles as two lanes.
- Can cause increased traffic speeds at low and moderate volumes.
- Introduce the possible cost of purchasing and paving additional right-of-way.
- May not serve the needs of group B/C riders.

Use of Wide Curb Lanes as Two Lanes by Motor Vehicles

Although several studies comment on the problem of wide outside lanes being used as two lanes, there is little consensus about what width creates this problem. The *AASHTO Guide* suggests 14 ft (4.3 m):

> Widths greater than 14 ft (4.3 m) may encourage the undesirable operation of two motor vehicles in one lane, especially in urban areas, and consideration should be given to striping as a bicycle lane when wider widths exist.[2]

On the other hand, the New Jersey Department of Transportation notes that:

> Empirical studies have shown, however, that when outside lane width exceeds 15', then motor vehicle traffic tends to "double-up" in the wide lane at intersections and during periods of peak traffic volumes.[18]

The New Jersey DOT recommends the use of paved road shoulders to the right of the road edge stripe in addition to a 15-ft (4.6-m) curb lane in situations where high speeds and truck traffic requires additional lateral separation between bicycles and motor traffic.[18] Other reports indicate the "doubling-up" problem begins to occur at 16 ft (4.8 m) or 17.6 ft (5.3 m).[15,19]

Wide Curb Lanes and Speed Control Problems

Other observers express the concern that wide curb lanes may result in increased motor vehicle speeds in conditions of moderate or light traffic, even to the point of exceeding posted speed limits. It is necessary, they argue, to maintain narrow lanes in order to assure motor vehicle speeds can be controlled. They would rather create additional roadway width either by use of a shoulder or a designated bike lane.[20]

Cost of Additional Right-of-way and Pavement

The Florida DOT estimates the cost of providing widened curb lanes on both sides of a new highway to be $40,000 per mile, compared to $30,000 per mile for 4-ft (1.2-m) shoulders and $60,000 per mile for 4-ft (1.2-m) bike lanes.[21]

Does Not Serve Group B/C Cyclists

Wide curb lanes can serve existing, confident cyclists—those comfortable riding with traffic—quite well. However, for the novice cyclist wide curb lanes do not always provide the degree of comfort or feeling of safety required to persuade them to ride on a busy highway.

The Florida DOT has recently altered its policy of providing wide curb lanes on all new highways in urban areas in favor of providing designated bike lanes. Accommodation of the group B/C rider was a key determinant in this decision.

DETERMINATION OF PROPER LANE WIDTH

Many of the reports reviewed included recommended lane widths for wide curb lanes. In some reports, the determination of proper lane width was based on either simple selection criteria or was applied to all roadways. In other cases, quite complex multiple-factor criteria were used. Summaries of some of these criteria are given below.

The *AASHTO Guide* recommends:

> On highway sections without bicycle lanes, a right lane wider than 12 feet (3.7 m) can better accommodate both bicycles and motor vehicles in the same lane and is thus beneficial to both bicyclists and motor vehicles....In general, a lane width of 14 feet (4.3 m) of usable width is desired. Usable width would normally be from curb face to lane stripe, or from edge line to lane stripe, but adjustments need to be made for drainage grates, parking, and longitudinal ridges between pavement and gutter sections. Widths greater than 14 feet (4.3 m) may encourage the undesirable operation of two motor vehicles in one lane, especially in urban areas, and consideration should be given to striping as a bicycle lane when wider widths exist.(2)

These recommendations have been quite specifically challenged by the Non-motorized Transportation Committee of the American Society of Civil Engineers, which believes 14 ft (4.3 m) is the minimum width appropriate for a wide curb lane for shared use by motor vehicles and bicycles.(12)

Florida DOT requires that:

> Wide curb lanes are to be provided as the minimum treatment in conjunction with other roadway improvements (curb and gutter construction) in or within one mile [1.61 km] of all urbanized (population 50,000 or more) areas unless right of way is inadequate and the cost associated with acquisition for this purpose is not feasible. For those projects that require additional right of way for the construction of the road, the additional right of way necessary to provide wide curb lanes will be acquired unless the additional cost is excessive....
>
> The minimum width for curb lanes is 14 feet [4.3 m], measured from the edge of the adjacent travel lane to the lip of the gutter, or 15 feet [4.6 m] to the face of the curb, if the 1 foot 6 inch [0.5 m] gutter is not constructed....
>
> Wide curb lanes are also to be considered in urban areas (5,000-50,000 population) based on anticipated bicycle travel needs as previously identified. Urban resurfacing projects may include restriping to provide wide curb lanes by using 11 foot [3.4 m] interior lanes.(14)

The New Jersey DOT suggests the use of 12-ft (3.7-m) outside lanes on roads carrying less than 1,200 vehicles per day. Where shoulders are not present, a 15-ft

(4.5-m) right lane is to be used on roads with more than 1200 ADT. This configuration is acceptable on roadways with either a 55 mi/h (88 km/h) posted speed and minimal truck traffic, or on roadways with a 45 mi/h (72 km/h) posted speed and heavier truck volumes. Under conditions where both a 55 mi/h (88 km/h) posted speed and significant truck volumes exist, 18 ft (5.5 m) of space is called for in an unspecified combination of outside lane width and shoulder.(18)

The Pima (AZ) area MPO recommends:

> ...that all principal streets and highways have outside lane widths (including paved shoulders) of no less than 16 feet [4.9 m]. This provision shall be implemented when a street/highway is constructed or reconstructed. When no major construction or reconstruction is contemplated, adjustment of other lane widths to provide maximum feasible outside lane width (up to 16 feet [4.9 m]) shall be undertaken following overlays or sealcoats.(17)

In *Bicycle Transportation*, Forester advocates several outside lane widths for two-lane and multilane roads at various motor vehicle speeds. He offers these as:

> ...the lane widths that have proved satisfactory for lane sharing in the experience of well-informed cyclists in California.(16)

These and other recommendations are summarized in tables 2 and 3.

Table 2. Lane widths required for lane sharing.(16)

Two-Lane Roads

Motor Vehicle Speed (mi/h)*	Lane Width (ft)
25-45	14
45-65	16

Multilane Roads

Motor Vehicle Speed (mi/h)	Lane Width (ft)
30-45	12
45-70	14
70+	16

* 1 mile = 1.61 kilometer; 1 foot = 0.305 meter

Table 3. Summary of curb lane width recommendations.

AASHTO[2]	12-14 ft* with 14 ft preferred
Florida DOT[14]	14 ft minimum in urban areas required if feasible 14 ft minimum in small urban areas suggested
New Jersey[18]	12 ft below 1200 ADT 15 ft above 1200 ADT 15 ft plus additional 3 ft of paved surface when ADT is over 1200 and posted speed is above 45 mi/h and significant truck traffic exists
Pima Area MPO[17]	16 ft combination lane width and/or shoulder
Yuma County MPO[22]	14 ft up to 45 mi/h posted speed 14 ft plus add 3 ft width over 45 mi/h
Munn[23]	15 ft
Jones[19]	13-15 ft
Forester[16]	As per table 2
McHenry & Wallace[15]	14-17 ft
ASCE[12]	14-16 ft

* 1 foot = 0.305 meter

WIDE OUTSIDE LANES VS PAVED SHOULDERS

Although the use of paved shoulders to accommodate bicycles is explored in greater depth in chapter 4, it is appropriate here to outline some factors that should be considered as to whether wide outside lanes or paved road shoulders are the preferred option. In general, two factors should be taken into account:

1. The locational environment of the improvement (rural or urban).

2. The type of bicyclist projected to be using the facility.

Locational Environment

A wide curb lane is generally the preferred option in *urban* environments because:

- Urban roads tend to be designed with a curb-and-gutter section while rural or suburban roads are more often built with an open edge.

- Rural roads tend to have higher posted speeds and heavier truck traffic, both of which require additional clearance between bicycles and the adjacent motor vehicle stream. The additional lane width required to accommodate such use may exceed the maximum recommended lane width to prevent the operation of two motor vehicles in the same lane.

These points are discussed by several authors:

> Wide curb lanes are best suited for curb and gutter highways because bicyclists on highways without would be further removed from the motor vehicle flow by providing smooth and adequate road shoulders.[19]

> 4-foot [1.2-m] paved shoulders are required on all new construction, reconstruction, and lane addition projects for rural, open drainage, free access highways....[This] does not apply to urban curb and gutter construction.[14]

> A lane width of 14 ft (4.3 m) of usable pavement width is desired. At speeds above 40 mi/h [64.4 km/h], either an open section with shoulders or greater lane width is recommended.[22]

Type of Cyclist Using Facility

The type of cyclist using the facility is also an important consideration, as the New Jersey Department of Transportation explains:

> Novice or inexperienced bicyclists tend to believe that a paved shoulder separated from the travel lane by an edge stripe will normalize the tracking paths of bicycles and motor vehicles and provide them with a safer operating space....Experienced cyclists, on the other hand, tend to believe that the benefits of wide outside lanes (as opposed to standard width lanes with shoulders delineated by an edge stripe) outweigh the real and imagined benefits of such striping.

> Providing a wide outside lane as the space in which bicycle traffic can operate (with or without an adjacent paved shoulder) permits motor vehicles to migrate into the area where bicyclists ordinarily operate. This is considered a benefit by experienced bicyclists because traffic `sweeps´ the pavement free of debris. Accidents caused by debris (sand, gravel, grit) though usually unreported, are thought to occur relatively frequently.[18]

Group B/C riders are likely to prefer shoulders to wide curb lanes. Space to the right of the edge stripe offers a greater sense of security and a more clearly defined space in which riders can operate.

WIDE CURB LANES VS STRIPED BICYCLE LANES

As is explained more fully in chapter 3, there is still some controversy within the bicycle planning community concerning the decision to use striped bicycle lanes or unstriped wide curb lanes.

In general, group A bicyclists prefer wide curb lanes, arguing that bike lanes unduly restrict the lateral movement of bicycles in midblock road segments and can make turning movements in intersections more complicated for both motorists and bicyclists. group B/C bicyclists, though, prefer bike lanes with their channelized movement of motor vehicles and bicycles and lower the level of perceived conflict between the two.

Both groups, however, agree that very narrow bicycle lanes are both unpleasant and dangerous. The *AASHTO Guide* recommends a minimum 4-ft (1.2-m) width for bike lanes (5 ft [1.5 m] where adjacent on-street parking exists). In Florida and California jurisdictions are experimenting with 3.5-ft (1-m) bike lanes (plus the curb and gutter), and the experience should be followed closely to assess the implications of this narrower width of bike lane.

Wide curb lanes work best where the intent is to accommodate group A bicyclists. Bicycle lanes work better where the intent is to encourage more bicycle use by group B/C riders. There is evidence to suggest that marked bicycle lanes are a significant attraction in the choice of routes for many bicyclists.(24)

In a six-State survey of cyclists, Kroll and Summer found:

> ...cyclists were definitely not satisfied with fourth-rate bike lanes on narrow streets of poor surface quality. However, brightly painted bike lanes on well-surfaced streets, especially if not adjacent to parked cars, were viewed as solid evidence of a city's interest in improving cycling safety.(25)

Although effective in increasing the capacity of the roadway and the comfort of bicyclists, wide curb lanes are a relatively low-visibility improvement with a limited ability to actively encourage increased use of bicycles for recreation or transportation. A Harris survey of both bicyclists and nonbicyclists suggests that the provision of "safe bicycle lanes" would motivate more people to consider bicycle commuting than financial incentives, the provision of shower facilities and bicycle storage lockers, or a steep rise in the price of gasoline.(26)

Because bicycle lanes can complicate the turning movements of both motor vehicles and bicycles at intersections, wide curb lanes are generally a better choice on road segments where intersections are frequent. Also, because the bicycle lane stripe may discourage bicyclists from moving left to increase "shy distance" from automobiles partially entering the roadway from driveways, wide curb lanes are generally a better choice on roads where driveways (particularly commercial driveways) are frequent. This is especially true where limited sight distances or visual clutter force the motorist to "nose out" of a driveway to see around obstacles.

Bicycle lanes appear to reduce accident rates for group B/C bicyclists. In particular, they reduce the incidence of accidents resulting from wrong-way bicycle riding, a significant contributor to the generation of bicycle/motor vehicle accidents.[27]

Bicycle lanes also tend to attract group B/C bicyclists from sidewalks, thus reducing the potential for driveway/intersection crashes and conflicts between bicyclists and pedestrians.

CONCLUSIONS AND RECOMMENDATIONS

1. Increasing the width of the outside travel lane of a roadway to 14 ft (4.3 m) or more is an effective method of increasing the safety and comfort of bicycle users. Such a treatment also confers safety, convenience, and capacity advantages to motorists.

2. Wide curb lanes are most appreciated by, and are most effective for, group A riders. Routes intended to serve group B/C bicyclists (especially near college campuses or large recreational attractions) should be considered for road shoulders or striped bicycle lanes.

3. Wide curb lanes work best on urban section (curb and gutter) roadways. On rural section (open-edge) roads, the use of a 4-ft (1.2-m) paved shoulder to the right of the edge line may be preferred. This is particularly true on roads with a posted speed limit of 35 mi/h (56 km/h) or over and truck or recreational vehicle traffic.

4. The recommended minimum width of a wide curb lane is 14 ft (4.3 m), measured from the lane dividing stripe to the edge of the gutter pan, or 15 ft (7.5 m) to the curb face if a standard gutter pan is not used.

5 At posted speeds of 45 mi/h (72 km/h) or over, the use of a 14-ft (4.3-m) outside lane may be insufficient to counteract the lateral "wind blast" effect of passing motor traffic, especially for heavy trucks. In these cases additional lane width (15 or 16 ft [4.5 or 4.9 m]) or a 12-ft (3.6-m) lane and 4-ft (1.2-m) to 6-ft (1.8-m) shoulder should be used.

6. Wide curb lanes are generally preferred over road shoulders or bicycle lanes on roadways with frequent intersections and/or commercial driveways.

7. Wide curb lanes have the lowest maintenance requirements of any bicycle facility. They generally do not require a special sweeping schedule or debris policing.

8. Wide curb lanes have a limited benefit in encouraging increased use of bicycles or altering the route choice of cyclists. Agencies desiring to promote changes in modal splits should consider facilities designed to meet the needs of group B/C bicyclists.

3. BICYCLE LANES

DEFINITION

The *AASHTO Guide* defines a bicycle lane (or "bike lane") as "a portion of the roadway which has been designated by striping, signing, and pavement markings for the preferential or exclusive use of bicyclists."[2]

The California Department of Transportation's (CALTRANS) *Highway Design Manual*, using an older designation terminology, refers to bicycle lanes as Class II bikeways.

> Class II bikeways (bike lanes) for preferential use by bicycles are established within the paved areas of highways. Bike lane stripes are intended to promote the orderly flow of traffic, by establishing specific lines of demarcation between areas reserved for bicycles and lanes to be occupied by motor vehicles. This effect is supported by bike lane signs and pavement markings. Bike lane stripes can increase bicyclists' confidence that motorists will not stray into their path of travel if they remain within the bike lane. Likewise, with more certainty as to where bicyclists will be, passing motorists are less apt to swerve towards opposing traffic in making certain they will not hit bicyclists.[28]

As the 1991 draft *Oregon Highway Design Manual* notes, this road treatment is usually applied in urbanized areas.

> Bike lanes [are] where a portion of the roadway is designated through striping, signing, and pavement markings for the preferential or exclusive use of bicyclists. This type of bikeway is appropriate for urban arterials and other roads where bicycle and motor vehicle use is high.[29]

Florida DOT's *Road Plans Preparation Manual* says:

> Bicycle lanes may be warranted in lieu of wide curb lanes in some areas of the state. Collectors and the more lightly traveled arterials that have only a moderate level of commerce, and have fewer turning movements, may serve bicyclists with a bike lane.[14]

Although location and design criteria are covered in more depth elsewhere in this chapter, three design principals are universally agreed upon and are of such importance they should be inherently included in the definition of a bicycle lane:

1. Bicycle lanes should be one-way facilities carrying bicyclists in the same direction as motor vehicles in the adjacent travel lane(s).

2. In general, bicycle lanes should be on the right side of the roadway.

3. Bicycle lanes should be placed between the outside through traffic lane and the road edge or parking lanes.

There are important reasons for observing all three of these guidelines:

> Bicycle lanes should always be one-way facilities and carry traffic in the same direction as adjacent motor vehicle traffic. Two-way bicycle lanes on one side of the roadway are unacceptable because they promote riding against the flow of motor vehicle traffic. Wrong-way riding is a major cause of bicycle accidents and violates the Rules of the Road statutes in the Uniform Vehicle Code. Bicycle lanes on one-way streets should be on the right side of the street, except in areas where a bicycle lane on the left will decrease the number of conflicts (e.g., those caused by heavy bus traffic).[2]

> Bicycle lanes shall not be placed between the parking area and the curb. Such facilities increase the conflict between bicyclists and opening car doors and reduce visibility at intersections. Also, they prevent bicyclists from leaving the bike lane to turn left and cannot be maintained.[28]

Even when left-side bicycle lanes do decrease operating conflicts, they can have significant detrimental effects during their initial period of use. Though such a facility in Madison, Wisconsin did reduce accidents in the long run, a large increase in accidents during its first year of operation prompted two observers to recommend:

> Given the initial adverse accident experience with a left-side bicycle lane in Madison, other similar new bicycle facilities should be implemented only in conjunction with special signing to alert both bicyclists and motorists to the potential hazards. At a minimum, signs identifying the existence, location, and intended use of the bicycle lane should be highlighted with red flags for the first several months.[30]

With the growing awareness in the last 10 years that wide curb lanes can confer many of the benefits of bicycle lanes in situations where lanes may not be desired, some agencies are now recommending this alternative on one-way streets.

> Generally, bike lanes are undesirable on one-way streets, since it is difficult to accommodate all origin/destination needs without placing lanes on both sides of the roadway. Instead, consider the value of adding extra width to both the right and left (curbside) travel lanes to accommodate mixed bike/motor vehicle traffic.[22]

ADVANTAGES OF BICYCLE LANES

The argument as to what benefits are conferred to bicyclists by the installation of a bike lane on a street or road has been shrouded in confusion. A bike lane is usually added to a road as part of the reconstruction or reconfiguration of the roadway. Either the paved portion of the road is widened to accommodate the lane, or the existing roadway width is reallocated via a narrowing of the motor vehicle lanes or the elimination of a travel lane or parking area.

In any event, two things happen: the bicyclist receives designated travel space on the roadway, and this space is clearly delineated through bike lane markings. Munn points out these two changes are often lumped together in the minds of observers:

> ...the bike lane presents a paradox. For if the street is wide enough (case A) to include a designated bike lane which does not interfere with motor vehicles, the marking of the lane is unnecessary....On the other hand, for a heavily traveled street with narrow traffic lanes and hazardous conditions (case B), there will be no space for the bike lane. In the event that city government can be persuaded to eliminate on-street parking, give up one or more traffic lanes, rearrange the lane striping, and through these measures create space for bicycles...then case B reverts to case A, and the marked bike lane is still unnecessary....When reduced to essentials, the heart of the engineering issue has to do with the width of the outside lane.(23)

Munn is representing the views of the typical group A rider who is already confident riding in traffic. He does not address the impact of bike lanes on potential bicyclists. Over the years there has been a sustained public demand for designated bike facilities such as bike lanes—because group B/C riders want to have an identifiable place to ride that is differentiated from the motor vehicle traffic lane.(26) The total amount of space available may well be the same with or without a bike lane, but the perception of less confident riders is very different in the two situations.

So the question is not one of "bike lane or no bike lane." The better question is: given an identical width of space on the right side of the roadway, what, if any, positive effect is achieved by striping a bicycle lane? The one answer, it appears, that almost everyone agrees upon is improved channelization.

CHANNELIZATION

The field studies carried out as part of this research (see chapter 6) clearly identified the impact of bike lanes on channelization. At study sites with bikes lanes, 70 percent of vehicles passing bicyclists in the bike lane showed no change in lateral placement, i.e., they did not move from side to side or have to swing out to pass the bicyclist.

By contrast, at study sites with shared roadways, 26 percent of vehicles passing a bicyclist showed no change in lateral placement. The conclusion is that a marked bike lane tends to direct vehicular traffic in a manner that produces less perturbance when a car passes a bike.

For group B/C riders this effect is particularly important. Less confident riders need to feel that traffic is not going to be driving in the same lane with them and will not be moving about from side to side—with the potential for misjudgment—as they pass. Bike lanes make traffic behavior more predictable and reliable for group B/C riders.

Other opinions of the channelizing effect have been offered over the years.

> One of the advantages of providing a bike lane appears to be lessened probability of conflict between the two [types of] vehicles. For a typical situation, the spread of autos and bikes over a particular street was shown to narrow into bands with considerably less overlap when a bike lane is provided.[31]
>
> Bicycle lanes can be considered when it is desirable to delineate available road space for preferential use by bicyclists and motorists and to provide for more predictable movements by each. Bicycle lane markings can increase a bicyclist's confidence that motorists will not stray into his/her path of travel.[22]

The New Jersey DOT included some reference to different types of bicyclist in its 1982 design handbook—but prefers, as do Munn and others, to concentrate its efforts on accommodating existing use rather than encouraging new users.

> There are some studies which suggest that lane striping does confer positive benefits in terms of traffic operational flow characteristics and bicycle/motor vehicle collisions in mid-block (non-intersection) situations. However, bicyclists—particularly inexperienced bicyclists—tend to have an exaggerated perception of the benefits conferred by delineating the space where motor vehicles are to operate, as the type of accidents on which such striping may have an effect are relatively infrequent. Experienced bicyclists, on the other hand, tend to believe that the benefits of wide outside lanes outweigh the real and imagined benefits of such striping.[18]

As the above excerpts indicate, while the benefits are still being debated, the belief that bicycle lanes do channelize both bicycle and motor vehicle traffic is widespread. This is supported by our field studies and is also reflected in a detailed study of bicyclist and driver behavior with and without bicycle lanes in two California cities by Kroll and Ramey.[31] Much of this work was carried out on road sections on which temporary bike lanes were applied in order to gain detailed before-and-after data. The research team concluded:

> The separation distance between a bicycle and an overtaking car was primarily a function of overall street width and not of the presence or absence of bike lanes. However, the variability of this separation (as reflected in the standard deviation of separation distances) was smaller on bike lane streets. This effect was most pronounced on low speed streets (25 mi/h [40 km/h]), less so on medium speed roads (40 mi/h [64.4 km/h]), and nonexistent on 55 mi/h [88.5 km/h] roadways.
>
> Bicycle lanes also decreased the variation in lateral location on the roadway by both bicyclists and motor vehicles. The effect was most pronounced on bicyclists, with a reduction in the standard deviation of lateral distance from the road edge reduced by 16 inches [0.4 m].[31]

A study of bicycle/motor vehicle accidents in Davis, California concluded that the channelization effect resulted in a significant reduction of two types of accidents: those in which a motorist rear-ends a bicyclist or sideswipes a bicyclist traveling in the same direction ("overtaking" accidents); and those in which a bicyclist exits an alley or driveway into the traffic stream and is hit by a motor vehicle from the right or left ("cyclist ride-out" accidents).[27]

Both accident types are important. Ride-out accidents are the leading cause of injuries to child bicyclists under age 13, while the overtaking type of accident is the leading cause of bicyclist fatalities.[32] However, the channelization effect is not without drawbacks. Munn identified the primary problem with bicycle lanes:

> The marked lane diminishes the bicyclist's and the motorist's flexibility to use the total street width to accomplish turning movements or other necessary maneuvers.[23]

This problem is particularly acute when the bicyclist turns left, either into a driveway or at an intersection. The bicycle lane appears to encourage the bicyclist to turn left directly from the bike lane, across all traffic lanes, instead of merging into the left through lane, then turning left across only the oncoming through lanes. This effect was verified by Lott and Lott's Davis study which found:

> The improper left turn by bicyclists is the one accident type that our analysis shows is increased by bike lanes...the subtype that appears to be increased by bike lanes is Subtype D3, in which the bicyclist tries to make a turn at an intersection from the bike lane through the auto lane. This type of turn is illegal under the ordinances that govern bike riding on the lanes in Davis. Nevertheless, the increased frequency of this type of accident suggests that the lanes themselves cause the rider to conform to that requirement (or opt for that protection) all the way to the intersection, and then make a quick and convenient, but dangerous and illegal, left turning maneuver.[27]

Bike lane design, as typified by the *AASHTO Guide* and others, has evolved to address issues such as this.[33] In many places bike lanes marked by a solid white line either come to an end just prior to an intersection, or the lane stripe will become a dashed or broken line. Bike lane policy in Florida reflects this approach:

> ...lines denoting bicycle lanes will be dropped fifty feet [15.2 m] in advance of each intersection of local/residential streets. At intersections with collectors or arterials, this stripe should be dropped 75 feet [22.9 m] in advance of the intersection. The continuous line should also be dropped or dashed ten feet [3 m] prior to driveways with one hundred or more one way trips per day.[34]

Another potentially conflicting movement is a right-turning motor vehicle crossing the path of a straight-through bicyclist heading in the same direction. As California's *Highway Design Manual* points out, this is a special problem when there is a right-turn-only bay.

> When confronted with such intersections [those with right-turn bays] bicyclists will have to merge with right-turning motorists. Since bicyclists are typically traveling at

speeds less than motorists, they should signal and merge where there is sufficient gap in right-turning traffic, rather than at any pre-determined location. For this reason, it is recommended that either all delineation be dropped at the approach of the right turn lane or that a single, dashed bike-lane line be extended at a flat angle across the right-turn lane.

A pair of parallel lines (delineating a bike lane crossing) to channel the bike merge is not recommended, as bicyclists will be encouraged to cross at a predetermined location, rather than when there is a safe gap in right-turning traffic. Also, some bicyclists are apt to assume they have the right of way, and may not check for right-turning motor vehicle traffic. A dashed line across the right-turn-only lane is not recommended on extremely long lanes, or where there are double right-turn-only lanes. For these types of intersections, all striping should be dropped to permit judgment by the bicyclists to prevail.[28]

Figure 1 presents an illustration accompanying these instructions in the *Highway Design Manual.* This treatment amounts to a reduction in the channelizing strength of the bike lane in intersections by converting the bicycle lane stripes to dashed lines 50 to 100 ft (15 to 30 m) before an intersection or eliminating the stripe at this location altogether. As the *AASHTO Guide* indicates, such a treatment is also beneficial to bicyclists wishing to make a vehicular-type left turn:

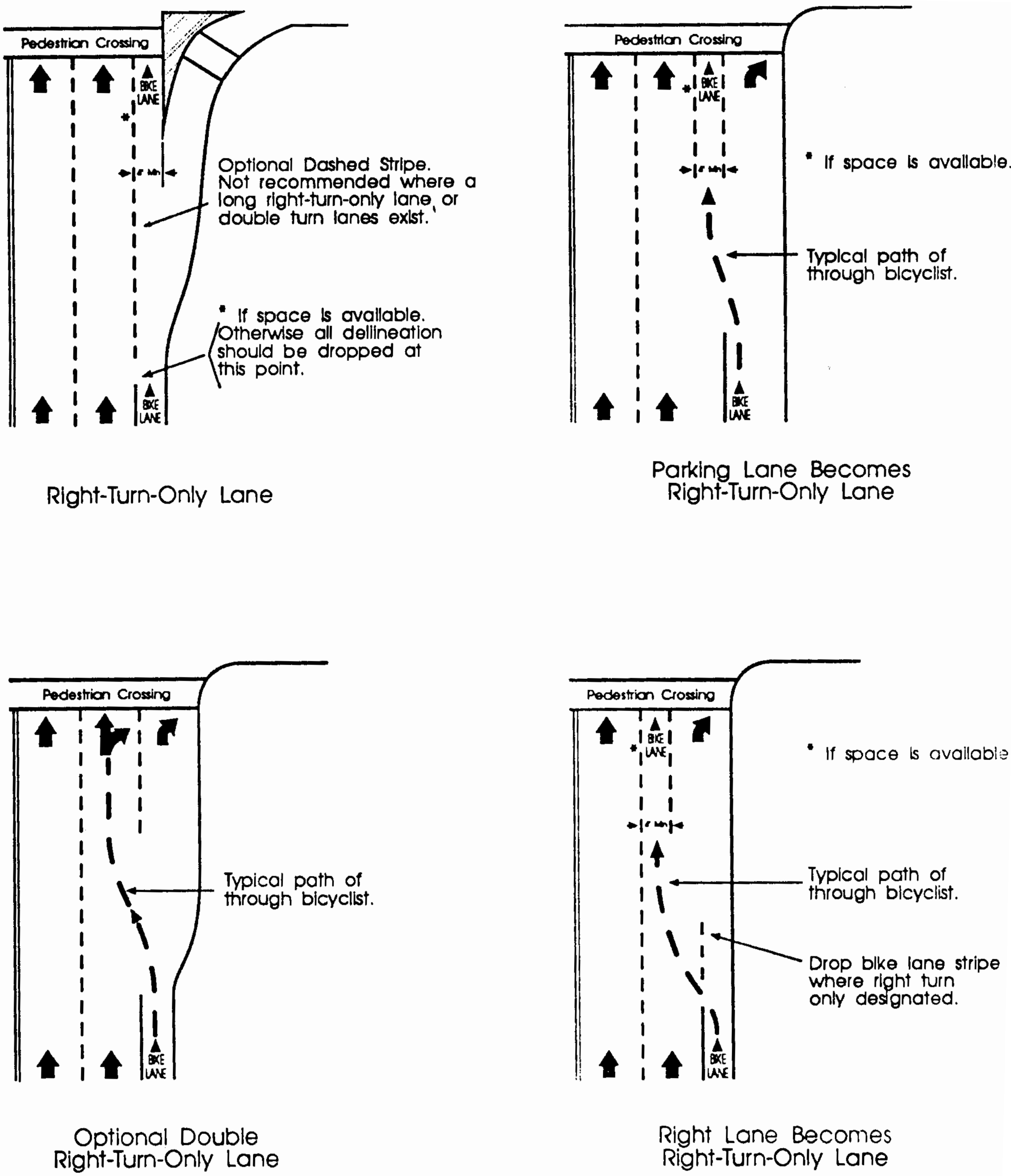
At intersections, bicyclists proceeding straight through and motorists turning right must cross paths. Striping and signing configurations which encourage these crossings in advance of the intersection, in a merging fashion, are preferable to those that force the crossing in the immediate vicinity of the intersection. To a lesser extent, the same is true for left turning bicyclists; however, in this maneuver, most vehicle codes allow the bicyclist the option of making either a "vehicular style" left turn (where the bicyclist merges leftward to the same lane used for motor vehicle left turns) or a "pedestrian style" left turn (where the bicyclist proceeds straight through the intersection, turns left at the far side, then proceeds across the intersection again on the cross street.[2]

The *Guide's* suggested treatments for pavement markings for bicycle lanes in the area near intersections are similar to those shown in figure 1.

In addition to encouraging use and the channelization effects detailed above, the literature describes two other advantages of bike lanes:

1. Bicycle lanes facilitate the placement of special detector loops for bicyclists at signalized intersections.

2. Bicycle lanes can aid bicycle planning by acting as a significant attraction for bicyclists in their choice of route.



Bicycle Lanes Approaching Motor Vehicle Right-Turn-Only Lanes

Figure 1. Bicycle lane markings at intersections.[26]

Use of Detector Loops

Because bicyclists will tend to follow the line of the bicycle lane up to the stop bar of a signalized intersection, the installation of a quad loop induction detector within the bicycle lane is both useful and effective, as the Yuma County, Arizona MPO explains:

> At intersections where there are bike lanes and traffic signals, installation of bicycle-sensitive loop detectors [in the bicycle lane] are desirable. This is particularly important where signals are traffic actuated and will not change for a bicyclist unless the bicyclist leaves the bicycle lane to trip the signal within the traffic lane. Generally, push-button actuators are unsatisfactory at intersections unless located for use by bicyclists at curbside without dismounting.[22]

The truth of this latter point was well documented by a study done in Tempe, Arizona which found that push-button actuators placed adjacent to the bicycle lane at a height convenient for bicyclists to use without dismounting were used almost four times as often as conventional pedestrian actuator buttons. The study also found that the conventional pedestrian actuators led to bicyclists stopping at the apex of the curb radius, where they were more vulnerable to being struck by traffic.[35]

Route Attraction

The installation of a bicycle lane on Anderson Road in Davis, California, a primary access route to the University of California campus, allowed researchers to measure the effect of a bicycle lane on route choice. The researchers described their results:

> For the 44 bicyclists living east of Anderson Road, use of the new bicycle lanes meant traveling an additional block or two on each end of a 1 to 2 [1.6 to 3.2 km] mile trip. In contrast, the 64 bicyclists living west of Anderson Road were provided a more direct bicycle lane route to the university campus....Among the bicyclists living east of Anderson Road there were striking changes among the 25 years or older group in the choice of Anderson Road. Male use increased from 40 to 80 percent and female use increased from 36 to 64 percent....The pattern of change was different west of Anderson Road. Nearly two-thirds of the men aged 25 and over were already using Anderson Road so the increase in mature males from 63 to 84 percent was less dramatic. Female bicyclists over 25 years old increased use of the Anderson Road route from 39 to 64 percent. Considerable increase took place in the elementary, high school and college groups as well.[24]

Such influence in route selection could be a powerful tool for planners or engineers interested in promoting bicycle use on a particular street within a transportation corridor. On the other hand, the researchers noted that:

> ...if a bicycle lane route is markedly less convenient than a route without one, convenience generally determines the choice. College-age riders are substantially less influenced by the availability of bicycle lanes than are other riders.[24]

This conclusion was echoed in a six-State survey of bikeway users:

> The present survey indicates that bicyclists think most bikeways are safer and more comfortable than city streets but a substantial number of riders will continue to travel by the most direct route possible whether or not those routes have been improved for bicycle movement.[25]

DISADVANTAGES OF BICYCLE LANES

Besides the deleterious effects associated with channelization noted in the previous section, two other disadvantages of bicycle lanes have been commented on:

1. They require an increased commitment to perform maintenance, including frequent sweeping for road grit and debris and maintenance on the lane markings themselves.

2. They may not work as well when placed adjacent to on-street parking.

Increased Maintenance

As was noted before, when bicycle lanes are not present on a street or road, the motor vehicle traffic in the right lane tends to have a wider variation in lateral placement in the roadway. One positive byproduct of this effect is that the traffic tends to sweep road dust and debris away from the travel lanes into the gutter pan. When bicycle lanes are present, the tighter variation in lateral placement means that this effect does not extend all the way to the road edge and that grit and other debris can collect in the bicycle lane. For this reason, the installation of bicycle lanes will require a higher level of inspection and maintenance on these road segments than would normally be the case.

The *AASHTO Guide* cautions: "The agency responsible for the control, maintenance, and policing of bicycle facilities should be established prior to construction. The costs involved with the operation and maintenance should be considered and budgeted for when planning a facility."[2]

Adjacent Parking

> As a general rule, bicycle lanes and on-street parking are incompatible due to increased problems with visibility and detection of bicyclists, increased turning movements and increased likelihood of pedestrians.[22]

The proper placement of a bicycle lane when on-street parking is present is between the outer motor vehicle lane and the parking lane. Placement of the bicycle lane to the right of the parking lane (between the parked car and the curb) has proven unsatisfactory and is specifically not recommended by the *AASHTO Guide*.[2]

When on-street parking is present, AASHTO and most State standards recommend that both sides of the bicycle lane be striped. The outer (right) bicycle lane stripe tends to act as a delineator of the lane where motor vehicles should park and prevents parked cars from protruding into the bicycle use area. Bicycle lanes should not be installed where angled parking is present.[2]

BICYCLE LANE WIDTH

Almost all State and local design standards for bicycle lanes conform closely to the *AASHTO Guide* recommendations, first outlined in that organization's 1981 publication *Guide for Development of New Bicycle Facilities*, and reprinted in an essentially unchanged form when the *Guide* was revised in 1991.[36,2] The *Guide* suggests a minimum bicycle lane width "under ideal conditions" of 4 ft (1.2 m) and a minimum width of 5 ft (1.5 m) when the bicycle lane is adjacent to a parking lane.

> Where parking is permitted but a parking lane is not provided, the combination lane, intended for both motor vehicle parking and bicycle use, should be a minimum of 12 ft (3.7 m) wide. However, if it is likely the combination lane will be used as an additional motor vehicle lane, it is preferable to designate separate parking and bicycle lanes....If parking volume is substantial or turnover is high, an additional 1 or 2 ft (0.3 or 0.6) of width is desirable for safe operation.
>
> On roadways without a curb and gutter, bicycle lanes should be located between the motor vehicle lanes and the roadway shoulders. Bicycle lanes may have a minimum width of 4 ft (1.2 m) where the shoulder can provide additional maneuvering width. A width of 5 ft (1.5 m) or greater is preferable; additional widths are desirable where substantial truck traffic is present, or where vehicle speeds exceed 35 mi/h (56.3 km/h).[2]

The CALTRANS *Highway Design Manual* specifies:

> With a normal 2-ft [0.6-m] gutter, the minimum bike lane width is to be 5 ft [1.5 m]. The intent is to provide a minimum 4-ft [1.2-m] wide bike lane, but with at least 3 ft [0.9 m] between the traffic lane and the longitudinal joint at the concrete gutter....Where gutters are wide (say, 4 ft [1.4 m]), an additional 3 ft [0.9 m] must be provided because bicyclists should not be expected to ride in the gutter. Where possible, the width of bike lanes should be increased to 6 to 8 ft [1.8 to 2.4 m] to provide for greater safety.
>
> Bike lanes are not advisable on long, steep downgrades, where bicycle speeds greater than 30 mi/h [48.3 km/h] are expected. As grades increase, downhill bicycle speeds will increase, which increases the problem of riding near the edge of the roadway. In such situations, bicycle speeds can approach those of motor vehicles, and experienced bicyclists will generally move into the motor vehicle lanes to increase sight distance and maneuverability.[28]

Oregon's draft *Highway Design Manual* recommends that "the desirable width for bike lanes is 6 feet [1.8 m]."[29]

The Yuma County *Comprehensive Bicycle Plan* cautions:

> Widths greater than 5 feet [1.5 m] [when no adjacent parking lane is present] should not be used, since this will tend to attract parking and create difficult enforcement conditions. 'No Parking' signing is needed in areas where there is a high desire to park.
>
> The typical width for a motor vehicle lane adjacent to a bike lane is 12 feet [3.6 m]. There are situations where it may be necessary to reduce the width of motor vehicle lanes in order to stripe bicycle lanes. In determining the appropriateness of narrower motor vehicle lanes, consideration should be given to factors such as motor vehicle speeds, truck volumes, alignment and sight distance. Where favorable conditions exist, motor vehicle lanes of 10 or 11 feet [3.0 to 3.3 m] may be feasible.[22]

Although Florida's *Roadway Plans Preparation Manual* specifies a 4-ft (1.2-m) minimum width bicycle lane, the Florida DOT has given temporary approval to an application from the City of Fort Lauderdale to install an experimental bicycle lane measuring 3 ft (0.9 m) from curb face to bicycle lane stripe.[14] Both Florida and Fort Lauderdale will be observing the operation of this facility to determine its performance and safety.

Several other government agencies nationwide have expressed interest in 3-ft (0.9-m) bicycle lanes, primarily because this is the maximum width lane that can be created on most multilane arterials in existing rights-of-way through the narrowing of motor vehicle travel lanes to 10 or 11 ft (3 or 3.3 m). It is important to emphasize that this treatment is ***experimental*** and is not currently approved by existing design standards.

CONCLUSIONS AND RECOMMENDATIONS

1. Bicycle lanes work best on urban section (curb and gutter) roads without on-street parking and with a posted speed of 40 mi/h (64 km/h) or less.

2. Bicycle lanes should be one-way facilities carrying bicyclists in the same direction as motor traffic in the adjacent travel lane.

3. Under ideal conditions the recommended width for a bicycle lane is at least 5 ft (1.5 m). At least 4 ft (1.2 m) of this width should lay to the left of the gutter pan seam. Bicycle lanes on roads with on-street parking, limited sight distances, or where vehicle speeds exceed 35 mi/h (56 km/h) should have a width of 6 ft (1.8 m) or more. Roadways with posted speeds of greater than 45 mi/h (72 km/h) will usually require a 6-ft (1.8-m) bicycle lane plus a paved road shoulder to allow bicyclists room to avoid the "wind blast" effect of trucks and recreational vehicles.

4. Bicycle lanes have a strong channelizing effect on both bicycles and motor vehicles. This is an advantage where motorists are not used to sharing the roadway with bicycles or where the intention is to serve group B/C riders.

5. The channelizing effect of bicycle lanes can complicate turning movements for both bicycles and motor vehicles in intersections. Intersection striping should be carefully crafted to reduce turning-conflict accidents.

6. Group A bicyclists generally prefer unstriped wide curb lanes while group B/C bicyclists prefer bicycle lanes.

4. EFFECTS OF BICYCLE USE ON SHOULDERS

DEFINITION

The Uniform Vehicle Code (UVC) does not provide a specific definition of a shoulder, but does provide some guidance in the definitions of "roadway" and "highway."

> **1-128 Highway.—**The entire width between the boundary lines of every way publicly maintained when any part thereof is open to the use of the public for purposes of vehicular travel.
>
> **1-169 Roadway.—**That portion of a highway improved, designed or ordinarily used for vehicular travel, exclusive of the sidewalk, berm or shoulder even though such sidewalk, berm or shoulder is used by persons riding bicycles or other human powered vehicles.[37]

This distinction becomes more important in a discussion of the legal status of bicyclists using shoulders, which follows in the next section. Meanwhile, AASHTO offers a complete definition of a shoulder.

> A shoulder is the portion of the roadway contiguous with the traveled way for accommodation of stopped vehicles, for emergency use and for lateral support of subbase, base, and surface courses. It varies in width from only 2 ft [0.6 m] or so on minor rural roads, where there is no surfacing or the surfacing is applied over the entire roadbed, to about 12 ft [3.7 m] on major roads, where the entire shoulder may be stabilized or paved.
>
> Shoulders may be surfaced either full- or partial width to provide a better all-weather load support than that afforded by the native solids. Materials used to surface shoulders include gravel, shell, crushed rock, mineral or chemical additives, bituminous surface treatments, and various forms of asphaltic or concrete pavements.
>
> Desirably, a vehicle stopped on the shoulder should clear the pavement edge by a least 1 ft [0.3 m], preferably by 2 ft [0.6 m]. This preference has led to the adoption of 10 ft [3 m] as the normal usable shoulder width that should be provided along high-type facilities. In difficult terrain and on low-volume highways, usable shoulder width of 2 ft [0.6 m] should be considered for the lowest-type highway, and a 6- or 8-ft [0.9- or 2.4-m] width is preferable. Heavily traveled and high-speed highways and those carrying large numbers of trucks should have usable shoulders at least 10 ft [3 m] and preferably 12 ft [3.7 m] wide.
>
> Regardless of the width, a shoulder should be continuous....Even though shoulders should be continuous, narrow shoulders and intermittent shoulders are superior to no shoulders.

Well-designed and properly maintained shoulders are necessary on rural highways with an appreciable volume of traffic, on freeways, and on some types of urban highways.[11]

LEGALITY OF BICYCLE USE ON SHOULDERS

All 50 States define or treat bicycles as vehicles. Most States also require that all vehicles on the highway ride on the right half of the "roadway," which, as we have seen, does not include a shoulder. Thus, in a strict interpretation of many State laws and the Uniform Vehicle Code, bicycles are not legally allowed to ride on shoulders.

A number of States have taken specific action to correct this anomaly. The California Vehicle Code (Section 21650(g)) provides that these definitions do not "prohibit the operation of bicycles on any shoulder of a highway, where the operation is not otherwise prohibited by this code or local ordinance."[38]

The State of Washington has a similar provision:

> Every person operating a bicycle upon a roadway shall ride as near to the right side of the roadway as practicable and may utilize the shoulder of the roadway or any specially designated bicycle lane if such exists....[39]

The confusion caused by these definitions prompted the Ohio Department of Transportation to direct bicyclists not to ride on shoulders for a time, until in 1987 the Ohio Bicycle Transportation Administration concluded that bicyclists do have a legal right to use the shoulder.[40]

Other States have gone even further and require bicyclists to use shoulders where they exist and are usable. Section 21-1205.1 of the Maryland Vehicle Code states:

> (1) Where there is a bike lane paved to a smooth surface or a shoulder paved to a smooth surface, a person operating a bicycle shall use the bike lane or shoulder and may not ride on the roadway except in the following situations:
>
> > i) when overtaking and passing another bicycle, pedestrian or other vehicle within the bike lane or shoulder if the overtaking and passing cannot be done safely within the bike lane or shoulder;
> >
> > ii) when preparing for a left turn at an intersection or into an alley, private road or driveway; or
> >
> > iii) when reasonably necessary to leave the bike lane or shoulder to avoid debris or other hazardous condition.
>
> (2) A person operating a bicycle may not leave a bike lane or shoulder until the movement can be made with reasonable safety and then only after giving an appropriate signal.[41]

Similarly, the Colorado State vehicle code requires bicyclists to ride in the right lane except whenever a paved shoulder suitable for bicycle riding is present.(42)

Still more States have done nothing to alter the legal definitions provided by the UVC and others, but in practice encourage and support the use of shoulders by bicyclists in literature, design manuals, and policy documents.

A brochure describing the New York State bicycle laws says "you should generally bicycle as far to the right as is safe. If there is a safe shoulder, use it instead of the traffic lane."(43) A 1986 supplement to the New York State highway design manual concludes that "widening and paving shoulders is usually the best way to accommodate bicyclists in rural areas."(44)

The Minnesota DOT State Bicycle Transportation System Plan says "the greatest need for bikeway improvements in the trunk highway system are four foot [1.2-m] shoulders," and both Florida and Virginia have design manuals that include paved shoulders in a list of available "bicycle facilities."(45,46,47)

In the Pacific Northwest, the Washington DOT design manual for bicycle facilities states that the development and maintenance of 4-ft (1.2-m) paved roadway shoulders is "a goal to work towards," and in Oregon "shoulder bikeways" are one of four types of bicycle facility described in their Bicycle Master Plan.(48,49)

PRACTICALITY OF BICYCLE USE ON SHOULDERS

Even though strict interpretation of their own State vehicle codes might disallow bicycle use of shoulders, State highway agencies almost universally encourage and support such use. The reasons are straightforward. Bicycle use of shoulders seems to benefit bicyclists and motorists, and the provision of shoulders is justifiable for a wide range of reasons besides offering bicyclists a good place to ride.

Among a list of 14 "more important advantages" of shoulders described by AASHTO is "space is provided for pedestrian and bicycle use."(11) The *AASHTO Guide* adds:

> Adding or improving shoulders can often be the best way to accommodate bicyclists in rural areas, and they are also a benefit to motor vehicle traffic.(2)

A Florida DOT policy memo states that construction of paved shoulders will improve traffic flow, increase capacity, and enhance highway safety. Specifically, shoulder pavement will:

1. Provide protection for bicyclists.
2. Allow motorists to pass bicyclists without delays.
3. Reduce edge of pavement drop-off due to wind erosion created by trucks.

4. Provide better roadway pavement drainage and reduce potential for hydroplaning.

5. Reduce potential for "run-off the roadway pavement" accidents. Edge of pavement drop-offs that occur due to erosion will be further removed from the driving lane.[50]

Jones identified additional benefits. Noting that bicycle/motor vehicle accident studies have shown that narrow, two-lane rural highways are associated with many bicycle fatalities, he states that smooth shoulders could be expected to reduce overtaking accidents by enabling bicyclists to ride off the roadway. As shoulders also help reduce accidents for motor vehicles, their cost can be better justified.[19]

This finding is amply borne out by a 1986 report on the feasibility of paving shoulders for low average daily traffic flow highways prepared by the Wisconsin Department of Transportation (see appendix 5). Without any reference to bicycling, the report recommends, based on reduced maintenance and accident costs, and "an overwhelmingly positive response from the general public" that

> ...the present shoulder policy be revised such that three foot [0.9 m] shoulders would be required on any state trunk highway with an average daily traffic flow of 1000 or more. This recommendation is based on the results of an economic analysis of paved shoulders and review of the opinions of District personnel.[51]

Since then other States have adopted similar general policies.[47]

PLANNING AND DESIGN CONSIDERATIONS

There seems to be a growing consensus that in urban areas wide curb lanes and striped bike lanes are more appropriate facilities to develop for bicyclists than wide shoulders, but shoulders are preferable in rural areas.

The 1981 edition of the *AASHTO Guide* stated that "wide curb lanes and bicycle lanes are generally preferred over shoulders for use by bicyclists. However, if it is intended that bicyclists ride on shoulders, smooth paved shoulder surfaces must be provided."[36]

By 1991 sentiments had changed. The new *AASHTO Guide*, based on comments made to AASHTO, says "Wide curb lanes and bicycle lanes are usually preferred in restrictive urban conditions and the widened shoulder will generally be more accommodating in rural circumstances."[2] Both versions of the Guide go on to say:

> Adding or improving shoulders can often be the best way to accommodate bicyclists in rural areas, and they are also a benefit to motor vehicle traffic. Where funding is limited, adding or improving shoulders on uphill sections first will give slow moving bicyclists needed maneuvering space and decrease conflicts with faster moving motor vehicle traffic.[2,36]

At the city level the same views are prevalent. The Lake County, Florida bicycle and pedestrian plan recommends sidewalks and wide curb lanes should be developed to 1 mile [1.6 km] beyond the corporate limits of municipalities. After that, there should be at least a 4-ft (1.2-m) shoulder added to the county roads to 3 mi (4.8 km) beyond the city limits, and a lower priority was to have them to 5 mi (8 km) outside city limits.(52)

In general, therefore, smooth, well maintained and adequately wide shoulders can provide a viable alternative to wide travel lanes, and in some situations may be preferable—for example, on highway segments with high-speed and/or high-volume traffic or rural routes with restricted sight-distance. The question to be considered is under what conditions are shoulders desired or needed?

McHenry and Wallace state that a shoulder, rather than a raised curb, on the highway will reduce the optimum lane width necessary for mode sharing and may eliminate the need for a wide curb lane (depending on shoulder width), if the shoulder is paved to the same surface smoothness as the adjacent roadway, and debris is regularly removed from the shoulder surface. The significance of this point is that shoulders can (if applicable laws permit) serve as a substitute for wide lanes.(15)

Again, the ideal condition for shared use of any street or highway is sufficient "space" to accommodate such use without inherent conflict. This might be achieved with either wide outside travel lanes or paved shoulders. However, in urban and suburban areas with high traffic volumes and frequent intersections, the use of shoulders by bicyclists will likely result in the same set of merging and turning conflicts and accidents associated with bike lanes. Therefore, it seems prudent to try to limit the use of shoulders as a means of serving bicycle traffic to rural highways and high-speed urban arterials.

The California DOT policy defining shoulder requirements for bicycle travel stipulates that in maintaining and improving existing State highways the effective width of shoulders not be reduced. Further, to provide a minimum 4-ft (1.2-m) paved shoulder, the policy permits reducing travel lanes to 11 ft (3.3 m) if traffic operations and safety will not be significantly impaired, or there is anticipated bicycle traffic, or there are right-of-way restrictions.(53)

The report by the New Jersey DOT on bicycle-compatible roadways puts the issue of shoulders for bicyclists in perspective. The presence of shoulders and the width of the shoulders is considered as additional operating space for bicyclists. That is, the space available for shared use is the sum of the outside travel lane and the shoulder. The amount of space desirable for shared use is a function of traffic volume, traffic mix, and traffic speed.(18)

As early as 1974, CALTRANS developed a bicycle travel rating for 11,000 mi (17,600 km) of potential State highway bicycle routes. The rating was based on shoulder width, ADT volume, and an assumed 12-ft-wide (3.7-m) outside lane. On multilane highways an estimated ADT for the outside lane was used. Three ratings of shoulder width were defined:

- Deficient: need more width.
- Marginal: may or may not need more width.
- Acceptable: width is satisfactory.

Figure 2 shows the relationship between ADT and shoulder width used to determine the route ratings.

As noted previously, the Minnesota DOT has developed tables for assessing the suitability of a rural highway for bicycle travel based on lane width, shoulder width and surface, and ADT. Separate tables are provided for undivided and divided highways.[55] The data appear very conservative. For an undivided rural highway with a 12-ft (3.7-m) through lane and a 10-ft (3.0-m) wide paved shoulder, the maximum ADT that will qualify for a rating better than "poor" is 8421. This improves somewhat when divided highways are considered; the maximum ADT for the same conditions is 18,113. For 8-ft (2.4-m) wide shoulders, this drops to 13,913.

Other factors that increase the need for or desirability of shoulders for bicycle traffic include:

- Long, steep grades on rural highways with narrow lanes, and many curves
- High speed highways, especially with restricted sight distance, and
- Significant volumes of large trucks, buses or recreational vehicles on narrow lane highways or high-speed facilities.[55]

Figure 3 details the effect of heavy vehicles on bicyclists based on speed and separation.

Finally, NCHRP Report 254 prescribes widths for shoulders intended to serve bicyclists based on street and highway classification (i.e., freeways, arterials, collectors, and neighborhood or local streets).[57]

CRITERIA FOR THE WIDTH OF SHOULDERS INTENDED TO SERVE BICYCLISTS

The question now turns to what width constitutes an "adequate shoulder" for bicycle use and possible designation as a bicycle route? As has been noted, various factors are used to establish the desirability or need for shoulders. Criteria for many of these same factors have been used to establish specific shoulder width requirements. Apparently, few of these criteria are based on research, but are instead proffered as professional judgment. This probably explains the wide variation in values. Table 4 gives the criteria for shoulder width contained in some of the more recent references.

SHOULDERS AS DESIGNATED BICYCLE FACILITIES

As we have seen, there is considerable variation in the treatment of shoulders as bicycle facilities. Some States have policies stating that shoulders should not be

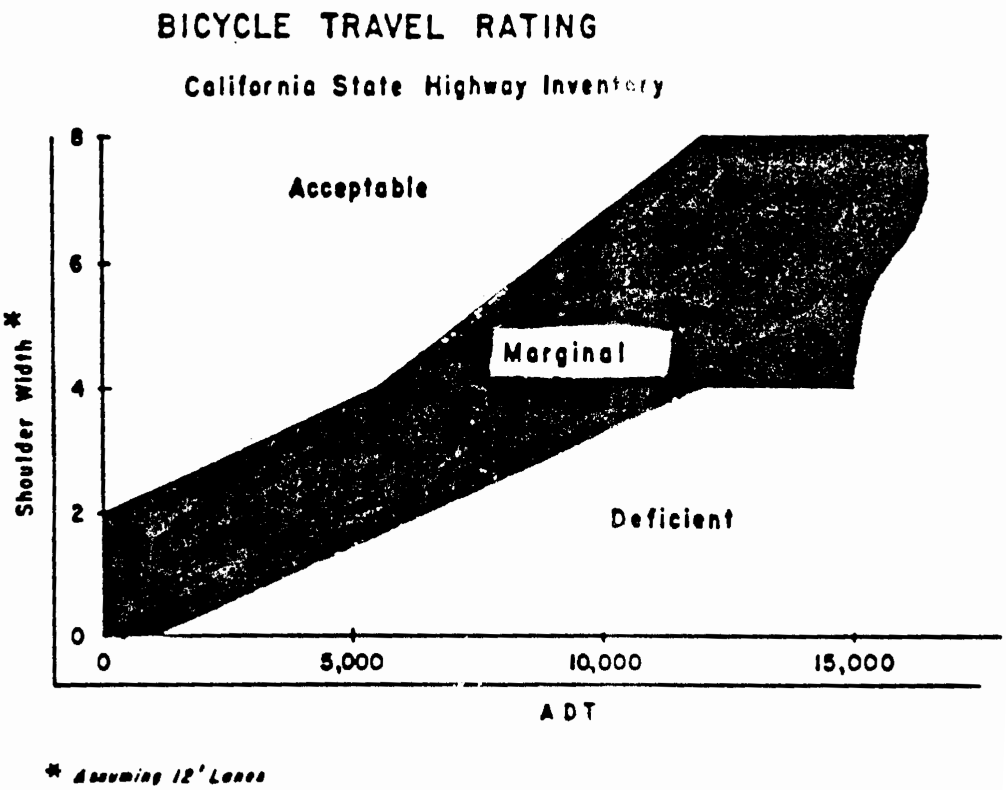


Figure 2. Bicycle travel rating.[54]

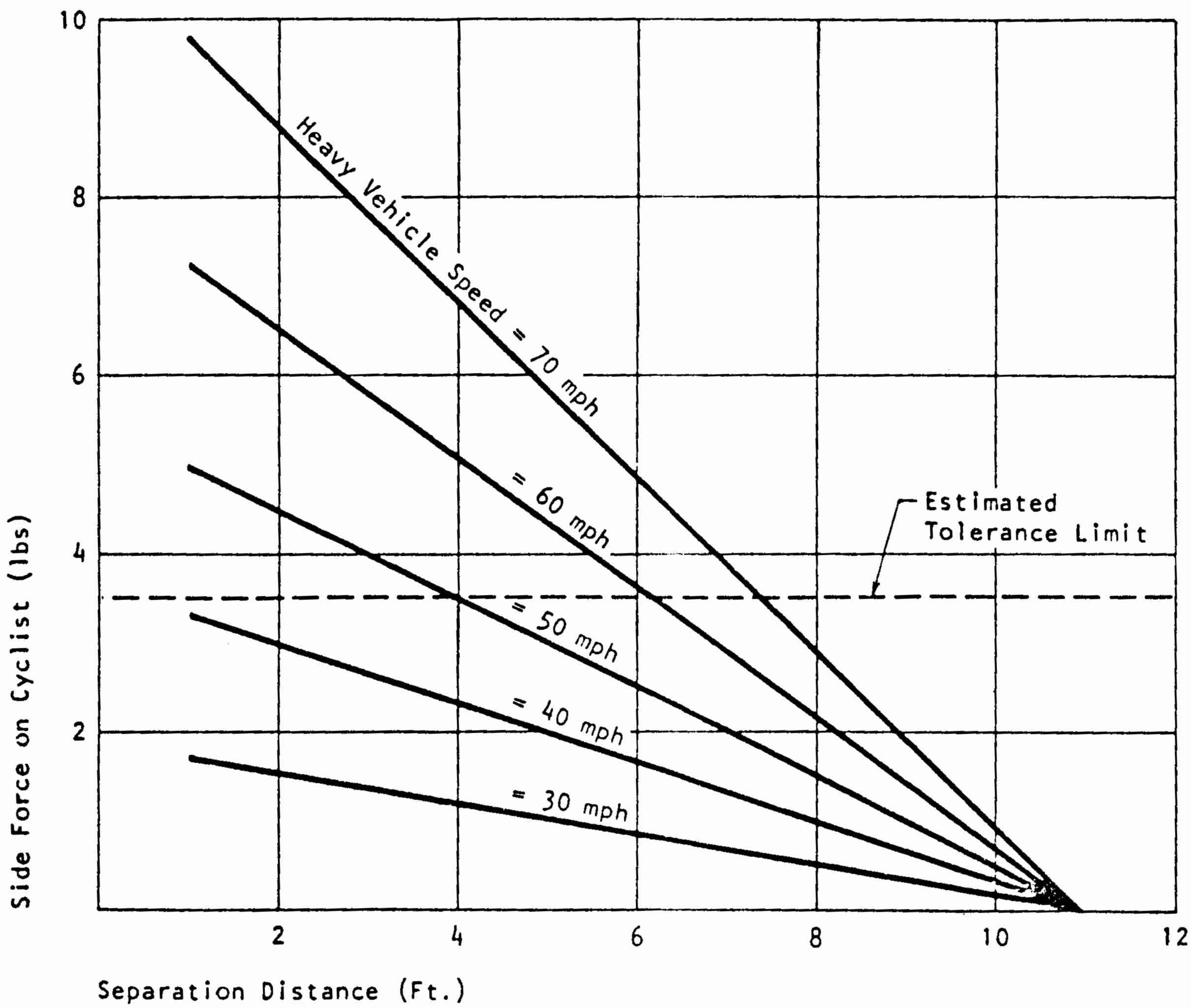


Figure 3. Lateral force on bicyclists.[56]

Table 4. Summary of criteria for shoulder width.

New Jersey DOT[18]	
12 ft (3.7 m) or 13 ft (4.0 m) outside lanemin. minimal truck ADT, 55 mi/h (88 km/h) or less	3 ft (0.9 m)
12 ft (3.7 m) or 13 ft (4.0 m) outside lanemin. heavy truck ADT, 45 mi/h (72 km/h) or less	3 ft (0.9 m)
12 ft (3.7 m) to 15 ft (4.6 m) outside lane heavy truck ADT, speeds above 45 mi/h (72 km/h)	min. 6 ft (1.8 m) or 3 ft (0.9 m) with min. of 18 ft (5.5 m) paved surface
AASHTO[2]	
If shoulders intended for bicycle travel and vehicle speed over 35 mi/h (56 km/h)	min. 4 ft (1.2 m)
If trucks, RV's or bus traffic high, or static obstruction on right side	more than 4 ft (1.2 m) desirable
McHenry, Wallace[15]	
Posted speed limit 40 mi/h (64 km/h) or less	min. 4 ft (1.2 m)
Posted speed limit above 40 mi/h (64 km/h)	min. 8 ft (2.4 m)
If minimum 4 ft (1.2 m) cannot be maintained	stripe wider outside lane (14 ft/4.3 m)
Maryland DOT[58]	
All new construction projects where expected posted speed is 40 mi/h (64 km/h) or less	4 ft (1.2 m) min.
All new construction projects where expected posted speed in excess of 40 mi/h (64 km/h)	8 ft (2.4 m) min.

Retain shoulders in reconstruction projects. Travel lanes may be narrowed to provide minimum shoulder widths. Where minimum widths of 4 ft (1.2 m) cannot be maintained, an outside lane width of 14 ft (4.2 m) is preferred.

Table 4. Summary of criteria for shoulder width (continued).

NCHRP[57]

Freeways, no alternate route	min. 6 ft (1.8 m)
Arterials, collectors, locals	Optimal 6 ft (1.8 m); Acceptable 4 ft (1.2 m)

"Consider providing 2 ft (0.6m) buffer between traveled lane and bicycle path."
"Bicyclists will use any available shoulder if the surface is paved and smooth."

New York DOT[44]

Shoulders generally considered adequate	4 ft (1.2 m)

More than 4 ft (1.2 m) to be considered whenever:
a) motor vehicle speeds exceed 35 mi/h (56 km/h)
b) The percentage of trucks, buses and recreational vehicles exceeds 5 percent
c) Static obstructions exist immediately at the right
d) Adjacent land use generates bicycling by children
e) More than occasional pedestrian use shared with bicycling.

Washington DOT[48]

"Development and maintenance of at least 4 feet [1.2 m] of paved shoulders with a standard edge stripe can significantly improve safety and convenience for bicyclists and motorists along such routes."

Oregon DOT[49]

Roadway shoulders for bikeways preferably	5 to 6 ft (1.5 to 1.8 m)
With width limitations, will suffice at	4 ft (1.2 m)
Against curb face	5 ft (1.5 m) (or 4 ft [1.2 m] from gutter joint)
Guardrail or barrier	5 ft (1.5 m)
Climbing lanes	5 ft (1.5 m)

designated as bike routes unless there is significant bicycle traffic. This practice apparently stems from the belief that widespread use of the bike route sign reduces the impact of the sign with motorists. For example, the Washington DOT says that:

> In most cases, it would be inappropriate to designate [the] highways as bikeways because of limited use and the lack of continuity with other bike routes.(48)

A more specific approach is described in an Oregon DOT report where highway shoulders are seen as the primary approach to providing for bicycle use of State highways. Some, but not all of these shoulders may be signed as bikeways, with the determination based on the following policy statement:

> The shoulder of existing roadways may be considered for signing as bikeways when need and demand can be shown, where physical conditions warrant the signing, and when increased safety and motorist awareness can result.(49)

The Illinois DOT takes this a step further by providing guidelines for marking bike lanes on shoulders. Referring to this treatment as a Class IID Bike Lane, the report gives as requirements both location in rural areas and minimum shoulder width and maximum ADT.(59)

Finally, a somewhat confused reference to this subject is included in an NCHRP report on shoulder use:

> Shoulders designated as bike routes are normally marked with a 4 in. [1 mm] white painted stripe. Several agencies require a minimum of 2-ft [0.6-m] separation between the shoulder edge stripe and the bike-lane stripe, which provides a safer operation of the bike lane. Signing includes the upright `Bike Path´ sign and several painted messages and decals on the bike path such as `Bike Lane,´ `Bike Only,´ a bicycle decal or a diamond shape which (although observed) is not considered appropriate, as it seems to conflict with the `High Occupancy Vehicle Lane´ designation.(57)

Several inaccuracies in this statement should be noted. First, the report seems to confuse the designation of shoulders as a bike route with the marking of shoulders as bike lanes. There is no evidence to support the claim that shoulders designated as bike routes are routinely marked as bike lanes. Further, the Illinois DOT design guidelines (1980) noted above notwithstanding, bike lanes are rarely marked on shoulders. In fact, the definition of bike lanes stipulates "on the roadway."

Also, many transportation agencies have come to recognize that bicyclists generally ride on the left-most portion of the shoulder even if there is a lane marked farther to the right. This is due to several facts as noted in the following comment from Jones:

> On a wide shoulder, most bicyclists will choose to ride on the left portion of the shoulder near the roadway anyway. This occurs for many reasons, the most important being that the air currents generated by passing motor vehicles tend to

> sweep the left side of the shoulder free of debris such as stones, sand, soil, leaves, sticks, and trash. Much of the debris is swept from the left side to the right side of the shoulder, and this makes bicycle riding even more difficult or hazardous on the right.
>
> The bicyclist who rides near the left edge of the shoulder is more visible to motorists who are exiting from side streets or driveways and also to drivers on the main highway who are turning left or right across the bicyclist's path.(19)

The authors of the NCHRP report offer no evidence or references to support their assertion that the 2-ft (0.6-m) separation between shoulder edge stripe and bike-lane stripe provides for safer operation of the bike lane. Finally, the comment on the use of the diamond-shaped Preferential Lane Symbol only serves to demonstrate the authors' lack of familiarity with the Manual on Uniform Traffic Control Devices (MUTCD).

> The diamond-shaped Preferential Lane Symbol is intended for use on highway facilities where lanes are reserved for exclusive use by a particular class of vehicle. Designated bikeways are considered as this type of lane and shall include use of the Preferential Lane Symbol as a pavement marking and on appropriate signing.(60)

In summary, while some attention has been given to establishing bike lanes on highway shoulders, the practice has not been widely adopted. Also, the use of signs to designate shoulders as bike routes seems to be something that the States approach as a limited practice, employing it only when some specific purpose is to be served. The presence of shoulders is a significant factor in the assessment of the suitability of a particular street or highway to accommodate shared use.

SHOULDER SURFACE QUALITY

In addition to shoulder width, the type and condition of the surface is a significant criterion in assessing the potential serviceability of the shoulder for bicycling. Several reports address this issue.

McHenry and Wallace state that a smooth surface asphalt shoulder should be provided on new highway construction projects. During roadway resurfacing on highway with existing surface treated or smooth surface shoulders, the bituminous concrete surface should be applied on the roadway and shoulder. Where the entire width of the shoulder cannot be resurfaced, the 4 ft (1.2 m) of the shoulder adjacent to the roadway should be smooth surfaced.(15)

The *AASHTO Guide* suggests that if bicyclists are intended to ride on shoulders, smooth paved shoulder surfaces must be provided. Pavement edge lines supplement surface texture in delineating the shoulder from the motor vehicles lanes. Rumble strips can deter bicycling on shoulders and their benefits should be weighed against the probability that bicyclists will ride in the motor vehicle lanes to avoid them.(2)

The *Traffic Control Devices Handbook* notes that consideration for bicyclists should be given when resurfacing, and full shoulders should be resurfaced, as well as traffic lanes, and uneven joints with the gutter should be avoided. When constructing truck passing lanes, the paved shoulder should not be sacrificed as this would cause bicyclists to ride within truck lanes. When restriping a roadway after an overlay has been applied, an attempt should be made to provide sufficient room outside the stripe for bicyclists.[(61)]

The following discussion, while specifically addressed to bike lanes, applies equally to shoulders intended for use by bicyclists.

> A properly striped bike lane is not intended for use by motor vehicles. It, therefore, does not experience the "sweeping action" of traffic. In fact, traffic in the adjacent traveled way tends to sweep debris into the bike lane. This accumulation of glass, gravel, and other debris reduces the effective width of the bike lane and causes the bicyclist to ride on the extreme left, i.e., closer to moving traffic. Where there is a large accumulation of debris, the bicyclist will frequently choose to ride in the motor vehicle lane, thus eliminating the usefulness of the bike lane entirely. Frequent machine sweeping of the bike lane may be necessary to keep certain bike lanes free of debris.[(61)]

New Jersey DOT comments that bicycles require a smooth riding surface. Where shoulders provide the pavement width necessary to accommodate bicycle traffic, they should be paved with material as smooth as the adjacent travel lane. Bituminous concrete is preferred over asphaltic oil and gravel. The outside pavement area (where bicycle traffic normally operates) should be finished free of longitudinal seams. On portland cement concrete pavement, transverse expansion joints (if necessary) should be saw-cut to ensure a smooth ride.[(18)]

Jones' study of shoulder use by bicycles is one of the most extensive in the literature. He notes that most bicyclists are reluctant to ride on rough bituminous concrete shoulders because the ride is uncomfortable and requires more effort to pedal the bicycle. One common type of rough shoulder surface unacceptable to most bicyclists is the double surface treated shoulder. This type of treatment is used to provide a visual and audible warning to motorists straying onto the shoulder. However, where this shoulder surface treatment is used, bicyclists will usually ride on the roadway itself, especially when they do not perceive a vehicle approaching from behind.[(19)]

It is important to realize that any substantial increase in roughness will decrease the probability that a bicyclist will ride on the shoulder. This is true even if the State vehicle code requires bicyclists to use the shoulder.

CALTRANS has developed a very specific policy for shoulder requirements for bicycle travel. In the placement of thin blankets and maintenance overlays, paved shoulders shall be overlaid, as well as traffic lanes, to prevent creation of a longitudinal step along the righthand portion of the roadway. Routine roadway maintenance (e.g., repairing deteriorated pavement, roadway excavations, etc.) should be done in such a manner that a uniform surface, free of obstructions, is maintained across the full paved width of roadways, including shoulders. If the righthand portion of roadways is not properly maintained, bicyclists will find it necessary to ride in traffic lanes, having to share the lanes with motorists. Routine restriping should be done in a manner that will not take away from the existing available shoulder width.[(53)]

The authors of NCHRP Report No. 254 note that all agencies reported bicyclists will normally not use textured or unpaved shoulders, and in fact, demand paved shoulders.[(57)] Along designated bicycle routes, most agencies provide a smooth asphalt shoulder to encourage cyclists to use the shoulder in lieu of the main lanes. Along one specific designated bicycle route, Nebraska omitted the corrugations in concrete shoulders in deference to bicyclists.

RUMBLE STRIPS

"Rumble strips," according to Williams, are "devices placed along the edge of the roadway and are used to wake up sleepy, inattentive, or intoxicated drivers by producing either a noise or a vibration or both. Some are raised bumps while others are depressions. They are installed roughly perpendicular to the direction of travel; some run continuously along the edge of the road while others are spaced at intervals of 50 ft (15.2 m) or longer."[(62)] (The text of this article is reproduced in appendix 1 as it accurately reflects the concerns of the bicycling public with the use of rumble strips, and provides some practical recommendations and suggestions to be followed by highway departments.) Williams concludes that:

a. As rumble strips constitute a hazard for bicyclists they should not be used where bicyclists are allowed.

b. Rumble strips should not be seen as a primary countermeasure for the problem of sleepy or inattentive drivers.

c. Highway departments should use rumble strips only in specific, identified crash locations, rather than as a general addition to the roadway.

d. On narrow roads with less than 8-ft (2.4-m) shoulders rumble strips are unlikely to work and should not be used.

e. Rumble strips should not be used on sections with many intersections or driveways.

f. 3-ft (0.9-m) wide rumble strips should be tried, so as to leave more of the shoulder usable.

g. Something else should be designed to treat this problem.

California's highway design standards prohibit rumble strips on highways where bicyclists are permitted.[(28)]

The 1991 *AASHTO Guide* is less definitive, believing that "rumble strips can be a deterrent to bicycling on shoulders and their benefits should be weighed against the probability that bicyclists will ride in the motor vehicle lanes to avoid them."(2)

The Ohio Department of Transportation takes the position that "rumble strips shall not be extended across shoulders or other areas intended for bicycle travel."(63)

The Washington DOT attempts a compromise by recommending that, "Where rumble strips are used on shoulders, the outside three feet [0.9 m] should be left clear for bicycles."(48) This approach must be balanced with the consideration of where bicyclists ride on the shoulder and where debris builds up and makes a shoulder unridable.

The Federal Highway Administration provides guidance to States in at least two separate Technical Notes. In a 1986 notice, reproduced with the Williams article, FHWA recommends that "If bicycling is desired on the shoulder, the type of treatment and its benefit should be weighed against the probability that bicyclists will ride in the traveled way to avoid them."(62) A 1990 note recommends that to accommodate bicyclists "corrugations may also be placed in the middle one-third of the shoulder."(64)

CONFLICTS WITH OTHER USERS

In addition to bicycling, highway shoulders are used for a range of different activities. An NCHRP report lists as many as 30 distinct functions, ranging from bicycle and pedestrian use to informal park and ride lots, mail delivery vehicle parking, snow storage, HOV facilities, bus stops, full-running lanes, and, of course, breakdowns.(57)

The degree to which bicycling conflicts with these myriad uses is impossible to determine with any degree of certainty. On most rural Interstates and highways such conflicts are likely few and far between as bicycle use is low and other uses intermittent. On urban Interstates, where bicycles are rarely allowed to operate, the use of shoulders for additional peak-flow capacity is unlikely to cause any difficulties.

By contrast, however, many urban and suburban arterials with shoulders are valuable commuter routes for bicyclists. In this instance (for example, U.S. Route 1 in New Jersey, State Route 29 in Maryland) the use of shoulders by buses or as additional traffic lanes during the peak hours can cause conflict.

Where realistic and equally attractive alternatives exist for bicyclists, the problem may be lessened. Highway departments should, however, consider the following:

Where bicycle use of shoulders for commuting is currently observed, those shoulders should not be used as additional traffic lanes during the peak hours. There may be exceptions to this general rule where:

i) An alternative, direct and continuous equivalent parallel route already exists or is under construction.

ii) Vehicle use is limited to bus operation with a limited number of bus movements.

Whenever bicycle use of shoulders is relatively common there should be an attempt to limit other activities that might conflict with such use, and other users of the highway or shoulder should be made aware of the likely presence of bicyclists.

COST OF SHOULDERS

The Minnesota DOT State Bicycle Transportation System Plan identifies the greatest need for bikeway improvements in the trunk highway system as being 4-ft (1.2-m) shoulders. A detailed analysis of the scope of improvements necessary to bring portions of the highway system up to acceptable bikeway standards revealed that more than 1,000 miles [1610 km] of the trunk highway system needed at least 4 ft (1.2 m) of additional shoulder width. Increases in shoulder width of less than 4 ft (1.2 m) were also required on a further 400 mi (644 km) of highway. The cost for such improvements was estimated at around $1,300 per foot of width—or $10,586 per mile of 4-ft (1.2 m) shoulder—with a total cost of $17 million.(45)

Florida DOT estimates a 4-ft (1.2-m) shoulder on each side of a highway would cost $30,000 per mile, and Hillsborough County, FL, estimated in 1987 that the cost of paving an existing 5 ft (1.5 m) grass shoulder was $30,000 per mile.(21,65)

The Hillsborough County study estimated the total cost of paving 112 mi (180 km) of rural roadways to be $3,360,000. Adding shoulders to rural roads without grass shoulders was significantly more expensive due to the need to purchase more right-of-way. To provide paved shoulders on 260 mi (418 km) of rural roads was estimated to total $285,273,000, more than $1 million a mile.(65)

A detailed report on the costs and benefits of providing paved shoulders by the Virginia DOT concluded that 2-ft (0.6-m) paved shoulders would be economically justifiable on:

a) All new four-lane and six-lane roads.
b) New two-lane roads and existing four-lane roads that exceed certain ADT thresholds.
c) Many existing six-lane roads.

In addition, 4-ft (1.2-m) paved shoulders would be justifiable on:

a) All new six-lane roads.
b) A majority of new four-lane roads.
c) A limited number of new two-lane roads and existing four- and six-lane roads.(66)

VDOT estimated the cost of adding a shoulder to new roads and highways during resurfacing, considering both the actual cost per mile of the shoulder and the additional cost to the whole project. The results are reproduced in table 5.

Table 5. Cost of shoulder additions.[66]

Facility	Shoulder	$ Cost/mile (Percent increase) New	Resurfacing
Two-lane road	two-foot	35,682 (16.7%)	36,000 (72%)
	four-foot	71,387 (33.3)	72,000 (134%)
Four-lane road (one direction)	two-foot	17,841 (8.3%)	18,000 (36%)
	four-foot	35,682 (16.7%)	36,000 (72%)
Six-lane road (One direction)	two-foot	17,841 (5.5%)	18,000 (24%)
	four foot	35,682 (11 %)	36,000 (48%)

BICYCLES ON CONTROLLED ACCESS FREEWAY SHOULDERS

Bicycle use of the shoulders of controlled access freeways (including Interstate highways) can still be a controversial subject despite the fact that such use has been permitted in some areas and on certain freeway facilities for more than 25 years. The following discussion presents the background on this topic, reviews the issues that have typically been raised when use of the shoulders on controlled access freeways is proposed and summarizes the procedures currently used by various agencies to determine whether to permit bicycles on the shoulders of freeways. Conclusions based on the materials reviewed are included in the last section in this chapter.

Background

Several major developments in highway programs in the mid-1950's set the stage for the present prohibition (in most States) of bicyclists' use of freeways. The first involved research which provided the justification for freeways by establishing that as the number of intersections increased, so did the number of accidents. Disruption of the traffic flow was also greater, affecting level of service and highway capacity. Finally, speed differential was noted as a significant factor in accident cause and severity.

This research led to the concept of a greatly expanded system of controlled access highways. These major highways were envisioned as the travelways of the future: safer, faster, more convenient. As part of the design, pedestrians, horse carts, and bicycles were to be banned by law or policy to increase the "safety" of the highway.

This era also saw the development of the National Defense Highway System—the Interstates. To spur development of this "super highway" system, a new funding program was devised which offered the States 90 percent Federal funding to subsidize construction of these highways.

All these developments took place in a period of growing prosperity, characterized by rapidly expanding ownership of motor vehicles and declining interest in bicycles (from the levels reached during the war years). Bicycles were viewed as something that the kids used until they were old enough to drive. For the most part, this was an accurate assessment.

This situation began to change in the late 1960's as adult Americans "rediscovered" the bicycle and began using it, in ever increasing numbers, for recreation and transportation. As the number of adult bicyclists grew, calls for access to portions of the Interstate highway system and other controlled access freeways began to be heard. Bicyclists saw controlled access freeways as facilities with few intersections, minimum grades, and smooth, wide shoulders. In many cases, they perceived these routes to be superior to alternate routes on uncontrolled roads with narrow lanes, no shoulders, steep grades, poor sight distances, and numerous intersections with streets and driveways, yet with a posted speed limit the same as, or only 5 mi/h (8 km/h) less. The shoulders of the controlled access freeways looked like a safer place to operate in these circumstances.

Another factor that prompted cyclists to seek access to the shoulders of at least some controlled access freeways related to mobility. In many instances, the construction of the new highways eliminated former, open-access routes, leaving bicyclists with no legal route to their destinations, or with very long detours. The matter is perceived by bicyclists as a question of the right of access.

In a 1977 report, CALTRANS defined four basic questions related to the issue of whether freeway shoulders should be opened to bicyclists:

1. Is there any need for bicyclists to use freeway shoulders?
2. If so, what is the extent of that need?
3. Has the Department's response to the bicyclists' needs been adequate?
4. If not, how can the Department's response be improved?(67)

In response to the first question, CALTRANS concluded that in some cases there is a need for bicyclists to use freeway shoulders. "There are areas in the State where it is impossible, very difficult, or unsafe to go from point A to point B on a bicycle, unless the bicyclist uses a freeway shoulder."(68)

Determining the extent of need was found to be more difficult. Two basic factors were considered: physical conditions and user demand. CALTRANS concluded that need should be determined on the basis of a comparison of alternative routes with the freeway segment. The existence of adverse physical conditions can be based on suggestions received from bicyclists, while need in terms of user demand would generally be an unknown factor. Complaints from bicyclists might indicate some user demand, but actual use would likely be light.

The report characterizes the Department's initial response to the needs of bicyclists as inadequate, with the general rule being to prohibit bicyclists from using freeways.

When complaints are received, specific freeway segments may or may not be opened. The actions were described as inconsistent, in part because they were made on a district-by- district basis, based on subjective factors, and done without the benefit of detailed statewide policy and guidelines. It was concluded that the Department's response to the needs of bicyclists could be improved:

1. By letting them know we will consider opening any freeway segment they suggest should be opened;

2. By evaluating the desirability of opening a freeway segment on the basis of known, specific criteria; and

3. By conducting the evaluation on a cooperative basis with bicycling organizations and law enforcement officials.[68]

The CALTRANS report includes several specific recommendations which have formed the basis for most subsequent State policies and procedures related to bicycle use on the shoulders of controlled access freeways.

- When no alternative exists, existing freeway shoulders should be open to cyclists.

- "Alternative routes" should not be longer or more dangerous than the freeway shoulder.

- Cyclists should ride within the righthand shoulder area.

- Criteria should be developed for the review of the alternative non-freeway road systems. These criteria should include: traffic volumes, road width, road surface, vehicle speeds, parked car conflict, length of out-of-direction travel, grades in excess of 6%, and truck traffic for the alternative road.

- Considerations for the proposed freeway section should include traffic volumes on ramps, interchange geometrics, merging lanes, volumes on freeway, freeway shoulder width, and narrow bridges.[68]

Accident Experience

The most basic issue is the question of safety. As noted by the New Jersey DOT "Care must be taken to distinguish between what has actually happened when bicyclists were (are) permitted on Interstates and speculations as to what might happen or could happen."[69]

As part of their study effort, the NJ DOT task force surveyed States that permit bicycle access to Interstate facilities to determine whether there were any safety problems, as evidenced by accident statistics, in allowing such access.

The results from these States showed the incidence of bicycle accidents on the Interstates is relatively low. Unfortunately, there are no records available on the number of bicyclists who use those sections of Interstates that are open. Additionally, it was noted, the number of bicycle accidents were so few that statistically valid conclusions were not possible. However, on the basis of the evidence presented, the task force concluded that:

> Although accident data are often scanty, the data certainly indicate that allowing bicycle traffic access to Interstate highways does NOT result in any unusual safety problem.[(69)]

A study by CALTRANS addresses a series of more specific issues in a somewhat unusual question-and-answer format. Because of its relevance, the full text of this discussion is included as appendix 2.

Policies and Procedures

While many concerns are raised about bicyclists using the shoulders of controlled access highways, most do not constitute an objective basis for denying access. They often reflect the subjective conclusions of individuals, are unsupported by data, and are not confirmed by experience. They do, however, persist.

Several States have made serious attempts to respond to the requests of bicyclists for access to the shoulders of controlled access freeway. The usual approach taken involves the development and application of objective criteria and a routine procedure to evaluate the relative suitability of a freeway segment and alternative routes, and to compare the relative convenience (or impact on mobility) of alternative routes. The approaches taken by some State highway administrations are summarized below, together with a presentation of what is currently the most comprehensive procedure for assessing bicycle use of controlled access freeway shoulders.

Oregon: On April 4, 1972, the Oregon Transportation Commission adopted rules to prohibit non-motorized traffic on the freeways within the Metropolitan areas only (41 mi [66 km] of the 740 mi [1191 km] of freeway in the State). The accident history on the freeway system since 1972 shows one fatality on the rural freeway system in 1980.[(70)]

California: The guidelines developed by CALTRANS include several sections, the first entitled, "When to Consider the Issue of Opening Freeway Shoulders to Bicycles" ("only if the bicyclists themselves bring the matter to the attention of the District"). The second is "How to Look at the Issue." In this section familiarity with bicycling is stressed. The third section is titled, "What Criteria to Apply." The criteria are general in nature and are intended to be used as a guide in comparing the desirability of using an alternate route with the desirability of using the freeway shoulder. It is recommended that each individual case be judged on its own merits. Safety is noted to be an extremely important factor, but convenience and reasonableness must also be considered.[(67)]

The following factors are given as affecting the desirability of using a particular freeway shoulder:

- The number of freeway ramps through the study section (numerous ramps increase potential conflicts in merge area).
- The traffic volumes on the ramps (high ramp ADT increases potential conflicts).
- The interchange geometrics (bicyclists can be required to exit the freeway without crossing ramp traffic on diamond, but not other types).
- The existence of merging lanes (shoulders may be used in merge design, leaving no width to provide for bicycle travel).
- Traffic volumes on freeway (high volumes may increase possibility of conflicts).
- Traffic mix on freeway (high percentage of truck traffic can affect cross wind factor for bicyclists).
- Width of freeway shoulders (width determines degree of proximity of bicycles to freeway traffic).
- Existence of narrow bridges (some freeway structures do not include full roadway shoulder width and would require a bicyclist to ride in a traffic lane).
- Existence of problem areas on the freeway shoulder (slotted drains, non-bicycle-proof drainage grates, bridge expansion joints, etc.) and potential for correction.[67]

New Jersey: The State DOT has dealt extensively with the question of bicycle use of controlled access highway shoulders and their resolution of the issue is unique. Cyclists who wish to use the shoulders of Interstate highways make application to the NJ DOT and they will be issued a permit "which entitles you to ride your bicycle on the shoulders of Interstate highways, with the exception of the sections of Interstate identified on the permit." Bicycle use is generally prohibited by regulation on Interstates.[69]

Colorado: The State Highway Administration's evaluation criteria were developed several years after California's.[71] The assessment process is taken a step further by quantifying the criteria and providing a model for combining them into a composite value or index for the segment under consideration.

Arizona: The Arizona Department of Transportation (ADOT) has adopted a policy regarding the use of freeway shoulders by bicycles.

> Arizona law does not prohibit the operation of bicycles on the State Highway System.

Arizona law provides authority to ADOT to prohibit by regulation the use of controlled-access highways by bicycles. Such regulations are effective only where official signs are erected.

A survey of the Western States shows that policies regarding the use of freeways by bicycles range from almost complete permission to almost complete prohibition.

Bicycle operation should be prohibited on urban freeways such as those in Phoenix and Tucson. There are many alternative routes available that are just as convenient and have less exposure for the bicyclist.

Bicycle operation on rural freeways should not be prohibited except where the Department determines that an alternative route is safer and provides reasonable convenience to the bicyclist.[17]

The Pima (AZ) Association of Governments (PAG) has developed a detailed procedure for evaluating both the "safety" and "reasonable convenience" of alternative routes which expands on the model developed by Colorado. Because the PAG approach is apparently the most comprehensive and detailed process developed to date, a complete description is included as appendix 3.

Federal Highway Administration (FHWA): The *Traffic Control Devices Handbook* includes discussion of bicycle operation on controlled access freeway shoulders.

Bicycle travel in the urban area is usually via the city street system. In the suburbs and rural areas, the bicyclist may have no convenient or available alternative roadway to travel on but a freeway. Several states allow bicyclists to operate on the freeways under special circumstances to retain the continuity of a specific bikeway....The use of freeways by bicyclists is a very special consideration and should be approached with extreme caution. The states known to allow this practice for unique situations are monitoring this usage closely. Until significant data are available, this practice should not be considered routine.[61]

This last assessment is more conservative than the approach taken by the States detailed above. Nonetheless, it serves to confirm that certain conditions warrant consideration of permitting bicycle use of freeway shoulders.

League of American Wheelmen (L.A.W.): A study in 1988 found the following States allow bicycle access to Interstate shoulders:

i) Access to all interstates (or access not prohibited): North Dakota, South Dakota, Montana and Wyoming.

ii) Access to rural interstates: Arizona, California, Colorado, Nevada, Oklahoma, Oregon, Texas, Utah, Washington and Wisconsin.

iii) Access to interstate sections with permit: New Jersey.[72]

Santa Clara Valley, CA: Bicyclists in the Santa Clara Valley (San Jose, Sunnyvale, Milpitas, etc.) have successfully campaigned to open virtually all sections of the expressway system to bicycle use, based on the argument that the shoulders of these direct routes were safer and more convenient for bicyclists than parallel roads that had higher speed limits, parked cars, frequent intersections, and other hazards.[(73)]

CONCLUSIONS AND RECOMMENDATIONS

1. If shoulders are present, have a surface similar to the adjacent travel lane, and are in reasonably good condition, both group A and B/C bicyclists will use them.

2. Shoulders can serve as good bicycle facilities where such use is permitted by law, where there are few intersections (such as in rural areas), where the outside travel lane is narrow, where sight distance is restricted, on highways with long, steep grades, and on highways with high-volume, high-speed traffic (such as urban arterials).

3. Some State vehicle codes may currently prohibit or restrict the use of highway shoulders by all vehicles (including bicycles). Some States require bicyclists to ride on shoulders (and not the roadway) where they exist.

4. For group A cyclists in particular, any width of shoulder is preferable to no shoulder at all. However, in urban areas, wide curb lanes or bike lanes are preferable to shoulders (except on high-speed arterials).

5. Bicyclists will use shoulders where the shoulders are paved to a quality equal to the surface of the roadway, in good repair, and generally free of debris. Further, bicyclists will generally operate on the left-most portion of highway shoulders where the sweeping effect of passing motor vehicles keeps the surface relatively free of debris.

6. Where highway shoulders are designated as bicycle routes, it is essential that they be kept in good repair and free of debris (this will likely require regular maintenance).

7. For urban arterials and rural highways with a posted speed limit of 40 mi/h (64 km/h) or less, and minimal truck, bus and/or recreational vehicle (RV) traffic, the desirable shoulder width to accommodate bicycle use is at least 4 ft (1.2 m).

8. For urban arterials and rural highways with a posted speed limit over 40 mi/h (64 km/h), or for highways with significant volumes of trucks, buses or RVs, the desirable shoulder width to accommodate bicycle use is at least 6 ft (1.8 m) (assuming a 12-ft [3.7-m] travel lane).

9. Where rumble strips or other textured pavement is used on shoulders many bicyclists will opt to ride on the roadway, especially when traffic volumes are light. Therefore, the use of textured pavement, corrugated pavement, and other

such surface treatments should be avoided where bicycle use of the shoulders is anticipated and/or desired.

10. Where highway shoulders are used by bicyclists, it must be ensured that the longitudinal joint between the roadway and the shoulder is maintained so as to be smooth and without any cracks or gaps which might trap the wheel of a bicycle, and with no variation in pavement level which could cause a fall.

11. Edge stripes should consist of a single, well-maintained, solid line. Paint is preferable to thermoplastic given the potential for the latter to become slippery when wet and cause falls. For similar reasons, raised line markers and reflectors should be avoided on routes intended for cyclists.

12. The approaches taken by various States to permitting bicycle use on controlled access freeway shoulders are to:
    a. Open all freeways.
    b. Open all freeways, with certain exceptions.
    c. Open freeway segments where it has been established that no alternative route exists.
    d. Open freeway segments where it has been determined that the freeway segment is "safer" than alternative routes, or more convenient (and not less safe).

13. The design standards for controlled access freeways are such that in many cases these facilities are more suitable for bicycling than alternative routes.

14. The accident experience on freeways where bicycle use has been permitted on the shoulder has not been appreciably different than that of other high-speed highways.

15. Objective factors and criteria are available, and should be used, to determine if permitting bicycle use on the shoulder of a segment of freeway is appropriate and desirable.

16. Special attention should be given to accommodating bicycle use on the shoulder of controlled access freeways where prohibiting access creates a major barrier to bicycle travel (e.g., bridges, mountain passes, tunnels, etc.).

17. When shoulder segments of controlled access freeways are opened to bicycling they should generally not be signed as a bike route.

5. OFF-ROAD PATHWAYS AND TRAILS

DEFINITION

The *AASHTO Guide* defines a bicycle path or bike path as "a bikeway physically separated from motorized vehicular traffic by an open space or barrier and either within the highway right-of-way or within an independent right-of-way."[(2)]

Further into the *AASHTO Guide*, bicycle paths are described as "facilities on exclusive rights-of-way and with minimal cross flow by motor vehicles." AASHTO encourages readers to think of bike paths as "extensions of the highway system that are intended for the exclusive or preferential use of bicycles in much the same way as freeways are intended for the exclusive or preferential use of motor vehicles."[(2)]

It is important to note, however, that few, if any, so-called bike paths actually serve the "exclusive or preferential use of bicycles." Rather, most serve a wide variety of users including runners, pedestrians, or people walking dogs and pushing baby strollers. Therefore, such facilities are perhaps more accurately described as "multi-use" paths or trails.

The AASHTO definition is adopted in a number of State facility guides and publications. For example, the California *Highway Design Manual* defines bike paths—or Class I Bikeways as they are known in California—as:

> ...facilities with exclusive rights of way, with cross flows minimized. Section 2373 of the Streets and Highways Code describes Class I bikeways as serving "the exclusive use of bicycles and pedestrians." However, experience has shown that if significant pedestrian use is anticipated, separate facilities for pedestrians are necessary to minimize conflicts.
>
> Sidewalk facilities are not considered Class I facilities because they are primarily intended to serve pedestrians, generally cannot meet the design standards for Class I bikeways and do not minimize motorist cross flows.[(28)]

The Oregon Bicycle Master Plan offers another variation on the same theme.

> Bike Path—A bike path is a bikeway which is physically separated from motorized vehicular traffic by an open space or barrier and may be within the roadway right-of-way or within an independent right-of-way. Bike paths are normally two-way facilities. Bike paths should be used to serve corridors not served by other bikeways and where there are few crossing roadways.[(29)]

The Oregon plan also makes specific comments on the inappropriateness of using sidewalks as bike paths.

> Early bike path efforts were aimed at multiple use of sidewalks as bike paths. While in rare instances this type of path may be desirable, in most cases it should

be avoided. Sidewalks are generally unsafe because they put the cyclist in conflict with motorists using driveways, and with pedestrians, utility poles and sign posts. Also the cyclist is generally not visible or noticed by the motorist so that the cyclist suddenly emerges at intersections, surprising the motorist and creating a hazardous condition.[29]

The *AASHTO Guide* discusses the implications of multiuse sidewalks and states that "providing a sidewalk bicycle path is unsatisfactory for a number of reasons."

- Sidewalks are typically designed for pedestrian speeds and maneuverabilities and are not safe for higher speed bicycle use.

- Conflicts are common between pedestrians traveling at low speeds (or exiting stores, parked cars, etc.) and bicyclists, as are conflicts with fixed objects (e.g., parking meters, utility poles, sign posts, bus benches, trees, fire hydrants, mail boxes, etc.)

- Walkers, joggers, skateboarders, and roller skaters can, and often do, change their speed and direction almost instantaneously leaving bicyclists insufficient time to react to avoid collisions. Pedestrians often have difficulty predicting the direction an oncoming bicyclist will take.

- At intersections, motorists are often not looking for bicyclists (who are traveling at higher speeds than pedestrians) entering the crosswalk area, particularly when motorists are making a turn.

- Sight distance is often impaired by buildings, walls, property fences and shrubs along sidewalks, especially at driveways.[2]

The terms "trail" and "greenway" are entering into more common use. A trail is typically a facility independent of a highway right-of-way, such as along an abandoned railroad corridor or river, designed for the shared use of bicyclists, pedestrians, joggers, and many other recreationists. A greenway is a corridor of park-type land that may or may not incorporate a trail within its boundaries.

APPLICATION OF BIKE PATHS

The Oregon Bicycle Master Plan states quite clearly that "bike paths can provide excellent bicycle facilities under certain circumstances."[29] They are one of the many bicycle facilities and treatments available to engineers and planners seeking to improve the lot of the bicyclist. There are places where bike paths are appropriate and places where they are not. The fact that some controversy remains associated with their use does nothing to diminish the value of a well-designed and maintained bike path or trail in the right location and situation.

Every bicycle facility design guide attempts to define the range of suitable applications for bike paths. For example:

The *AASHTO Guide* identifies a number of purposes for which bike paths are suitable.

> Bicycle paths can serve a variety of purposes. They can provide a commuting bicyclist with a short-cut through a residential neighborhood (e.g., a connection between two cul-de-sac streets). Located in a park they can provide an enjoyable recreational opportunity. Bicycle paths can be located along abandoned railroad rights-of-way, the banks of rivers and other similar areas. Bicycle paths can also provide bicycle access to areas that are otherwise served only by limited access highways closed to bicycles.[(2)]

The California DOT design manual is slightly more specific:

> Generally, bike paths should be used to serve corridors not served by streets and highways or where wide right-of-way exists, permitting such facilities to be constructed away from the influence of parallel streets. Bike paths should offer opportunities not provided by the road system. They can either provide a recreational opportunity, or in some instances can serve as direct high-speed commute routes if the cross flow by motor vehicles can be minimized.
>
> The most common applications are along rivers, ocean fronts, canals, utility right-of-way, abandoned railroad right-of-way, within college campuses or within and between parks. There may also be situations where such facilities can be provided as part of planed developments. Another common application of Class I facilities is to close gaps to bicycle travel caused by construction of freeways or because of the existence of natural barriers (rivers, mountains etc.).[(28)]

These two and many other design guides are equally clear in their identification of unsuitable applications for bike paths. While the Oregon plan confirms bike paths are "especially good where the bike path is isolated from motor vehicles, such as along parkways or streams," the following warnings are also offered:

> Special care must be taken to limit the number of at-grade crossings with cross streets or driveways. Poorly designed bikepaths can put a cyclist in a position where the driver of a motor vehicle does not expect him. Bike paths should not run immediately parallel and adjacent to roadways.
>
> (There should be 5-ft [1.5-m] minimum width separating them or a physical barrier of sufficient height.)[(29)]

IMPACT OF BIKE PATHS ON BICYCLE USE

Countless surveys of existing and potential bicyclists have asked "what would make you bicycle more often?" Near the top of the list of answers in each and every survey is the reply, "better bike facilities" or "more safe places to ride." In both cases, separate bike paths are among the types of facilities requested.[(26)]

A 1981 study conducted for the Federal Highway Administration reviewed a number of demand incentives for nonmotorized travel. The authors concluded:

> Separate facilities play an important role in people's preferences for nonmotorized modes, second only to compact land use. The significance of facilities is further emphasized by the fact that the compact land use scenario contains not only the important element of short trip distance but also the element of separate facilities for nonmotorized travel.[74]

While many opinion polls and questionnaires have pointed to the substantial demand for bike paths, and other facilities, there have been few attempts to actually count and evaluate levels of bicycle use. Few detailed studies have been carried out on the impact of different facilities in actually stimulating bicycle use.

Those that have been done seem to be very positive with regard to bike paths. For example, a 1978 evaluation of the Eugene, Oregon bikeway system, which incorporates all types of bicycle facilities, revealed a 76 percent increase over counts in 1971. Within this overall increase, off-street paths were found to be very attractive. Saturday or Sunday counts on the Greenway Bridge (crossing the Willamette River and a vital part of the riverbank trail system) exceeded 2,000 bicyclists. On weekdays, bicycle use had tripled from counts of 300 in 1977 to over 1,100 in 1981.[75]

A 1982 survey of bicycle use and accidents in Seattle monitored the effects of construction of the Burke-Gilman Trail. The study found:

> The city's most dramatic increases in bicycle use have been associated with the construction of off-street bicycle facilities which have directly enhanced physical bike access and operating space. At least 770 total daily weekday trips within the University district have been generated by the construction of the Burke Gilman Trail east of the University campus. This represents a minimum trip increase of 100 percent during the facility's first five years of service. As many as 2,700 daily weekend trips have been generated during the spring time on the same trail segment.
>
> Since construction of the Burke-Gilman and Northlake bike trails west of campus a 75 percent growth of weekday University area bike trips originating west of campus has occurred, representing about 466 new trips.[76]

The National Park Service and the Rails to Trails Conservancy have recently completed major surveys of trails across the country and almost without exception report the trails generating significant amounts of bicycling activity.[77]

At a training session for Illinois DOT engineers in 1991, the bicycle coordinator for the City of Seattle addressed one of the issues raised by increased bicycle use of the Burke-Gilman trail. With the increasing popularity of the trail, both among cyclists and pedestrians, fast cyclists are encouraged to ride on the nearby street system where their speed is more compatible with other users. This was just one of the reasons why the Burke-Gilman trail has generated higher levels of bicycling both on the trail and in the neighboring transportation corridor. Trails of this kind cannot and should not be viewed as a means of getting bicyclists "out of the way" of motorists.

IMPACT OF BIKE PATHS ON SAFETY

With all of the preceding sections in mind, it might seem strange to the casual reader that so much time and effort have gone into opposing bike paths by some elements of the bicycle community. The argument over the efficacy and value of separate facilities has divided engineers, planners, bicyclists and nonbicyclists alike for more than 20 years. Similar arguments have been posed in several European countries for years.

Some bicycle advocates oppose the development of trails, believing them to be dangerous and unsuitable for bicycling, and a threat to the right of bicyclists to use the roadway. The perception persists that bike paths are bad because they are more dangerous, and the statistic that bicyclists are 2.6 times more likely to crash on a bike path than on the street or highway is frequently repeated.[78]

Are separate bicycle paths dangerous? A simple answer is that they can be. If a bicycle path is poorly designed it could be more dangerous than a parallel or nearby street. But is this simply a question of inadequate planning or design, or is there something inherently dangerous about separate bicycle paths? Although off-road path accident statistics are available from several management agencies, few provide accident rates per cyclist or per mile traveled. This makes useful interpretation difficult.

The Washington, DC area has quite an extensive network of off-road bicycle trails. A report for the National Park Service on trail use and accidents points out that most accidents are never reported to the police or trail management.[79] There are some accident statistics available for two of the major trails in the region. For the years 1984 through 1986 the number of accidents reported on the Rock Creek Park trail were 8, 13 and 17, respectively. For the same years, accidents on the Mount Vernon Trail numbered 20, 20 and 59.[80]

While the report includes bicycle use counts on the Mount Vernon trail for 4 months of 1986, it does not provide a correlation between the level of use, time of day, time of year and the crashes. The Trails Coordinator for the National Capital Region reports:

> Statistics on safety, like those on use, are sketchy. Curiously enough, most accidents seem to occur at times of light to medium use. At times of peak use incidents are few. We know, further, that accidents on the Mount Vernon Trail increased from 20 in 1984 to 59 in 1986 and that they clustered at intersections and on steep or curving slopes. This suggests that crossing conflicts at intersections and excessive speed on slopes may be factors.[80]

Another major trail in the region, the Washington and Old Dominion Trail (W&OD), is one of the most popular in the country. The 44.5-mile (71.6-m) facility has an estimated 1 million users per year. The trail manager says only three car/bicycle accidents were reported in the last 6 years, even though there are 70 intersections with roads, each marked with stop signs.[81]

Other factors contributing to the W&OD's good safety record are:

- A painted yellow centerline, which has significantly reduced user conflicts.
- Widening busy sections of the trail from 8 to 10 ft (2.4 m) and adding a crushed rock shoulder. There are plans to widen the trail further to 12 ft (3.6 m).

The contention that separate bike paths are more dangerous for bicyclists, especially experienced cyclists, stems from one primary source: a 1974 study of travel and accident characteristics of regular adult bicycle users (the Kaplan Study).[78] Based on this single source, Forester articulated the theory that separate bicycle facilities are less safe than vehicular-style riding on the roadway.[82]

Kaplan's work has greatly influenced bicycle planning and engineering for almost 20 years. This is due largely to its adoption by Forester as a central plank in his theory of "effective cycling," which holds that bicyclists and bicycling are best served by behaving as much like motor vehicles as possible. Experienced, or "effective" cyclists should be able to ride on any road with no special facilities provided because they have been schooled in the science of "vehicular style riding."[1] "Better skills," not "better facilities," is the answer and those who would advocate designated bicycle facilities are accused of suffering the "cyclist inferiority complex."[1]

Today, "graduates" of effective cycling classes in the United States number no more than a few thousand, after more than a decade of operation. For the majority of bicyclists and potential bicyclists in the United States, the absence of a riding partner or lack of attractive places to ride far outweighs a lack of training and education as a reason for staying indoors or driving a car instead of bicycling.[8]

The Kaplan study is dated, based on a small number of accidents reported by a narrow sample of bicyclists, and is, at best, inconclusive. It has never been replicated. This report cannot be used as a sound basis on which to oppose the development of a whole genre of bicycle facilities which have proven to be enormously popular with the general bicycling public.

The important lesson from the last 20 years of debate, trial and error is where to take advantage of the benefits of separate bicycle paths and trails and where to avoid using them. In addition, careful attention must be paid to the design, operation, and maintenance of off-street bike paths, to avoid creating dangerous conditions for bicyclists and other path users.

ADVANTAGES OF BIKE PATHS

Bike paths are an addition to, or an extension of, the highway system. In certain instances, they can provide more direct access for bicyclists or a more attractive, pleasant route to certain destinations than the existing network of streets and highways. Bike paths are not a convenient way of simply "getting cyclists out of the way of motor vehicles," and should never be developed with that intention in mind.

Bike paths can provide much needed continuity to a network of on- and off-street bicycle facilities, for example, by providing a connection between two cul-de-sac streets or between parks. Such short stretches of path need careful design to ensure safe access and egress points, and ensure that the paths are not bisected by driveways and other streets.

There are no motor vehicles. Many group B/C bicyclists enjoy the traffic-free environment provided by trails and paths. Even group A bicyclists enjoy freedom from motor vehicle traffic.

Separate paths and trails often have very attractive environments. Indeed, many trails are found along greenways, where preservation of a green corridor for recreational use is the main motivation. Facilities in such locations allow for a very esthetically pleasing trip, provided these features do not compromise the safety of the facility by reducing sightlines or trail width.

Many separated bike paths follow railroad rights-of-way, canals, and rivers and thus have gentle grades.

One of the goals of national transportation policy is to encourage bicycling. There are many group B/C riders who will benefit from separate paths.

DISADVANTAGES OF BIKE PATHS

Separate bike paths are not an option in many locations. They require a continuous right-of-way and considerable space that does not exist in many urban and suburban areas. There will likely not be a separate system of bikepaths that totally supplants the highway system in any community.

Bike paths have limited application. They are not appropriate where continuity cannot be maintained and where there is potential for frequent conflicts with cross traffic on driveways, side streets, and intersections with major roads.

To remain usable and safe, bicycle paths require regular maintenance and sweeping. This cannot always be accomplished as part of the routine highway maintenance program as special equipment and techniques may be required. Developing a trail means making a commitment to maintaining it in safe state.

Intersections will always be a problem. There are few trails and bike paths that can justify construction of grade-separated intersections—where the right-of-way was not preserved with such grade separation intact—along their length, and each intersection carries with it the potential for car-bike conflicts.

If there are frequent intersections with busy roads, a separate path may not be appropriate. It is not possible to provide an absolute formula to determine how many and how far apart such intersections must be before a bike path is appropriate, as local circumstances vary. Continuity of the overall route corridor must be an important determinant.

Access and egress points to a bike path can also be conflict locations. Bicyclists must be able to get onto and off the path in a predictable manner that does not run counter to the general rules of the road. Thus, bike paths in median strips or on sidewalks put bicyclists getting onto or off the path in places where motorists are not expecting them to be. This can be a major source of conflict.

Sharing paths with pedestrians and other users is also a source of conflict. CALTRANS recommends that where "significant pedestrian use is anticipated, separate facilities for pedestrians are necessary to minimize conflicts."[28] Other strategies include:

- Striping the path to encourage users to keep right.
- Posting signs encouraging users to give audible warnings when passing, and to pass only on the left.
- Posting signs encouraging bicyclists to moderate their speed or to use alternate routes or streets.
- Widening the trail, either with more pavement or by providing a jogging path just off the paved part of the trail.

Bike paths can undermine bicyclists' right to the road. A real fear of many bicyclists is that they will be told—by motorists, the media, or law enforcement officials—they should be riding on the few trails available in the area, not on the streets.

Recent experience in Loudoun County, VA bears witness to this. Following the death of a bicyclist who was hit by a drunk driver, a letter appeared in a local paper saying, "If [they] had been on the bike trail where all cyclists should be for their own safety, the odds are that she would still be alive today."[83] The sheriff's office added in an interview with the paper that he wished bikes would stick to the trail. Loudoun County has just one major trail.

This simple example highlights the need to ensure the impression is never given that separate paths are an alternative to the highway system, but rather that they are an extension.

DESIGN AND PLANNING CONSIDERATIONS

Application of basic engineering principles—good sight distances, clear and adequate traffic control devices, and good surface maintenance—should minimize problems, as has been achieved along the W&OD Trail in northern Virginia and many others.

The *AASHTO Guide* provides good coverage of the basic design and planning considerations for developing bicycle paths. This is the standard reference for those considering bicycle path design. The *Guide* states:

> There are many similarities between the design criteria for bicycle paths and those for highways (e.g., in determining horizontal alignment, sight distance requirements, signing and markings). On the other hand, some criteria (e.g., horizontal and vertical clearance requirements, grades and pavement structure) are dictated by operating characteristics of bicycles that are substantially different from those of motor vehicles.[2]

The *AASHTO Guide* added a major new section on the separation between bicycle paths and roadways in the 1991 edition, identifying some of the operational problems that can occur with two-way bike paths located immediately adjacent to roadways:

1) Unless paired, they require one direction of bicycle traffic to ride against motor vehicle traffic, contrary to the normal rules of the road.

2) When the bicycle path ends, bicyclists going against traffic tend to continue to travel on the wrong side of the street. Likewise, bicyclists approaching the bicycle path often travel on the wrong side of the street in getting to the path. Wrong way travel by bicyclists is a major cause of bicycle/automobile accidents and should be discouraged at every opportunity.

3) At intersections, motorists entering or crossing the roadway often will not notice bicyclists coming from their right, as they are not expecting contra-flow vehicles. Even bicyclists coming from the left often go unnoticed, especially when sight distances are poor.

4) When constructed in narrow roadway right-of-way, the shoulder is often sacrificed, thereby decreasing safety for motorists and bicyclists using the roadway.

5) Many bicyclists will use the roadway instead of the bicycle path because they have found the roadway to be safer, more convenient or better maintained. Bicyclists using the roadway are often subjected to harassment by motorists who feel that bicyclists should be on the path instead.

6) Bicyclists using the bicycle path generally are required to stop or yield at all cross streets and driveways, while bicyclists using the roadway usually have priority over cross traffic as they have the same right-of-way as motorists.

7) Stopped cross street motor vehicle traffic or vehicles exiting side streets or driveways may block the path crossing.

8) Because of the closeness of motor vehicle traffic to opposing bicycle traffic, barriers are often necessary to keep motor vehicles out of bicycle paths and

bicyclists out of traffic lanes. These barriers can represent an obstruction to bicyclists and motorists, can complicate the maintenance of the facility and can cause other problems as well.[2]

Other basic design features for bike paths outlined in the *AASHTO Guide* include:

Width: A two-way bike path should be at least 10 ft (3 m) wide. For busy paths, especially shared with pedestrians and other users, 12 ft (3.6 m) should be the minimum. Path width of 8 ft (2.4 m) is an absolute minimum for a two-way path, and should only be used where bicycle traffic is low, pedestrian use is occasional, there are safe and frequent passing places, and maintenance vehicles will not damage the sides of the surface.

One way paths—of very limited use, as without strict enforcement they will be used as two-way facilities—should be at least 5 ft (1.5 m).

Clearance: 2 ft (0.6 m) of graded area should be maintained adjacent to either side of the pavement. If there are trees, poles, fences, or guardrails this should be increased to 3 ft (0.9 m). At least 5 ft (1.5 m) should be maintained between a path and an adjacent highway—or, a suitable physical divider should be used (with a minimum height of 4.5 ft) (1.3 m).

Grades: Grades greater than 5 percent are undesirable, and only 3 percent grade may be suitable for paths with crushed stone surfaces.

CONCLUSIONS AND RECOMMENDATIONS

1. Bike paths are a valuable addition to the highway system and to the range of facilities available to planners and engineers seeking to improve conditions for bicyclists and to increase bicycle use. Both group A and B/C riders can benefit from the additional opportunities for bicycling created by these facilities.

2. Bike paths can be used to good effect in providing long, continuous routes for commuting and recreation trips, access to destinations not otherwise available to bicyclists, and short cut-throughs between buildings and other breaks in the street network.

3. Sidewalk bike paths and other bike paths directly adjacent to roadways are not generally desirable and should be avoided.

4. Bike paths should be at least 10 ft (3 m) wide, and where possible 12 ft (3.6 m) wide; 8-ft (2.4-m) wide paths are generally not adequate given the wide variety of users, but may be appropriate in certain locations.

5. Bike paths are significant generators of bicycle traffic, both on the trail itself and in the general area of the facility. They offer an attractive environment, free of motor vehicles, for bicyclists of all abilities.

6. Bike paths are not inherently more dangerous than other bicycle facilities if they are well designed, thoughtfully applied, and adequately maintained.

7. Bike paths can serve both recreation and utility cyclists.

8. Bike paths should not have their continuity destroyed by frequent cross flows and intersections with highways. Intersections increase potential conflicts with motor vehicles and make routes less popular with riders seeking to maintain momentum.

9. Crossing points must be well designed, marked, and lit to reduce potential conflicts between bicyclists and motor vehicles.

10. Bike paths must be well maintained. The agency responsible for design and development of a facility must commit to routine maintenance, so the path is swept and inspected for defects on a regular basis.

11. A significant number of bicycle-bicycle, bicycle-pedestrian, and bicycle-only crashes occur as a result of bicyclist error and a loss of control of the bicycle. While these crashes can occur anywhere, the surroundings of a bike path may make bicyclists less attentive and careful. Signing and education efforts aimed at bicyclists and pedestrians should be initiated along bike paths.

6. FIELD STUDIES

INTRODUCTION

A series of field studies was conducted to determine what effect bike lanes and wide curb lanes of various widths have on safety and traffic operations. It was hypothesized that narrower marked bike lanes would result in a greater disruption of vehicle flow as evidenced by changes in the lateral placement and speed of vehicles passing bikes in the marked bike lanes. It was further hypothesized that narrower shared use lanes would have greater disruption of vehicle flow than would wider shared use lanes.

Another objective of the research was to investigate the safety and operational effects of off-road bicycle pathways, including their junctions with motor vehicle roadways. To quantify these effects, a series of behavioral observations was planned to determine the types, frequency, and potential severity of conflicts among the various users of off-road pathways. Four types of conflicts were considered: bike-bike, bike-pedestrian, bike-motor vehicle (at roadway junctions), and bike-other (skaters, roller-bladers, runners). Three hypotheses were developed and subjected to initial scrutiny:

- Wider pathways have fewer conflicts than narrower pathways.
- A pathway centerline reduces conflicts between users traveling in opposite directions.
- Signing (stop or yield) and/or speed bumps at roadway junctions have an effect on compliance and/or conflicts at these locations.

A series of pilot tests was conducted at several off-road pathways in the Washington, DC area. These pilot tests found that conflicts were dependent on horizontal curvature, vertical curvature and sight distance restrictions as well as bicycle and vehicle volumes. Because of these interactions, it was not possible to locate sites where the effects of these potential confounds could be separated from the design considerations of interest, i.e., pathway width, presence of a pathway centerline, and junction signing. Therefore, the field study effort focused on the safety and operational effects of bike lanes and shared use lanes.

Initial pilot testing began as an effort to quantify motorist and bicyclist behavior at intersection and midblock locations along bike lanes and shared use lanes. It soon became apparent that intersection conflicts depend on the way bicyclists choose to pass through an intersection. For example, in some situations bicyclists turn left by leaving the shoulder lane and merging with vehicular traffic in the left-turn lane. In other situations, bicyclists proceed through the intersection and make their left turn with the light in the crosswalk. The kinds of conflicts at a given location are correlated with the behaviors observed more than they are correlated with the characteristics of the bicycle facility being studied. The behaviors observed were a result of the adaptive behavior that bicyclists had learned in response to the unique characteristics of each intersection. Factors affecting route choice appear to include vehicle volumes, operating speed, turning volumes, and percent turning. Since the relationship between bicycle facility width and bicyclist safety at intersections appeared very difficult to demonstrate, research focused on the relationship between bicycle safety and convenience and facility width at midblock locations.

PROCEDURE

Site Selection

Because of their bicycle accommodations and bicycle usage, the cities of Madison, Wisconsin, Eugene, Oregon, and Blacksburg, Virginia were selected; all are near universities. Study sites in each city were chosen based on three criteria: a 200- to 250-ft (61- to 76-m) midblock observation zone at least 100 ft (31 m) from a stop sign or traffic signal; bike lanes with road markings or wide curb lanes signed as bike routes; and hourly bicycle volumes no less than 12. Figure 4 lists the study sites by city including the date and time of data collection.

Data Collection

Researchers collected data by observing bicyclist/motorist interactions and recording the information on a data form. A copy of the data form is included as figure 5. Each observation began when one or more bicyclists entered the study zone. The behavior of the bicyclist and any motor vehicle in or entering the zone during the observation period (while the target bicyclist was in the study zone) was coded on the data form. Other recorded data included bicyclist type, bicyclist tracking/placement on the roadway, motorist presence, motorist vehicle type, and motorist behavior.

Four types of bicyclists were defined. Type A included bicyclists for whom bicycling was more than recreation, including professional bicyclists. Type B consisted of strictly recreational riders. Type C included bicyclists of advanced age or children under 15. Type D contained any combination of type A, B, or C when traveling with a group. A group of bicyclists is defined as two or more bicyclists traveling within 15 ft (4.6 m) of each other or side by side.

The bicyclist's placement within the bike lane (left, center, right) was observed and recorded. It was recorded if the bicyclist tracked out of the bike lane, rode in the traffic stream, or traveled opposing traffic. Tracking of bicyclists at wide curb lane sites was limited to traveling in the traffic stream and opposing traffic.

For each bicycle observation, the presence of all motor vehicles entering the study zone was recorded. Motorists were observed as they traveled through the study zone. Vehicles were categorized and recorded by type at the same time as follows:

1. Passenger vehicle.
2. Pickup, utility, full size van, passenger van.
3. Straight truck.
4. Heavy truck.
5. Bus.

The lateral placement category included five behaviors:

1. No change - motorists who did not change their lane placement.
2. Possible shift - motorists who may have changed their lane placement.
3. Obvious shift - motorists who definitely changed their lane placement.
4. Crossed lane line - motorists whose vehicle tires (front or rear) touched or crossed the lane line pavement marking.
5. Crossed center line - same as 4, crossing centerline.

Site #	Street Location	Date of Data Collection	Time
	Madison, Wisconsin		
M1	W. Gorham east of Blair St.	10/18/91	1235-1335
M3	W. Dayton between Lake and Murray	10/18/91	1405-1505
M4	W. Gorham west of Broom St.	10/21/91	1620-1720
M5	W. Dayton between Lake and Murray	10/21/91	1055-1155
M7	W. Gorham west of Ingersoll	10/22/91	1012-1503
M8	Randall Ave. near Spring St.	10/22/91	1605-1705
M10	W. Dayton between Lake and Murray	10/23/91	0953-1053
M15	University between Orchard and Randall Ave.	10/23/91	0915-1015
M17	W. Johnson between Wisconsin Ave. and Pinkney	10/17/91	1650-1750
M18	W. Johnson between Bloot and Livingston	10/23/91	1030-1130
M19	W. Johnson between Blair St. and Bloot	10/18/91	1030-1130
M21	University between Murray and Park St.	10/19/91	1130-1230
M23	W. Johnson between Brearly and Ingersoll	10/21/91	1200-1630
M25	University between Frances and Lake	10/22/91	1640-1740
	Eugene, Oregon		
E1	E. 15th Ave near Onyx St	12/05/91	0915-1015
E2	E. 15th Ave at Onyx St	12/09/91	0920-1057
E3	Agate St between 15th St and 17th St (NB)	12/08/91	1135-1441
E4	Agate St between 15th St and 17th St (SB)	12/08/91	1138-1441
E5	University St near 18th St (NB)	12/09/91	1100-1208
E6	University St near 18th St (SB)	12/09/91	1100-1207
E7	Pearl St at 14th St	12/09/91	1325-1450
E8	Agate St between 15th St and 17th St (SB)	12/09/91	1456-1615
E9	Agate St between 15th St and 17th St (NB)	12/09/91	1456-1615
E10	5th Ave between Lincoln St and Charnelton St (EB)	12/10/91	1400-1505
E11	5th Ave between Oliver St and Charnelton St (WB)	12/10/91	1140-1305
E12	Agate St between 18th St and 17th St (NB)	12/10/91	1510-1620
E13	Agate St between 18th St and 17th St (SB)	12/10/91	1510-1620
E14	University St near 18th St (SB)	12/11/91	1225-1400
E15	University St near 18th St (NB)	12/11/91	1235-1400
E16	Agate St near 15th St (SB)	12/11/91	1415-1545
E17	Agate St near 15th St (NB)	12/11/91	1415-1545
E18	University St near 18th St (NB)	12/12/91	1400-1540
E19	University St near 18th St (SB)	12/12/91	1400-1540
	Blacksburg, Virginia		
B1	Toms Creek Rd between McBryde Dr and Stonegate Dr (NB)	12/06/91	1300-1500
B6	Toms Creek Rd between McBryde Dr and Stonegate Dr (NB)	12/05/91	1510-1710
B9	Toms Creek Rd between McBryde Dr and Stonegate Dr (SB)	12/06/91	1030-1230
B10	Mall St (EB) 800 ft (91.5 m) E of Main Street	12/05/91	1300-1500

Figure 4. Study sites by city.

SAMPLE DATA FORM - MID-BLOCK

Site # _____ City _____ Date _____ Day of Week _____ Weather _____ Pvmt Cond. _____ Obs. _____ Start Time _____ End Time _____ Page ___ of _____

CYCLIST TYPE	CYCLIST TRACKING					VEHICLE NOT PRESENT	VEHICLE PRESENT NOT PASSED	PASSED, LATERAL PLACEMENT					SPEED CHANGE				
	Trav Dir App	In Traffic Stream	BIKE LANE					No Change	Possible Shift	Obvious Shift	Crossed Lane Line	Crossed Centerline	Possible Reduction	Obvious Reduction	Applied Brakes	Increased Speed	Horn Use
			L	C	R												

Figure 5. Field study data collection form.

The speed change category included five behaviors:

1. Possible reduction - motorists who may have reduced their speed.
2. Obvious reduction - motorists who definitely reduced their speed.
3. Applied brakes - motorists who applied their brakes.
4. Increased speed - motorists who definitely accelerated.
5. Horn use - motorists who used their horns.

It was noted if motorists were present in the study zone but did not pass the bicyclist, or if no vehicles entered or were within the study zone during an observation.

The study period was concluded after 1 hour and a minimum of 30 separate bicycle observations. A 5-minute volume count was taken recording the number of bicycles and motor vehicles by travel direction. The number of motorists who crossed the lane or centerline in the study direction was also recorded.

Site Factors

A site documentation form was completed for each study site, including a detailed drawing with all relevant information, bicycle and vehicle lane measurements, and photographs. The following items were recorded on this form:

1. Area description - commercial, industrial, residential, school, playground, open area, city, or town size.
2. Roadway functional classification - local street, collector-distributor, major arterial.
3. Number of traffic lanes - travel lanes both directions.
4. Parking - allowed or restrictions.
5. Median - if any and type.
6. Shoulder - surface type.
7. Bike lane and implementation - existing space or space created.
8. Roadway markings - center line, edge, lane, crosswalks, symbols.
9. Bicycle lane markings - solid/dashed line, diamond, symbols.
10. Pedestrian accommodations - sidewalk (with/without curb), pathway, improved/unimproved shoulder.
11. Intersection proximity/type - 4-leg, "T," "Y," jog.
12. Roadway signs - within 200 (61 m) of site, warning, advisory, regulatory.
13. Speed limit.
14. Vertical placement - on level, initial up/downgrade, on up/downgrade, hillcrest.
15. Horizontal curvature - straight, 30°, 60°, 90° left or right.

The date, start and end time, weather and pavement condition was recorded for each observational period. Figure 6 shows the site documentation data collection form.

RESULTS

During the field observations, 934 cyclists were observed at 37 sites in the three study cities. Bike lane widths varied from 5 ft to 10.6 ft (1.5 m to 3.2 m); shared lane widths varied from 10 ft to 21 ft (3.0 m to 6.4 m). Sixty-two percent of the sites were two-way streets while 38 percent were one-way. Parking lane widths varied from 7.5 ft to 12 ft (2.3 m to 3.7 m) at the bike lane sites and from 7 ft to 13 ft (2.1 m to 4.0 m) at the shared use sites. The average bike volume of all sites was 25.2 bicycles/hour in the study

- State 1. Wisconsin 2. Washington 3. Oregon 4. Virginia ☐☐ 1
- City ______________________________ ☐☐ 2
- Field Investigator ______________________________ ☐☐ 3
- Site Number ______________________________ ☐☐ 4
- Site Location ______________________________ ☐☐ 5

  ____

- Date of Site Visit Month ☐☐ Day ☐☐ Year ☐☐ Time ☐☐ : ☐☐ to ☐☐ : ☐☐
- Day of Site Visit 1 Monday 2 Tuesday 3 Wednesday 4 Thursday 5 Friday 6 Saturday 7 Sunday ☐ 6
- Area Description: Choose appropriate cell from matrix below and code ______________ ☐☐ 7

	City	Small Tow	Suburban	Country
Commercial	01	11	21	31
Industrial	02	12	22	32
Residential	03	13	23	33
School	04	14	24	34
Playground	05	15	25	35
Open Area	06	16	26	36

- Roadway Functional Classification:
  Suburban, Small Town, City Locations ______________________________ ☐☐ 8
  01 Limited access (grade separated intersection only)
  02 Controlled access (intersections, but no access to abutting property)
  03 Major arterial highway (direct access to abutting property)
  04 Collector-Distributor
  05 Local street
  06 Frontage or service road
  09 Other, ______________

- Traffic Lanes. Record number of lanes:
  Approach direction of travel ______________________________ ☐ 9

  Other direction of travel ______________________________ ☐ 10

  Total traveled lanes ______________________________ ☐ 11

- Parking Restrictions ______________________________ ☐☐ 12
  01 Permitted, both sides
  02 Permitted approach direction
  03 Permitted other direction
  04 Prohibited both sides
  05 Prohibited approach direction
  06 Prohibited other direction
  07 02 + 06
  08 03 + 05
  09 Posted restrictions, approach direction
  10 Posted restrictions, roadway width limits parking, other direction
  11 09 + 10

- Median ______________________________ ☐ 13
  (The portion of a divided highway separating the traveled ways for traffic in opposite directions)
  1 None
  2 Barrier (fence, guardrail, NJ, etc.)
  3 Curb or island (takes precedence over 5, 6, 7, or 8)
  4 Painted pavement (other than center line markings)
  5 Grass
  6 Dirt or sand
  7 Gravel
  8 Trees and/or shrubs
  9 Other, ______________

- Shoulder Surface ______________________________ ☐ 14
  (Roadway edge from traveled roadway to change in slope, suitable for stopped vehicles, emergency use, or lateral support)
  1 None
  2 Concrete
  3 Bituminous (blacktop)
  4 Gravel, shall, shale
  5 Dirt or sand
  6 Grass (height __________)
  7 Combination ______________
  9 Other, ______________

- Bike Lane Implementation ______________________________ ☐ 15
  1 Installed using existing space
  2 Space created

Figure 6. Site description data collection form.

- Roadway Center Markings: ______________________________ ☐ 16
  (If highway is divided by a median or barrier, code the marking nearest the center of the roadway)
  1 None
  2 Double solid center line
  3 Single solid center line
  4 1 dashed, 1 solid center line (passing prohibited for V-1)
  5 1 dashed, 1 solid center line (passing permitted for V-1)
  6 Common left-turn lane markings
  7 Single dashed center line
  9 Other, ______________

- Roadway Edge Markings: ______________________________ ☐ 17
  1 None
  2 Pavement edge markings (paint only)
  3 Roadside delineators (on post or guardrail)
  4 Pavement delineators (raised and/or reflectorized)
  5 Pavement edge markings and roadside delineators
  6 Pavement edge markings and pavement delineators
  7 Parking lanes (marked)
  9 Other, ______________

- Roadway Lane Markings (2-lane, 2-way roadways have no lane markings; may have center marking) ______________ ☐ 18
  1 None
  2 Dashed lane markings
  3 Solid lane markings
  4 Dashed or solid lane markings with pavement delineators
  9 Other, ______________

- Special Roadway Markings (within 500' of site, both directions) ______________ ☐ 19
  1 None
  2 Pavement edge markings (paint only)
  3 Roadside delineators (on post or guardrail)
  4 Pavement delineators (raised and/or reflectorized)
  5 Pavement edge markings and roadside delineators
  6 Pavement edge markings and pavement delineators
  7 Parking lanes (marked)
  9 Other, ______________

- Pedestrian Accommodations at Site ______________________________ Approach Side ☐ 20 Other Side ☐ 21
  1 Unimproved shoulder
  2 Improved shoulder
  3 Pedestrian pathway
  4 Sidewalk, with curb
  5 Sidewalk, without curb
  6 Curb only, no sidewalk
  9 Other, ______________

- Intersection Proximity and Type
  Code distance from site, tenth of mile nearest intersection, in approach direction (code 000 if at intersection) ☐☐☐ 22

  Intersection Type ☐ 23
  1 None
  2 4-leg
  3 "T"
  4 "Y"
  5 Multiple leg
  6 Jog
  7 Interchange
  8 Other, ______________

  Signalization ______________________________ ☐ 24
  1 No intersection
  2 No signalization at intersection
  3 Signalization at intersection

- Roadway Signs (within 200' of intersection) ______________________________ ☐☐ 25
  1 None
  2 Vehicle warning ("yellow diamond type or school zone type")
  3 Stop or yield
  4 Speed limit
  5 2 + 3 + 9
  6 2 + 4 + 9
  7 3 + 4 + 9
  8 2 + 3 + 4 + 9
  9 Bike route
  10 Bike lane
  11 4 + 9
  12 4 + 10

- Posted or Legal Speed Limit, Study Leg and Direction ______________________________ ☐☐ 26
  Posted or Legal Speed Limit, Leg 2 ______________________________ ☐☐ 27
  Posted or Legal Speed Limit, Leg 3 ______________________________ ☐☐ 28
  Posted or Legal Speed Limit, Leg 4 ______________________________ ☐☐ 29

- Site Vertical Placement (relative to approach direction) ______________________________ ☐☐ 30

- Site Horizontal Curvature (Code 0 if accident occurred in intersection) ______________________________ ☐☐ 31

- Bike Lane Markings ______________________________ ☐ 32
  1 None
  2 Solid left
  3 Solid left and right
  4 Diamond + 2
  5 Diamond + 4
  6 Solid left, dashed right
  7 Diamond + 6

Figure 6. Site description data collection form (continued).

direction and 54.3 in the opposite direction. The average motor vehicle volumes at all sites was 723.7 vehicles/hour in the study direction and 215.1 vehicles/hour in the opposite direction.

The objective of the analysis effort was to identify the factors associated with observed changes in lateral placement and observed speed reductions. Since we wished to examine the proportion of vehicles at each type of site that exhibited a given behavior, a t-test was used to examine differences between the mean percentages at the bike lane sites and the mean percentages at the shared use lane sites.

The data on lateral placement changes are summarized by facility type as follows:

	Facility Type	
Category	Bike Lanes, %	Shared Use Lanes, %
No change in lateral placement	70	26
Possible change in lateral placement	18	26
Obvious change in lateral placement	6	16
Crossed lane line	3	19
Crossed centerline	2	13

On the sites with bike lanes, 70 percent of the approaching vehicles showed no change in lateral placement as they passed a bicycle in the bike lane. On shared use facilities only 26 percent of the approaching vehicles showed no change in lane placement. The difference between 26 percent and 70 percent was examined using a t-test and was found to be significant at <0.0005 level. This effect is not surprising. Since vehicles tend to track relative to the outside lane line or the bike lane line, when a bicycle is present and there is no marked bike lane, the approaching vehicle must move over to pass the bicycle. None of the other individual observed lateral placement differences between bike lanes and shared use lanes was found to be significant. However, if the three most serious lateral placement changes for the marked bike lanes—obvious shift in lateral placement (6%), crossed lane line (3%), and crossed centerline (2%)—are combined and compared to the corresponding categories for the wide curb lane—obvious shift in lateral placement (16%), crossed lane line (19%), and crossed centerline (13%)—the total, 11 percent for bike lanes and 48 percent for shared use lanes, is significantly different at the 0.01 level (t-test). Thus, it is apparent that a marked bike lane tends to direct vehicular traffic in a manner that produces less perturbance when a car passes a bicycle.

The observed speed reduction data for a bike lane and shared use lanes showed a similar trend. Because brake and horn applications occurred so rarely, the speed reduction data analysis was restricted to combining the behavior categories of possible speed reduction and obvious speed reduction. It was found that 33 percent of the vehicles at shared use lane sites had either a possible or an obvious speed reduction. At the marked bike lane locations, only 8 percent of the passing vehicles showed these behaviors. Not surprisingly, it appears that drivers approaching a bicyclist in wide curb lane situations are four times more likely to slow down than if the bicyclist is in a marked bike lane. This difference is significant at the 0.051 level (t-test).

The purpose of the data analysis was to identify those characteristics of both bike lanes and shared use lanes that are associated with the observed changes in lateral placement and the observed speed reductions. Correlation coefficients were compared between lateral placement and speed reduction changes and the relevant variables on the site form. A level of 0.05 or less was considered significant. It was found that lateral placement changes are not correlated with bike lane width, shared use lane width, or parking lane width. At shared use lane sites, lateral placement changes were found to be negatively correlated (-0.52) with the width of the entire roadway. This indicates that motorists tend to shift their lane position less on wider roads even though there is room to do so, probably because they tend to track closer to the lane line on wider roads.

At the bike lane sites, speed reduction changes were found to be not correlated with bike lane width, shared use lane width, or parking lane width. However, at these locations speed reductions were found to be negatively correlated (-0.42) with width of the entire roadway. This indicates that motorists at bike lane sites are more likely to slow down on narrower roads and less likely to slow down on wider roads where there is more room to shift their lane position. At the wide curb lane locations no significant correlation was found between speed reduction and lane width. Not surprisingly, it was found that lateral placement changes and speed reduction changes were positively correlated (0.66 at bike lane sites, 0.74 at shared use lane sites), i.e., motorists tend to slow down and move over.

At the bike lane sites, lateral placement changes were positively correlated with bicycle volume in the study direction (0.49) and with bicycle volume in the opposite direction (0.57). These significant correlations indicate that motorists at bike lane sites are more likely to shift their lane position when there are higher bicycle volumes. At the bike lane sites, the correlation between speed reduction and bike volumes in either direction was found to be not significant. At the shared use lane sites, the correlations between lateral placement changes and bike volume study direction (0.36) and bike volume opposite direction (0.46) were not significant. Similarly at the shared use lane sites the correlations between speed reduction and bike volume study direction (0.23) and bike volume opposite direction (0.20) were also not significant.

CONCLUSIONS AND DISCUSSION

The following conclusions can be made based on the field studies conducted:

1. Motorists tend to slow down and move over when passing bikes on bike lanes and shared use lanes.

2. There is less slowing down and less moving over at locations with marked bike lanes than there is at locations with shared use lanes.

3. These behaviors are not correlated with bike lane width, shared use lane width, or parking lane width.

These conclusions suggest that wider bike lanes and wider shared use lanes do not necessarily result in less disruption to vehicular traffic and that narrower facilities of either type do not necessarily produce more disruption.

7. EUROPEAN BICYCLE FACILITIES: AN OVERVIEW

INTRODUCTION

European countries and cities are at least as diverse as States and cities in the United States and generalizations about the way in which Europe deals with bicycle planning and engineering are impossible. It is possible to say that bicycling is a more common means of transport in most European countries than in the United States, but even this disguises some significant distinctions. In the Netherlands almost 30 percent of all trips are made by bicycle, and in the cities of Delft and Groningen this number rises to around 50 percent of all trips. By contrast, Spain has almost no tradition of utilitarian bicycling and in Madrid 0 (zero) percent of trips are made by bicycle and only 1 percent of residents even own bicycles![84]

Assuming the U.S. modal split for bicycles to be just less than 1 percent, countries such as Italy, France and Spain have similar levels of bicycling. In Great Britain approximately 4 percent of trips are made by bicycle, and Denmark, Sweden, Switzerland, and Germany have trip levels between 10 and 20 percent.[84]

There is as much diversity in the way in which bicycle planning and engineering has been carried out in these countries, and the debate surrounding the development of special facilities for bicyclists rages as fiercely in Europe as it does in the United States among planners, engineers, politicians, and bicyclists alike.

While the Dutch and Danish continue to develop extensive networks of separate bicycle facilities on major roads, with their own traffic signals and signing systems, German and Belgian cycle groups are desperately opposing the development of bicycle networks that comprise no more than narrow, red lanes painted on sidewalks.

A differing perception of "bicycle facilities" exists in these countries, and helps to explain the attitudes of cyclists towards government initiatives to promote bicycling. Most of the national governments mentioned have some kind of bicycle program underway, and an increasing number of cities and regional governments are recognizing the need to encourage more bicycling and greater bicycle safety.

In addition to national, regional, and local efforts to promote the development of better conditions for bicycling, some international initiatives have shed light on policies and provision for bicyclists in Europe. Foremost among these is a European Commission (EC)-sponsored report, carried out by the European Cyclists' Federation.[84]

CYCLE FACILITIES: A STATEMENT OF POLICY

Another important contribution to the debate over different bicycle facilities was provided by the European Cyclists' Federation (ECF) in June, 1987 with adoption of a statement of policy on cycle facilities. Basic principles adopted by the ECF include recognition that:

- Most bicycling will continue to take place on ordinary roads with no special provision for bicyclists.

- Reducing the speed of motor vehicles will assist cyclists in becoming more integrated into traffic flow.

- Cyclists should not be compulsorily segregated from other road traffic by cycle lanes, routes, paths, or other facilities.

- Cycle facilities should be taken from motor vehicle space, not pedestrian space.

The policy goes on to state that for cycle facilities to be successful and acceptable they must be direct, safe, attractive (well maintained) and well signposted.[85]

Both the policy statement and the EC report place a heavy emphasis on other traffic management and traffic calming measures as a means to developing a better bicycling environment. Indeed, in the EC report the greatest degree of consensus was reached among survey respondents to the statements that most cars are driven too fast and that car traffic has priority over bicycle traffic (with the exception of Denmark). As a result, survey respondents from all countries also reported that riding a bicycle is relatively unsafe.

NETHERLANDS

In the early 1970's Dutch national and local government agencies began to realize the potential impact of increased motorization on urban areas and the inability of the existing infrastructure to cope with a dramatic increase in auto traffic. As the economy is quite dependent on the movement of goods by road, there was a special incentive to ensure that "essential" travel was not made impossible by congestion.

Maintaining an already high level of bicycle use was seen as an essential element of keeping auto traffic levels manageable. In the mid-1970's bicycle route demonstration projects were initiated in Tilburg and the Hague to determine the impact such facilities would have on route and mode selection. Both projects involved constructing lengthy routes (about 10 km [6.2 mi]), taking significant space from auto routes, and providing some separation between cars and bikes.[86,87]

Not only did these projects attract cyclists away from other "dangerous" routes, but they encouraged a small number of motorists to leave their cars at home. The goal of maintaining bicycle use was certainly achieved, as national trends showed a decrease in bicycle use of 6 percent annually during the 1960's and 2 percent annually during the early 1970's.[86,87]

In the 1980's national and city planners realized that providing isolated facilities and routes was not enough to keep people bicycling. What was necessary was a complete network of bicycle facilities providing a very high level of speed, comfort, and service.

The city of Delft was chosen to evaluate this approach and from 1982 to 1987 the national government provided substantial funding for implementing a comprehensive bicycle plan. Once again, the demonstration was a success. Not only did the comprehensive network maintain cycle use at the original 40 percent of trips, but it actually increased the figure to 43 percent. The total distance traveled by bike in the city increased by 6 to 8 percent as a result of the network.[(88)]

The Delft plan focused on construction of important (and expensive) links between existing facilities and on upgrading existing facilities to enhance their convenience, comfort, and safety. A city level network of major routes was completed, providing a grid of corridors every 500 m (approximately 500 yd) comprising high-quality, separated facilities along major roads, with independent traffic signals.

A district and subdistrict level network was also completed with less complex and expensive facilities providing a grid of routes every 200 to 300 m (200 to 300 yd) and every 100 m (100 yd), respectively. The result was a coherent network with many route choices and a reduction in travel times for bicyclists.

As the 1990's dawned, the threat of increasing motor traffic once again became the inspiration for a new round of efforts to promote bicycling. Air pollution, global warming, and the continuing threat of congestion prompted the Dutch government to adopt a new transportation master plan with the goal of reducing the expected 70 percent increase in traffic to just 35 percent.[(89)] Among the strategies to achieve this, 3.5 billion more kilometers (2.17 million miles) must be traveled by bike in 2010 than in 1986, an increase of 30 percent. Further, more people are to be encouraged to use bikes and trains in combination by improving bicycle access to stations, and a reduction of 50 percent in cycling fatalities is sought by 2010.

The new cycling masterplan has three main themes: infrastructure improvements, innovation and demonstrations, and encouragement. The national government has already embarked on a major public information campaign and is supporting the city of Groningen in a demonstration project on a scale even larger than that in Delft.

The Ministry of Transport believes the separation of bicycle traffic from vehicle traffic on major routes is essential. In Delft the proportion of bicycle kilometers traveled on separate facilities grew from 30 to 35 percent (twice as much as on the network as a whole). A total of 60 percent of bicycle kilometers traveled were on the city level network, which comprises less than one-third the length of the total network.[(89)]

To make the plan work for bicyclists—who are very sensitive to time and distance—intersection treatments, pavement quality, signaling and other features give much greater priority and a sense of security to the cyclist.

On the district and subdistrict network in Delft, priority and time benefits are given to bicyclists through intersection design, bicyclist-only links (bridges, tunnels, etc.), contra-flow bicycle lanes and traffic calming measures.

DENMARK

With almost 20 percent of all trips being made by bicycle, Denmark is second only to the Netherlands in bicycle use, and many of the same pressures and developments have been evident in the Danish approach to providing facilities for bicycling.

Recent bicycle engineering projects in Denmark provide a fascinating insight into the development of facilities and networks in Copenhagen, a large urban area (1 million plus); Odense, a medium-sized city (175,000); and Nakskov, a small town (16,000); as well as a study of different types of facilities.

With a population of more than 1 million, Copenhagen has 30 percent of trips made by bicycle. In 1980 a bicycle path plan was developed to complete the existing network of paths, and over a 5-year period almost 40 km (24.8 mi) had been added to the network, at a cost of $15 million. In the same period, bicycle use in the central area grew by 50 percent. A number of the paths have been developed at the expense of parking and traffic lanes on major arterials entering the city.[(90)]

The city has attempted to protect bicyclists—and give them priority—at intersections by allowing them to wait ahead of motor traffic. At other intersections, bicycle lanes are painted in blue to highlight their presence for the benefit of motorists. Until recently, bicycle lanes were designed to end before intersections. While the design appeared to be safer for bicyclists, they did not feel secure, and preferred to have the bicycle lane continue through the intersection. New designs are being tried.[(90)]

In the mid-sized city of Odense, population 175,000, a network of more than 250 km (155 mi) of bicycle paths has been completed with the development of two major routes through the city center. These new routes, completed in 1988, comprise cycle paths, contra-flow lanes, cycle paths through pedestrian streets, and paths shared with bus lanes. Surveys have shown the routes have improved access and the perception of safety among users. Car use in Odense fell 30 percent between 1979 and 1988.[(91)]

The small town of Nakskov was chosen for a demonstration project in 1987, with the focus once again being the completion of a network of routes and paths for bicyclists. Traffic calming combined with special intersection design and signing is an essential element of the project.[(91)]

From 1984 to 1988 the Danish Roads Directorate carried out a pilot project in four cities to study different types of bicycle facility. Cycle only routes, cycle paths, cycle lanes, traffic calming, bus and bike lanes, and wide curb lanes were among the treatments studied. The results from Helsingor, Aarhus, Odense, and Herning are fascinating, according to Bracher in the EC report:

> A marked shift of traffic to the new routes has been observed in Aarhus and Odense. However, cyclists have mixed feelings. In the place where cyclists most praised the quality of the new route, Herning, it is least used. In Aarhus the route was especially heavily criticized, but most used.[(84)]

UNITED KINGDOM

While levels of bicycle use are considerably lower in the United Kingdom than in the Netherlands and Denmark, government agencies have been active in developing, studying, implementing, and experimenting with bicycle facilities—in particular, facilities shared with pedestrians. In a review of three national government experimental city programs, Clarke paid special tribute to the ability of traffic engineers in Nottingham to implement bicycle facilities within significant space constraints.(92)

The Department of Transport (DTp), in cooperation with the Transport and Road Research Laboratory (TRRL), is just concluding the last of six bicycle route projects in Bedford, Exeter, Nottingham, Cambridge, Canterbury, and Stockton. Each of the projects is described and evaluated in a series of Traffic Advisory Leaflets, and the DTp has presented papers on the projects at each of the last three Velo City conferences.(93)

The projects include almost every conceivable type of bicycle facility, ranging from fully segregated bicycle paths and new bridges exclusively for bicycle and pedestrians, through advisory cycle lanes (where bike lanes are marked with broken or dashed white line rather than a solid line), shared bicycle and pedestrian crossings of major roads, and abandoned railroad line conversions.

Other leaflets in the Traffic Advisory Leaflet series show the development of different facilities and routes over the last 7 years or more and provide valuable insight into the designs of shared use facilities, intersection treatments, and traffic calming measures. These are supposed to be supplemental to the Local Transport Notes, which offer more planning and engineering guidance to local traffic engineers and planners.(94)

The Cyclists' Touring Club (CTC), a national organization of cyclists in the United Kingdom with more than 40,000 members, has produced a number of useful bicycle facility and highway design manuals. "Cycle Planning" contains eight detailed information sheets on highway maintenance, bicycle facilities, the planning process, traffic management and the shared use of facilities by both bicyclists and pedestrians.(95)

In 1991 the CTC completed a review of "Cyclists and Roundabouts." These facilities have an accident rate for bicyclists 15 times higher than for cars and two to three times higher than at equivalent signal-controlled intersections. Large roundabouts are especially feared, but small traffic circles in residential areas do not have the same problems.(96)

A variety of remedial measures to improve cyclist safety at roundabouts have been tried, but none have any general applicability. The speed of motorists entering and leaving roundabouts is the greatest threat to cyclists.

The CTC recently completed an excellent review of the impacts of traffic calming measures on bicyclists, "Cyclists and Traffic Calming."(97) Besides describing many popular features of traffic calming, the report offers strategies for making them safe and attractive to bicyclists. For example, it recommends providing cyclists with a bypass (at least 700 mm [approximately 2 ft] wide) to physical obstacles such as speed humps, and never allowing traffic chokers or width restrictions to endanger cyclists.

Two features of bicycle planning in the United Kingdom stand out: the lack of a design manual equivalent to the *AASHTO Guide*, and the attention given to facilities shared with pedestrians. Lack of a manual is not unique to the United Kingdom as very few other countries have an equivalent. Even in the Netherlands it has been the membership group Fietsersbond ENFB that has produced the best facility manuals. While there are central government rules governing the installation of speed humps and other design features, the pressures of liability and conformity with minimum standards do not appear to exercise the minds of planners and engineers in Europe in quite the same way as in the United States. Facilities developed in Nottingham along one of the major bike routes, or in some of the other demonstration projects, feature very narrow lane widths, narrow cycle paths that have trees growing in the middle of them, sidewalk bikepaths and other extraordinary designs.[98]

The second noticeable feature of bicycle planning in the United Kingdom is the attention given to facilities shared with pedestrians. This is almost certainly a function of the lack of space and priority given to both cyclists and pedestrians, and is evident in Germany, Belgium, and other countries.

The Clifton cycle route in Nottingham has stretches of bikeway shared with pedestrians with no separation, with separation by level, by color, by surface type, and in some cases by all of these methods. Not surprisingly, both cyclists and pedestrians feel more comfortable with the maximum amount of separation.[99] Other designs include shared highway crossings, shared bridges and underpasses (subways) and special designs for accommodating blind and physically challenged users.

The Cyclists Touring Club, Pedestrians Association, and Friends of the Earth joined in 1988 to adopt a joint statement on the safety and comfort of pedestrians and cyclists to address some of the issues raised by the sharing of facilities.[100] The document provides policy, legislative, and design recommendations, and is contained in the CTC's Cycle Planning folder.

GERMANY

The greatest divergence between traffic planners and engineers and bicyclists seems to exist in Germany and Belgium. While 11 percent of trips are made by bicycle and some significant investment has been made in developing bicycle networks, bicyclists themselves are heavily critical of the facilities provided.

A typical bicycle facility in Germany consists of a narrow red stripe painted onto a sidewalk, which bicyclists must use. They may be two-way facilities on one sidewalk—requiring bicyclists to cross the highway just to use the facility and to cross back when it ends. The surface quality is often poor, and the facilities are provided at the expense of pedestrians, not motor traffic.

Researchers at the University of Oldenburg (1988) found that typical bicycle path surfaces and typical bicycles are not well matched with regard to vibrations and that not only safety would be improved by smoother surfaces. On the paved cycle paths studied, longer journeys were found to have the potential of being harmful to the health of riders.[(101)]

Perhaps it is not surprising that bicycle advocates in Germany have been ardent supporters of traffic calming, as they believe the best conditions for bicyclists will be created by slowing traffic down and bicycling on the ordinary highways.

The city of Erlangen, population 101,000, has one of the highest levels of bicycle use in Germany, increasing from 15 percent of trips to close to 30 percent between 1972 and 1990. The increase has been due largely to the development of an extensive bicycle network, parking facilities, traffic restraint, the provision of official bicycles for government employees, and a host of other promotional activities. Almost half of the 150-km (95-mi) network is made up red stripes 0.9 to 1.5 m (3 to 5 ft) wide, painted onto the sidewalks.[(102)]

Two bicycle-friendly towns were developed in western Germany during the 1980's, Rosenheim and Detmold. While both projects incorporated some work on the development of bicycle facilities, the whole project was more instructive in reviewing the institutional framework and system necessary to develop a bicycle-friendly town.

The study concluded that systematic action to promote bicycling can to a certain extent reduce motorized traffic, and that the investment necessary was a fraction of that necessary for cars or public transport. To make a city bicycle-friendly, the report identified the following elements:

- A systematically planned bicycle traffic network suited to the needs of the user, including streets with speed limits.
- A range of facilities—not just bike paths—throughout the city.
- Good bicycle parking, maps, and signing.
- Official bicycles for public servants.
- A city cycling officer (bicycle coordinator).[(103)]

In addition to this study, numerous works have considered the potential for shifting car drivers to bicycles.[(104)] A great deal of German literature—especially related to bicycling and traffic calming—exists only in the German language, which is a significant handicap.

OTHER EUROPEAN COUNTRIES

The four countries covered above provide a useful cross-section of examples and experience with bicycle planning and engineering in Europe. In France, Austria, Switzerland, and Sweden there are particular cities and regions where bicycling has been encouraged.

Italy, Spain, Portugal, Ireland, and Greece have little or no bicycling tradition, and smaller countries such as Belgium and Luxembourg are heavily influenced by their larger neighbors. The Dutch-speaking half of Belgium, for example, has bike facilities similar to those in the Netherlands, while the French-speaking areas have little provision at all.

SPECIAL FEATURES AND POTENTIAL U.S. DEMONSTRATIONS

While many common features of European bicycle networks have been imported to the United States over the years, a number deserve special attention and could provide the nucleus of a demonstration project or series of experimental designs.

Advanced Stop Line. Pioneered in the Netherlands and becoming increasingly common in Denmark, this facility allows bicyclists to get to the front of a line of traffic at an intersection and sit in front of traffic waiting at the light in a "reservoir" of space. A separate traffic signal allows bicyclists to move off first, allowing them to make a left turn in safety, and offering bicyclists a unique sense of priority.

An especially useful feature of such a design in the United States might be the ability of such an intersection to help prevent conflicts between cars turning right on red and bicyclists wishing to go straight ahead.

Bicyclist Traffic Signals. Not only do traffic signals in Europe commonly have detectors that pick up bicyclists, but signals just for bicyclists are becoming more common. In the Dutch networks independent cycle signal timings are essential. In the United Kingdom bicycle traffic lights (with an illuminated bicycle logo on the signal-head) are used at intersections where bicycle lanes and routes cross major highways. In France and the Netherlands it is common to see signal heads at eye level for bicyclists and pedestrians, and for the signals to be triggered by nonmotorized users on demand.

Contra Flow Bike Lanes. While a number of U.S. cities have examples of contra-flow lanes, for example, Seattle, WA, Eugene, OR and Madison, WI, no administration has yet decided to routinely allow cyclists to travel both directions on one-way streets the way Basel and other European cities have.

Bus and Bike Lanes. In London, a main feature of the bicycle riding environment is the availability of many miles of bus lanes in which cyclists are allowed to ride. They usually have red asphalt to distinguish them further from the ordinary highway.

Traffic Calming. Significant U.S. efforts at widespread residential traffic calming have yet to get underway, although cities such as Seattle are making a significant effort. Traffic calming is now a common feature of town planning in most European countries. Even more exciting is the potential for traffic calming techniques to be used in other locations, such as shopping areas and town centers.

CONCLUSIONS AND RECOMMENDATIONS

1. European experience with bicycle planning and engineering has considerable relevance to cities and States in the United States. The importance of developing coherent and continuous networks of routes, and the implementation of a wide range of different facilities to suit particular locations have real applicability to the United States.

2. Few European countries have design manuals and standards approaching the sophistication and level of detail available in the United States. In the United States, by contrast, the need to conform to rigid engineering principles due to liability concerns has most likely hampered the development of innovative solutions to bicycle access and safety problems.

3. There is an urgent need for transportation planners and engineers to learn from developments in Europe, especially in relation to traffic calming and methods of stimulating bicycling and other modes of travel.

4. A significant barrier to learning from European developments is language. Much of the best work is available only in German. Federal Highway Administration (FHWA) and/or the Transportation Research Board (TRB) should facilitate a better transfer of technology between nations.

8. THE BICYCLE PLANNING PROCESS

Transportation planning is a process for making decisions about the development of transport facilities. This includes providing accurate information about the effects proposed transportation projects will have on the community and projected users.[105] Bicycle planning is no exception. However, because much of the information needed to reach sound decisions about providing for safe, efficient bicycle use is already available as a byproduct of the normal operation of the road system, the bicycle planning process is a specific application of the overall transportation planning process.

This is especially true in the case of group A bicyclists, the more experienced and proficient bicyclists that comprise about 5 percent of bicycle users in the United States. These bicyclists are able to operate on the roadway in most traffic conditions and favor the directness and right-of-way preference given to roads with a high functional classification. The planning process used to develop or improve roadways for motorists is equally valid for this type of bicyclist.

There are, however, some important design features to be taken into account to best accommodate group A bicyclists, and for this reason planners and engineers should refer to the *AASHTO Guide* during the planning process for streets and highways.[2] Group A riders should be anticipated and provided for on all roadways where bicycles are not excluded by statute or regulation, regardless of functional classification.

The situation is very different for group B/C bicyclists (bicyclists of average skill and experience, and children). While these bicyclists value many of the same roadway features as group A bicyclists (i.e., accessibility, directness), they also value other characteristics such as designated bicycle facilities and lower traffic volumes.

Group B/C bicyclists typically prefer to ride on neighborhood streets and/or designated bicycle facilities. The location of these facilities is best determined through a planning process that seeks to determine where designated facilities are needed and the type of bicycle facilities that should be provided to accommodate and encourage group B/C bicyclists.

DEVELOPING A BICYCLE NETWORK PLAN

The following discussion details a planning process intended to identify a network of routes where special bicycle facility treatments should be employed to meet the needs of group B/C bicyclists.

Many model planning processes could be used to select routes and design facility treatments to accommodate group B/C bicyclists. Chapter 1 of the *AASHTO Guide* contains several suggestions for establishing a bicycle planning program. The following process is but one example.[2] It consists of six steps:

1. Establish performance criteria for the bicycle network.
2. Inventory the existing bicycle facility and roadway system.
3. Identify bicycle travel desire lines and corridors.
4. Evaluate and select specific route alternatives.
5. Select appropriate design treatments.
6. Evaluate the finished plan against the established performance criteria.

Establish Performance Criteria for the Bicycle Network

Performance criteria define the important qualitative and quantitative variables to be considered in determining the desirability and effectiveness of a bicycle facility network. These can include:

- Accessibility: This is measured by the distance a bicycle facility is from a specified trip origin or destination, the ease by which this distance can be traveled by bicycle, and the extent to which all likely origins and destinations are served. Some communities have adopted a criterion of having a bicycle facility within 1 mi (1.61 km) of every residence.[106] More importantly, no residential area or high priority destination (school, shopping center, business center, park) should be denied reasonable access by bicycle.

- Directness: Studies have shown that most bicyclists will not use even the best bicycle facility if it greatly increases the travel distance or trip time over that provided by less desirable alternatives.[24,25] Therefore, even for group B/C bicyclists, routes should still be reasonably direct. The ratio of directness to comfort/ perceived safety involved in this tradeoff will vary depending on the characteristics of the bicycle facility (how desirable is it?), its more direct alternatives (how unpleasant are they?), and the typical user's needs (in a hurry? business or pleasure trip?).

- Continuity: The proposed network should have as few missing links as possible. If gaps exist, they should not include traffic environments that are unpleasant or threatening to group B/C riders, such as high volume or high-speed motor vehicle traffic with narrow outside lanes.

- Route Attractiveness: This can encompass such factors as separation from motor traffic, visual aesthetics, and the real or perceived threat to personal safety along the facility.

- Low Conflict: The route should present few conflicts between bicyclists and motor vehicle operators.

- Cost: This would include the cost to both establish and maintain the system.
- Ease of Implementation: The ease or difficulty in implementating proposed changes depends on available space and existing traffic operations and patterns.

Inventory Existing System

Both the existing roadway system and any existing bicycle facilities should be inventoried and evaluated. The condition, location, and level of use of existing bicycle facilities should be recorded to determine if they warrant incorporation into the proposed new network or if they should be removed. If existing bicycle facilities are to be used as the nucleus of a new or expanded network, the inventory should note what improvements to the existing portions of the network may be required to bring the entire new network up to uniform design and operations standards.

A simple inventory of the roadway system could be based on a map of the annual average daily traffic (AADT) counts on each road segment within a community or region. A more complex inventory could include factors such as the number of traffic lanes, the width of the outside lane, the posted speed limit or actual average operating speed, the pavement condition, and certain geometric and other factors (e.g., the frequency of commercial driveways, grades, and railroad crossings).

Identify Bicycle Travel Corridors

Predicting bicycle travel corridors for a community is not the same as identifying the routes that bicyclists currently use. Instead, travel corridors can be thought of as "desire lines" connecting neighborhoods that generate bicycling trips with other zones that attract a significant number of bicycling trips.

For motor vehicle traffic, most peak morning trips are made between residential neighborhoods and employment centers. In the evening peak, the opposite is true. In the evening or on weekends, the pattern of trip generation is much more dispersed as people travel to shopping centers, parks, and the homes of friends or relatives.

Estimating these trip flows for an entire city can be a complex, time consuming effort requiring significant amounts of raw data and sophisticated computer models. Fortunately, transportation planning for bicycles is much simpler. Unlike traditional transportation planning that attempts to predict travel demands between future zones on as-yet-unbuilt streets and highways, bicycle planning attempts to provide for bicycle use based on existing land uses assuming that the present impediments to bicycle use are removed. These desire lines are, in fact, well represented by the traffic flow on the existing system of streets and highways.

The underlying assumption is that people on bikes want to go to the same places as do people in cars (within the constraints imposed by distance), and the existing system of streets and highways reflects the existing travel demands of the community. Further, most adults have a mental map of their community based on their experience as motor vehicle operators. Thus, they tend to orient themselves by the location of major streets and highways.

Therefore, a good way to estimate desire lines for bicyclists and to project bicycle trips is based on the existing pattern of motor vehicle flows. The simplest way to do this is to multiply the AADT of each segment of the road system by the bicycle mode split (the percentage of all trips that are made by bicycle) for the community or region. For the first time, the 1990 census will provide bicycle mode splits for census tracts and entire communities. Mode split estimates of total trips by bicycle in American cities have ranged between 3 and 11 percent.[107,108,109]

Again, it is important to note that the resulting map may not be a representation of where bicyclists are now, but instead is a reflection of where bicyclists wish to go. The actual travel patterns of group B/C cyclists are heavily influenced by their perception of the bicycling environment they face. Uncomfortable or threatening bicycling conditions will cause these bicyclists to alter route choice from their most preferred alignment, choose a different travel mode, or not make the trip at all. Thus, the task of the transportation planner for bicycling is to ask "Where are the bicyclists now?" and "Where would they be if they could go where they preferred?"

Although this use of existing traffic flows is a useful overall predictor of bicyclists' desire lines, a few special situations may require adjustments to the corridor map:

- Schools—especially colleges and universities—and military bases can generate a disproportionately large share of bicycle trips. This is especially true for campuses where motor vehicle parking is limited.

- Parks, beaches, libraries, greenways, rivers and lakesides, scenic roads, and other recreational facilities attract a proportionately higher percentage of bicycle trips.

<u>Evaluate and Select Specific Route Alternatives</u>

The corridor identification procedure identifies desire lines for bicycle travel between various locations. The next step is to select specific routes within these corridors that can be designed or adapted to accommodate group B/C bicyclists and provide access to and from these locations. The aim is to identify the routes that best meet the performance criteria established in the first step of this planning process.

Typically, this step and the selection of appropriate design treatments are a highly interactive processes. The practicality of adapting a particular route to accommodate group B/C bicyclists may vary widely depending upon the type of design treatment selected. For example, a less direct route may become the best option if comparatively few, inexpensive, and easily implemented design improvements are required.

Therefore, steps 4 and 5 should be approached as an iterative loop in which both route selection and design treatment are considered together to achieve a network that is highly advantageous to the user, is affordable, has few negative impacts on neighbors and other nonusers, and can be readily implemented.

In summary, the selection of a specific route alternative is a function of several factors, including:

- The degree to which a specific route meets the needs of the anticipated users as opposed to other route options.

- The possible cost and extent of construction required to implement the proposed bicycle facility treatment.

- The comparative ease of implementing the proposed design treatment. For example, one option may entail the often unpopular decision to alter or eliminate on-street parking while another does not.

- The opportunity to implement the proposed design treatment in conjunction with a planned highway construction or reconstruction project.

A more inclusive list of factors to be considered in the selection of a specific route is presented in the *AASHTO Guide.*[2]

<u>Select Appropriate Design Treatments</u>

Guidelines for selecting an appropriate design treatment are presented in chapter 9 of this report. In overview, the principal variables affecting the applicability of a design treatment are:

- <u>The design bicyclist</u>. Is the proposed route projected to be used primarily by group A bicyclists, or is it intended to also serve as part of a network of routes for group B/C bicyclists?

- <u>The type of roadway project involved on the selected route</u>. Is the roadway scheduled for construction or reconstruction, or will the incorporation of design improvements be retrofitted into existing geometrics or right-of-way widths?

- <u>Traffic operations factors</u>. The most significant traffic operations factors for determining the appropriateness of various design treatments are:

  - Traffic volume.
  - Average motor vehicle operating speeds.
  - Traffic mix.
  - On-street parking.
  - Sight distance.
  - Number of intersections and entrances.

Evaluate the Finished Network Plan Using the Established Performance Criteria

Will the proposed network meet the criteria established at the start of the planning process? If it does not meet most of these criteria, or inadequately meets a few critical goals, either the proposal will require further work, or the performance criteria must be modified. In the latter case, the planning process as a whole should be reviewed to determine if previously discarded routes should be reconsidered. They may now be more preferred options in light of the newly modified criteria.

This reality check is important. Many well-considered proposals flounder when it is determined that the finished product no longer meets its established objectives.

9. DESIGN SELECTION AND SPECIFICATIONS

This chapter provides recommendations for selecting roadway design treatments to accommodate bicycles. Specific dimensions are suggested for the width of the recommended facility type. These recommendations reflect the current state of the practice in the design of bicycle-friendly roadways, and should be treated as "guidelines" rather than absolute standards.

TYPES OF FACILITIES

Five basic types of facilities are used to accommodate bicyclists:

- Shared lane: shared motor vehicle/bicycle use of a "standard" width travel lane.
- Wide outside lane: an outside travel lane with a width of at least 14 ft (4.2 m).
- Bike lane: a portion of the roadway designated by striping, signing, and/or pavement markings for preferential or exclusive use of bicycles.
- Shoulder: a paved portion of the roadway to the right of the edge stripe designed to serve bicyclists.
- Separate bike path: a facility physically separated from the roadway and intended for bicycle use.

DESIGNATING BICYCLE FACILITIES

An important consideration regarding the five types of facilities designs is whether or not they should be designated, by pavement markings and/or signs, as bicycle facilities. As discussed in chapter 1, group B/C bicyclists prefer designated facilities for bicycle use. Therefore, when bike lanes or shoulders are provided to serve group B/C riders, some designation should be included.

However, the legality of bicycle use on highway shoulders may not be well-defined in every State. This is due, in part, to the current language in the Uniform Vehicle Code regarding where vehicles are permitted to operate. Users of this manual are encouraged to contact their State Attorney General's office to determine the current situation regarding bicycle use on selected highway shoulders. Consideration should be given to amending some State vehicle codes to explicitly permit this widespread practice.

When design treatments are provided primarily to serve group A riders, designation is optional. In some cases, it may be more desirable not to designate the facility for bicycle use. For instance, if bicycle use is permitted on the shoulder of a controlled access freeway, it is usually not appropriate to designate this roadway as a bicycle facility unless this route serves as the only link between two points.

Another consideration involves minor or marginal roadway improvements for bicyclists, such as providing a narrow (less than 4-ft [1.2-m]) shoulder. This can significantly improve riding conditions for group A bicyclists and should be considered if no better treatment is possible. However, this width is less than the minimum called for in virtually all design specifications and therefore should not be designated as a bicycle facility. Where a facility is intended to be designated as a "bicycle facility" it is essential the design conform to the State standard or AASHTO guidelines.

PREPARING TO SELECT A DESIGN TREATMENT

To determine the appropriate highway design treatment to accommodate bicyclists, several factors associated with the specific route or project must be assessed:

- What types of bicyclists is the route most likely to serve?
- What type of roadway project is involved (new construction, reconstruction, or retrofit)?
- What are the current and anticipated traffic operations and design characteristics of the route that will affect the choice of a bicycle design treatment?

What Types of Bicyclists is the Route Most Likely to Serve?

This manual takes its lead from the *AASHTO Guide*, which states:

> To varying extents, bicycles will be ridden on all highways where they are permitted. All new highways, except those where bicyclists will be legally prohibited, should be designed and constructed under the assumption that they will be used as a bicycle street.[2]

Using the concept of two broad types of design bicyclists—group A and group B/C—the recommendations included in tables 1 through 6 are keyed to the most likely type of users. All streets and highways where bicycles are permitted to operate should, *as a minimum*, incorporate the design treatments recommended in the tables for group A bicyclists. Where it is determined that use by group B/C bicyclists is likely, the tables recommending design treatments for group B/C should be used. The group B/C design treatments will also accommodate group A bicyclists.

At a minimum, all streets and highways open to bicycle use should have roadways incorporating the design treatments recommended for Group A bicyclists. Where a planning process has determined a given route is the best choice to form part of a network of routes to provide access to the community for group B/C bicyclists, the recommended design treatment appropriate to B/C riders should be implemented.

New Construction and Reconstruction vs. Retrofitting

The recommended design treatments in the tables are most easily implemented when new construction or reconstruction is planned. It is a relatively straightforward process to adopt the specified design treatment for bicycles at the project planning stage.

When implementation involves retrofitting an existing roadway to accommodate bicycle use, the project can be more complex. Existing streets built with curb and gutter section will often be viewed as having a fixed width and improvements will likely be limited to "moving paint," that is, restriping the existing lanes.

When working with existing streets and highways, planners should investigate the opportunity to make at least minor or marginal improvements. However, where the need is to serve group B/C bicyclists, it is essential to commit the resources necessary to provide facilities that meet the recommended design treatments. Only then can routes and facilities be designated for bicyclists and provide the desired access to the community.[110]

What Traffic Operations and Design Factors Help Determine the Appropriate Design Treatment?

A general consensus has emerged among transportation planners and engineers working with bicycle facilities on the traffic operations and design factors having the greatest effect on bicycle use.[110] Six factors are most often cited; five are used to define the recommendations contained in the tables.

Each of these factors is discussed below along with the ranges of values used to differentiate levels of needs. Determining these ranges was difficult; there is little in the state of the practice to go by, and there is tremendous regional variation in prevailing conditions. Therefore, it is again suggested that the tables be used as a "guide" and that adjustments be considered to reflect, for instance, different values for the ranges for annual average daily traffic volume (AADT). The six major factors are as follows:

- Traffic volume. Higher motor vehicle traffic volumes represent greater potential risk for bicyclists and the more frequent overtaking situations are less comfortable for group B/C bicyclists unless special design treatments are provided. The recommendations contained in the tables are based on three ranges of AADT:

  - Under 2,000 AADT.
  - 2,000 - 10,000 AADT.
  - Over 10,000 AADT.

- Average motor vehicle operating speed. The average operating speed is more important than the posted speed limit, and better reflects local conditions. Again, motor vehicle speed can have a negative impact on risk and comfort unless mitigated by special design treatments. Four ranges of average speeds are used:

- Less than 30 mi/h (less than 48.3 km/h).
- 30 - 40 mi/h (48.3 - 64.4 km/h).
- 41 - 50 mi/h (66 - 80.5 km/h).
- Over 50 mi/h (Over 80.5 km/h).

- Traffic mix. The regular presence of trucks, buses, and/or recreation vehicles (i.e., approximately 30 per hour or more) can increase risk and have a negative impact on comfort for bicyclists. At high speeds, the wind blast from such vehicles can create a serious risk of falls. Even at lower operating speeds, shared lane use is less compatible. All types of bicyclists prefer extra roadway width to accommodate greater separation from such vehicles. Many bicyclists will choose a different route or not ride at all where there is a regular presence of such traffic unless they are able to remove themselves several feet from these motor vehicles.[2] The recommendations contained in the tables suggest different design treatments and widths depending on whether or not the volume of truck, bus, and/or recreational vehicles is likely to have a negative impact on bicycle use.

- On-street parking. The presence of on-street parking increases the width needed in the adjacent travel lane or bike lane to accommodate bicycles. This is primarily a concern associated with streets and highways built with an urban section. It is addressed in the recommendations by including a separate set of tables for urban sections with on-street parking.

- Sight distance. "Inadequate sight distance" relates to situations where bicycles are being overtaken by motor vehicles and where the sight distance is likely less than that needed for a motor vehicle operator to either change lane positions or slow to the bicyclist's speed. This problem is primarily associated with rural highways, although some urban streets have sight distance problems due to poor design and/or sight obstructions.

  The most effective response to the problem is to correct it. Providing for bicycle operation to the right of the designated motor vehicle lane (i.e., on a bike lane or shoulder) or, at speeds less than 41 mi/h (66 km/h), by adding extra width to a wide outside lane, are viable approaches.

- Number of Intersections. Intersections pose special challenges to bicycle and motor vehicle operators, especially when bike lanes or separate bike paths are introduced. The *AASHTO Guide* and various State design manuals include general guidelines for intersection treatments.[2,33,110]

  While not included as a selection factor in the tables, the number and/or frequency of intersections should be considered when assessing the use of bike lanes. There is some evidence to suggest that the disruption in traffic operations associated with bike lanes is temporary. Over time, both bicyclists and motorists adapt to the new traffic patterns, learning to look for each other and effect merges prior to intersections.

How to Use the Tables to Determine the Recommended Treatment

Recommended roadway design treatments and widths to accommodate bicycles are presented in tables 1 through 6. There are separate tables for group A and group B/C bicyclists. The design treatments for group A bicyclists should be used as a guide to the minimum design for any roadway on which bicycle use is permitted. The recommended design treatments for group B/C bicyclists should be considered the desirable design for any route on which this type of bicyclist is likely to ride.

There are separate tables for the two basic types of roadway sections: urban (with curb and gutter) and rural (without curb and gutter). Separate tables are provided for highways with urban sections with on-street parking and with no on-street parking.

> *[Note: Controlled access freeways are considered a special case and are not addressed by the tables. Several States now permit bicyclists to operate on the shoulder of some or all of their controlled access freeways.[110] Controlled access freeway rights of way also have been used for separate bike paths.]*

The tables indicate the appropriate design treatment given various sets of traffic operations and design factors. The tables do not include any specific recommendations for separate bike paths. The use of separate bike paths depends on specific right-of-way conditions (e.g., very few intersections, adequate set-back) that do not exist along most highways. These conditions are most often found along parkways, river and lake shores, in park and recreation areas, on abandoned railroad rights-of-way, and on the right-of-way of some controlled access freeways. Where such suitable conditions exist, separate bike paths can be pleasant additions to the facilities available to bicyclists. However, they cannot take the place of access to the roadway of the street and highway system.

Recommendations are provided for the width of the various recommended design treatments. These recommended dimensions are considered to be "desirable widths." They should be treated as "minimum widths" unless special circumstances preclude such development. Any treatment specifically designated for bicycle use must meet the minimum design standards called for in the *AASHTO Guide* or the appropriate State standard.

Finally, these recommendations are preliminary and should be tested and refined over time. It is anticipated that this manual will be revised to reflect the continuing evolution of the state of the practice in selecting design treatments for roadways to accommodate shared use by bicycles and motor vehicles.

Table 6. Group A bicyclists, urban section, no parking.

average motor vehicle operating speed	average annual daily traffic (AADT) volume											
	less than 2,000				2,000-10,000				over 10,000			
	adequate sight distance		inadequate sight distance		adequate sight distance		inadequate sight distance		adequate sight distance		inadequate sight distance	
		truck, bus, rv	truck, bus, rv			truck, bus, rv	truck, bus, rv			truck, bus, rv	truck, bus, rv	
less than 30 mi/h	**sl** 12	**sl** 12	**wc** 14	**wc** 14	**sl** 12	**wc** 14	**wc** 14	**wc** 14	**wc** 14	**wc** 14	**wc** 14	**wc** 14
30-40 mi/h	**wc** 14	**wc** 14	**wc** 15	**wc** 15	**wc** 14	**wc** 15	**wc** 15	**wc** 15	**wc** 14	**wc** 15	**wc** 15	**wc** 15
41-50 mi/h	**wc** 15	**wc** 15	**wc** 15	**wc** 15	**wc** 15	**wc** 15	**sh** 6	**sh** 6	**wc** 15	**wc** 15	**sh** 6	**sh** 6
over 50 mi/h	**sh** 6	**sh** 6	**sh** 6	**sh** 6	**sh** 6	**sh** 6	**sh** 6	**sh** 6	**sh** 6	**sh** 6	**sh** 6	**sh** 6

Key:* **wc** = wide curb lane** **sh** = shoulder **sl** = shared lane** **bl** = bike lane **na** = not applicable

1 mi/h = 1.61 km/h

Table 7. Group A bicyclists, urban section, with parking.

average motor vehicle operating speed	annual average daily traffic volume (AADT)											
	less than 2,000				2,000 – 10,000				over 10,000			
	adequate sight distance		inadequate sight distance		adequate sight distance		inadequate sight distance		adequate sight distance		inadequate sight distance	
		truck, bus, rv	truck, bus, rv			truck, bus, rv	truck, bus, rv			truck, bus, rv	truck, bus, rv	
less than 30 mi/h	wc 14	wc 14	wc 14	wc 14	wc 14	wc 14	wc 14	wc 14	wc 14	wc 15	wc 15	wc 14
30–40 mi/h	wc 14	wc 14	wc 15	wc 15	wc 14	wc 15	wc 15	wc 15	wc 14	wc 15	wc 15	wc 15
41–50 mi/h	wc 15	wc 15	wc 15	wc 15	wc 15	wc 15	wc 16	wc 16	wc 15	wc 15	wc 16	wc 16
over 50 mi/h	na	na	na	na	na	na	na	na	na	na	na	na

Key: **wc** = wide curb lane **sh** = shoulder **sl** = shared lane **bl** = bike lane **na** = not applicable

1 mi/h = 1.61 km/h

Table 8. Group A bicyclists, rural section.

average motor vehicle operating speed	annual average daily traffic volume (AADT)											
	less than 2,000				2,000 – 10,000				over 10,000			
	adequate sight distance		inadequate sight distance		adequate sight distance		inadequate sight distance		adequate sight distance		inadequate sight distance	
		truck, bus, rv	truck, bus, rv			truck, bus, rv	truck, bus, rv			truck, bus, rv	truck, bus, rv	
less than 30 mi/h	**sl** 12	**sl** 12	**wc** 14	**wc** 14	**sl** 12	**wc** 14	**wc** 14	**wc** 14	**wc** 14	**wc** 14	**sh** 4	**sh** 4
30–40 mi/h	**wc** 14	**wc** 14	**sh** 4	**sh** 4	**wc** 14	**wc** 15	**sh** 4	**sh** 4	**sh** 4	**sh** 4	**sh** 4	**sh** 4
41–50 mi/h	**sh** 4	**sh** 4	**sh** 4	**sh** 4	**sh** 6	**sh** 6	**sh** 6	**sh** 6	**sh** 6	**sh** 6	**sh** 6	**sh** 6
over 50 mi/h	**sh** 4	**sh** 6	**sh** 6	**sh** 4	**sh** 6	**sh** 6	**sh** 6	**sh** 6	**sh** 6	**sh** 6	**sh** 6	**sh** 6

Key: **wc** = wide curb lane† **sh** = shoulder **sl** = shared lane **bl** = bike lane **na** = not applicable

1 mi/h = 1.61 km/h

†Note: a 12 ft. lane with a 2-3 ft. shoulder is an acceptable substitute.

Table 9. Group B/C bicyclists, urban section, no parking.

average motor vehicle operating speed	annual average daily traffic volume (AADT)											
	less than 2,000				2,000 – 10,000				over 10,000			
	adequate sight distance		inadequate sight distance		adequate sight distance		inadequate sight distance		adequate sight distance		inadequate sight distance	
		truck, bus, rv	truck, bus, rv			truck, bus, rv	truck, bus, rv			truck, bus, rv	truck, bus, rv	
less than 30 mi/h	**wc** **14**	**wc** **14**	**wc** **14**	**wc** **14**	**wc** **14**	**wc** **14**	**wc** **14**	**wc** **14**	**bl** **5**	**bl** **5**	**bl** **5**	**bl** **5**
30–40 mi/h	**bl** **5**	**bl** **5**	**bl** **5**	**bl** **5**	**bl** **5**	**bl** **6**	**bl** **6**	**bl** **5**	**bl** **5**	**bl** **6**	**bl** **6**	**bl** **5**
41–50 mi/h	**bl** **5**	**bl** **5**	**bl** **5**	**bl** **5**	**bl** **6**	**bl** **6**	**bl** **6**	**bl** **6**	**bl** **6**	**bl** **6**	**bl** **6**	**bl** **6**
over 50 mi/h	**bl** **6**	**bl** **6**	**bl** **6**	**bl** **6**	**bl** **6**	**bl** **6**	**bl** **6**	**bl** **6**	**bl** **6**	**bl** **6**	**bl** **6**	**bl** **6**

Key: **wc** = wide curb lane **sh** = shoulder **sl** = shared lane **bl** = bike lane **na** = not applicable

1 mi/h = 1.61 km/h

Table 10. Group B/C bicyclists, urban section, with parking.

average motor vehicle operating speed	annual average daily traffic volume (AADT)											
	less than 2,000				2,000 – 10,000				over 10,000			
	adequate sight distance		inadequate sight distance		adequate sight distance		inadequate sight distance		adequate sight distance		inadequate sight distance	
		truck, bus, rv				truck, bus, rv				truck, bus, rv		
less than 30 mi/h	wc 14	wc 14	wc 14	wc 14	wc 14	wc 14	wc 14	wc 14	bl 5	bl 5	bl 5	bl 5
30–40 mi/h	bl 5	bl 5	bl 5	bl 5	bl 5	bl 6	bl 6	bl 5	bl 6	bl 6	bl 6	bl 6
41–50 mi/h	bl 6	bl 6	bl 6	bl 6	bl 6	bl 6	bl 6	bl 6	bl 6	bl 6	bl 6	bl 6
over 50 mi/h	na	na	na	na	na	na	na	na	na	na	na	na

Key: **wc** = wide curb lane **sh** = shoulder **sl** = shared lane **bl** = bike lane **na** = not applicable

1 mi/h = 1.61 km/h

Table 11. Group B/C bicyclists, rural section.

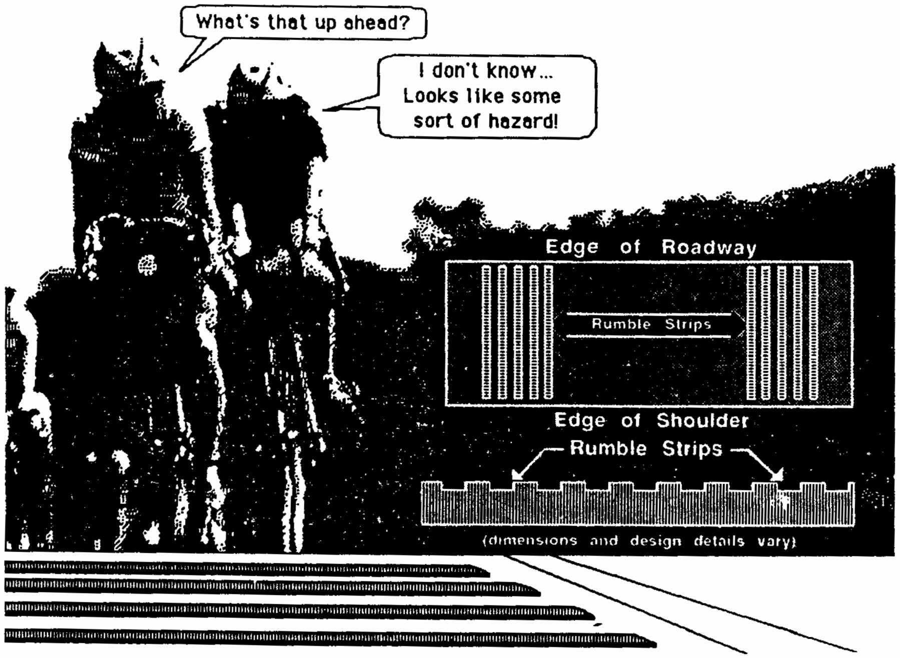
average motor vehicle operating speed	annual average daily traffic volume (AADT)											
	less than 2,000				2,000 – 10,000				over 10,000			
	adequate sight distance		inadequate sight distance		adequate sight distance		inadequate sight distance		adequate sight distance		inadequate sight distance	
		truck, bus, rv				truck, bus, rv				truck, bus, rv		
less than 30 mi/h	sh 4	sh 4	sh 4	sh 4	sh 4	sh 4	sh 4	sh 4	sh 4	sh 4	sh 4	sh 4
30–40 mi/h	sh 4	sh 4	sh 4	sh 4	sh 4	sh 6	sh 6	sh 4	sh 6	sh 6	sh 6	sh 6
41–50 mi/h	sh 6	sh 6	sh 6	sh 6	sh 6	sh 6	sh 6	sh 6	sh 6	sh 6	sh 6	sh 6
over 50 mi/h	sh 6	sh 6	sh 6	sh 6	sh 8	sh 8	sh 8	sh 8	sh 8	sh 8	sh 8	sh 8

Key: **wc** = wide curb lane **sh** = shoulder **sl** = shared lane **bl** = bike lane **na** = not applicable

1 mi/h = 1.61 km/h

APPENDIX 1

RUMBLE STRIPS AND BICYCLE WHEELS[62]



Rumble Strips and Bicycle Wheels

Are these 'countermeasures' coming to your state? *by John Williams*

Recently, the Montana Department of Highways began installing rumble strips on the shoulders of rural highways. They did this as a test with the intention of installing more if these proved successful.

Rumble strips are devices placed along the edge of a roadway and are used to wake up sleepy, inattentive or intoxicated drivers by producing either a noise or a vibration or both. Some are raised bumps, while others are depressions. They are installed roughly perpendicular to the direction of travel; some run continuously along the road edge while others are spaced at 50' or longer intervals.

The new interest in rumble strips seems to be at least partly the result of a Federal Highway Administration Notice issued in 1986. The text of the Notice is included in the accompanying sidebar.

As a cycling organization, Bikecentennial was naturally concerned when we learned of Montana's experiment and we alerted our local members. They, in turn, voiced their objections to the Highway Department, who then reconsidered their previous approach and issued a Draft Policy on Rumble Strips.

The Draft Policy was a significant step in the right direction, in that it addressed some of the safety concerns of cyclists and it limited use of rumble strips to the traffic-side of wide highway shoulders. However, we were still leery of the whole approach. In preparing our response to the Draft Policy, we considered the national implications of a heightened interest in rumble strips and decided to find out what some of the most progressive cycling states were doing. Here's what we learned:

From Dick Unrein, Bicycle Program Manager of the Oregon Department of Transportation, we learned that *"no rumble strips are used in Oregon at the present time. The main disadvantages are the reluctance of slow-moving traffic to use the shoulder area and the potential liability issues from bicycle accidents."*

Rick Knapp, Deputy District Director for the California Department of Transportation District One Office, sent us a copy of CalTrans Policy & Procedure Memo P78-14, which specifically rejects rumble strip treatments where bicycle traffic is allowed.

It says *"Asphalt concrete dikes, raised traffic bars or other similar devices shall not be placed between the traveled way and paved roadway shoulders. These devices represent a hazard to bicyclists and motorists and prevent bicyclists from entering and exiting the shoulder area."*

Mr. Knapp was one of the principal authors of the CalTrans Standard, which was the model used in developing the 1981 AASHTO Guide for the Design of Bicycle Facilities. He mentioned liability and safety as their primary concerns with respect to rumble strips.

Paul Graham of the Ohio Department of Transportation said that *"Our shoulder policy specifically states that rumble strips shall not be extended across shoulders or other areas intended for bicycle travel. The only alternative that has been tried that I know of is a 'reverse' rumble strip. This is an indentation pressed into a concrete shoulder. However, this feature happens to be along a section of I-70, on which bicycles are prohibited to travel by law.*

"If you had a wide enough shoulder, you could try installing rumble strips (or reverse ones) on just the half abutting the lane. That way, a bicyclist could leave the travel lane if necessary and only hit a bump or two before coming to the smooth half of the shoulder which would accommodate bicycle travel. This would provide a good area to travel until the bicyclist could get back into the travel lane."

S. A. Moon, Locations-Design Engineer for the Washington State Department of Transportation sent us copies of their Rumble Strip Policy, which was developed with input from the State's Bicycling Advisory Committee. He mentions in his letter that *"These are being placed and tested in areas of high numbers of 'run off road' accidents."*

According to Don Lund of Moon's office, to date, there are two locations in the State of Washington with rumble strips, both of which had serious run-off-the-road accident problems. Further, the Policy states that *"where bicycles are of a concern, and shoulders are six feet or more, leaving a three-foot minimum untextured strip on the outside edge of the shoulder allows bicyclists to be separated from traffic."*

Alex Sorton, Associate Director of the Engineering Division of the Traffic Institute, in conversation with the author, suggested that rumble strips only be used on wide shoulders (eight feet or greater) where there is a demonstrated history of run-off-the-road accidents.

In such situations, he suggested keeping the rumble strips narrow (perhaps as narrow as one foot) to maximize the useable width of the shoulder.

Mr. Sorton said that narrow shoulders (four feet wide, for example) would likely not benefit from placement of rumble strips because, without a recovery area beyond, a sleepy motorist would be off the road before he or she was able to wake up and react. Further, he stated that such rumble strips would be potentially dangerous for cyclists who would be forced to ride in the traffic lane on high speed roadways.

According to the FHWA Notice itself, *"Shoulder-texture treatments are recommended for use when resurfacing highways with long tangent or monotonous sections and a history of run-off-the-road accidents. On other sections of highways with high run-off-the-road accident histories, the FHWA encourages consideration of these treatments because of their low cost and potentially high benefit/cost ratios. Where these treatments are installed, the highway agency should evaluate their effectiveness."*

It goes on to say, *"If bicycling is desired on the shoulder, the type of treatment and its benefit should be weighed against the probability that bicyclists will ride in the traveled way to avoid them. The decision to use a shoulder-texture treatment or the exact design should be determined on a case-by-case basis."* It further quotes research that has shown that *"accident reductions of 20% were observed on rural Interstate sections with long tangents or gently curving alignments."*

Further Considerations

According to the best available car/bike accident study (Cross 1977), rural roadways tend to be the locations for one of the most serious accident types: overtaking. Nationwide, roughly 250 cyclists per year are killed and another 1600 seriously injured when a motorist fails to overtake in a safe manner.

U.S. Department of Transportation
Federal Highway Administration Notice
Shoulder Texture Treatments for Safety
N 7560.9 April 28, 1986
Expiration Date: April 28, 1987

1. Purpose: To endorse the use of and encourage implementation of special shoulder-texture treatments as an effective method of improving highway safety. Special shoulder-texture treatments can effectively supplement other activities undertaken to improve highway safety through special delineation and pavement markings.

2. Background: Several State highway agencies are implementing shoulder-texture treatments as a countermeasure to reduce run-off-the-road accidents on long highway sections. Recent research studies, including a study sponsored by the Federal Highway Administration (FHWA) titled "Effects of Shoulder-Texture Treatments on Safety," by AMAF Industries, Inc., have concluded such treatments can be effective in reducing run-off-the-road accidents on long sections of highway which may be monotonous to drivers. Accident reductions of 20 percent were observed on rural Interstate sections with long tangents or gently curving alignments. This type of treatment may be particularly effective when drivers may be drowsy, under the influence of alcohol, or otherwise inattentive. The AMAF study found found that with construction costs reaching as low as $.07 per foot, very high benefit/cost ratios of up to 50:1 occurred. In another study, Nevada's evaluation of the bituminous indented strip showed a benefit/cost ratio of 33:1. The Nevada study was based on over 700 miles installed at a cost of approximately $300 per mile.

3. Current Practices: Shoulder-texture treatments can be implemented on newly-constructed shoulders, resurfaced shoulders, or on existing shoulders (either portland cement concrete or bituminous). Descriptions of several current methods are included in the Attachment to this Notice. Although no significant maintenance problems have been identified with these treatments, certain precautions should be taken:

a. In areas requiring snowplowing, raised treatments should not be used and quality control procedures for depressed or indented treatments should ensure that the pavement cross slope is not distorted (hence causing a snowplowing problem).

b. Depressed treatments may "silt up" in areas where aggregates are used for treating "icy road" conditions. Other treatments may be considered such as surface treatment on bituminous shoulders.

c. Care should be taken to ensure that roadway surface drainage is not affected by shoulder-texture treatments. An offset from the longitudinal lane-shoulder joint is recommended to facilitate joint sealing and minimizing surface water infiltration.

d. Design thickness of new shoulders should consider the loss of section if depressed treatments are used. Information on shoulder design is contained in FHWA Technical Advisory T 5040.18, Paved Shoulders, dated July 29, 1982.

4. Application:

a. Shoulder-texture treatments are recommended for use when resurfacing highways with long tangent or monotonous sections and a history of run-off-the-road accidents. On other sections of highways with high run-off-the-road accident histories, the FHWA encourages consideration of these treatments because of their low cost and potentially high benefit/cost ratios. Where these treatments are installed, the highway agency should evaluate their effectiveness.

b. If bicycling is desired on the shoulder, the type of treatment and its benefit should be weighed against the probability that bicyclists will ride in the traveled way to avoid them. The decision whether to use a shoulder-texture treatment or the exact design should be determined on a case-by-case basis.

5. ADDITIONAL INFORMATION: Additional information is available in a short slide/audio tape presentation distributed to all FHWA regional and division offices by memorandum dated May 9, 1985, from the Offices of Implementation and Highway Safety. The research report number, FHWA/RD-85/027, "Effects of Shoulder-Texture Treatments on Safety" has been printed and distributed to all regional and division offices. Copies of the report are available for official use while the supplies last from the FHWA, Research, Development and Technological Report Center, HRD-11, 6300 Georgetown Pike, McLean, VA 22101. Additional copies for the public are available from the National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161. A charge may be imposed for each copy ordered from the NTIS.

6. CONTACT: Further information can be obtained by contacting the Office of Highway Safety at (202) 426-2131.

R. Clarke Bennett
Director, Office of Highway Safety

Factors in these collisions include:

- Narrow roadways without rideable shoulders
- Most often two travel lanes
- High speed limits

With these factors in mind, it is easy to imagine rumble strips contributing to the problem, especially when installed on narrow shoulders. These strips would force the cyclist closer to the passing stream of

high speed traffic. And, it goes without saying that accidents involving high speed motorists tend to be fatal for the cyclist.

According to the Background section of the FHWA Notice, "This type of treatment may be particularly effective when drivers may be drowsy, under the influence of alcohol, or otherwise inattentive."

These are precisely the situations in which overtaking car/bike accidents happen. For example, approximately 30% of all drivers involved in overtaking crashes had been drinking. In many more cases, the motorist involved 'just didn't see the bicyclist in time.' The accident typically happens after dark, when drivers are also most likely to be "drowsy".

Thus, it seems likely that a blanket policy of rumble strip treatments would save some lives—drunk drivers, for example—at the expense of lawfully riding cyclists.

Next, cyclists, like other road users need to cross the roadway at various places. They do this in order to turn left or to avoid an object in their path—for example, a disabled car. If cyclists have to pay undue attention to the roadway itself, in order to avoid crashing on the rumble strips, this will make it harder to pay attention to traffic. Clearly, anything that distracts cyclists from the task at hand is hazardous to their safety.

Further, debris tends to accumulate on the highway shoulders. In the "Snow Belt" after a winter of sanding and plowing, there is often little more than a narrow strip of clean pavement to the right of the edge line. Rumble strips just to the right of the edge stripe may well exacerbate this problem by forcing the cyclists to ride either in the travel lane or off in the sand and debris.

Even in parts of the country with mild climates, debris tends to accumulate on the shoulders. Bottles, cans, old tires, mufflers...these are some of the obstructions found on the extreme right edge of the pavement. Cyclists will do all they can to avoid these.

Our Recommendations

With these factors in mind, we suggest that states looking at rumble strip policies consider the following:

1. Overall, since rumble strips constitute a hazard for bicycle travel, they should not be used where bicyclists are allowed. Bicyclists are legitimate users of the roadways and their safety should not be compromised in an attempt to solve other problems.

2. When deemed necessary, rumble strips should be only used as FHWA suggested in their Notice: as a "supplement [to] other activities undertaken to improve highway safety through special delineation and pavement markings." In fact, strong enforcement of drunk driving laws (and stiff penalties) may well do more for run-off-the-road accidents than a blanket policy of providing rumble strips. Further, since the best results from the use of rumble strips are only on the order of a 20% reduction, they should certainly not be the first countermeasure considered when a problem is identified.

3. Highway Departments should *only* consider rumble strips where there is a well-documented safety problem rather than as a general practice. This would mean using rumble strips as specific countermeasures to identified problems.

4. On narrow roadways with shoulders less than eight feet in width, rumble strips are inappropriate. Their utility is questionable when there is no recovery area beyond and they seriously jeopardize the safety of all cyclists using these roadways.

5. Rumble strips should not be used on sections where there are intersections or driveways. Such sections would tend to happen closer to towns and would be more likely to have young riders and riders crossing the roadway. These would tend not to be the places where run-off-the-road accidents occur anyway.

6. Further, we suggest experimenting with rumble strips narrower than three feet. According to Alex Sorton of the Traffic Institute, the Cook County Road Department is trying these and we suspect they'd have nearly the same effect as wider ones AND they would leave more of the shoulder useable. Further study on this topic is needed.

7. Finally, designers should develop rumble strip treatments that do not impair the safety of the cycling public. Clearly, accident countermeasures should not cause accident problems of their own.

APPENDIX 2. USE OF FREEWAY SHOULDER BY BICYCLISTS

Concern of the Engineer and View of the Bicyclist
CALTRANS[68]

CHILDREN ON FREEWAY

(Concern) Opening of freeway shoulders to bicyclists will allow "child cyclists" with their inherent unpredictable behavior to travel or the "play on the freeway."

(Response) The same concern holds true for major nonfreeway routes. The problem, however, is almost nonexistent despite the fact that some nonfreeway routes are even more of a hazard. The reason for this is quite obvious. The types of trips that children take are short—to a friend's home, to the grocery store or to school. Their pattern of travel does not fit the freeway mode. Another reason is that the trips children make are near homes and, therefore, in an area where a street or road pattern exists. Even in highly developed residential areas, there has never been a real problem with children on freeways despite the fact that many young bicyclists are not able to read the signs prohibiting bicycles. Parental supervision and guidance plus the child's lack of desire to use the freeway keep them off now, not our signing. No significant problem has been evident where freeways are now open to bicyclists.

HIGH ADT ON FREEWAYS

(Concern) High ADTs on the freeway make it less safe for bicyclists. The higher ADT also creates more disabled vehicles parked on the shoulders requiring bicyclists to encroach on the traffic lane. Additional trucks create turbulence when overtaking and passing the bicyclist.

(Response) The volume of vehicular flow has little effect on its relative safety for the bicyclist on the shoulder. In fact, the sweeping action of the truck turbulence tends to produce a clean shoulder thus allowing the bicyclist to ride further out on the shoulder and thereby minimizing conflicts. Bicyclists must always contend with the "parked vehicle on the shoulder" which is a far greater problem on local streets and roads than on a freeway. Obviously, care would have to be exercised when passing a parked vehicle on any high volume route. Few bicyclists would opt to ride any route with a high volume of truck traffic unless there is no reasonable alternate route.

SHOULDER WIDTH

(Concern) Narrow shoulders are a hazard for bicyclists.

(Response) Shoulder width is a concern to bicyclists regardless of the type of facility. However, freeways usually have a minimum four-foot shoulder, which is considered adequate by bicyclists if maintained. Normally, shoulders are less than four feet only in mountainous areas where the constructed shoulder width has not been maintained, or in metropolitan areas where the freeway has been restriped for additional lanes. In the former situation, ADTs are usually less. In the latter case, bicyclists would normally not be permitted on the freeway. The problem of narrow shoulders can often be helped by placing the edge stripe in the 12-ft position rather than encroaching on an already narrow shoulder. One must keep in mind that the shoulders on the alternative route are probably even narrower. It should also be pointed out that the narrower shoulders tend to be swept clean for more of its width due to the flow of traffic.

INTERCHANGES

(**Concern**) Crossing high-volume ramps or weaving and merge areas are hazardous to bicyclists.

(**Response**) High-volume ramps and weaving sections are a real concern to bicyclists. These features, however, usually exist only in the urban setting where the bicyclist usually will be using the local network of streets—not the freeway. Bicyclists avoid this type of situation. Remember, the bicyclist desiring to use the freeway is the long trip experienced rider. He is well aware of the difficulty of crossing a high-volume ramp with his back to traffic. Where high-volume ramps create a problem, bicyclists can usually be routed over the ramps themselves, exiting and reentering the freeway on the ramp shoulders, thus avoiding any conflict with ramp traffic. At some locations, a separate bike path may be necessary to provide routing around a specific barrier. Since the number one desire of bicyclists is to use freeways only to close gaps in otherwise usable routes, the high-volume ramp problem is minimized.

SHOULDER MAINTENANCE

(**Concern**) Shoulders will require more maintenance to provide adequate width free of debris.

(**Response**) The lack of maintenance is of concern to the bicyclist. At present, almost no effort is spent to keep the shoulders free of debris. This will require some education of our maintenance personnel, and an altering of priorities.

Debris-covered shoulders require the bicyclist to ride nearer the traffic or even onto the outside lane, creating conflict problems. This problem is compounded on long downhills where speed is usually higher and evasive action by the bicyclist must be anticipated further in advance. It appears that other than the debris problem, very little maintenance will be required.

BRIDGES

(**Concern**) Narrow bridges exist along freeways with approach shoulders of adequate width. Also, the height of bridge rail is not adequate for cyclists.

(**Response**) Bicyclists recognize the problem of narrow bridges. This is especially critical on a long bridge. A responsible bicyclist could probably handle a short bridge by waiting for a break in motorized traffic. Here, ADT could have a bearing as it would affect the break in traffic. Longer bridges with no shoulders, on an otherwise adequate section of freeway, may need to be widened or provided with a outboard walkway if the user demand dictates. In the case of a structure or an interchange, it may be possible to route the bicyclist around the bottleneck by use of the ramps or with a short bicycle path. Each case must be studied individually.

Railing height is not a really critical issue, especially on a bridge with wide shoulders. Obviously, some barrier is quite comforting, particularly on a high-level structure. However, less than the recommended 4-ft minimum can be tolerated. If railing height is a real problem, it may be necessary to raise the railing. In any case, a low railing in itself should never be a reason to prohibit bicycles.

NIGHT USE

(Concern) There could be a visibility problem with present law requiring only a red reflector on the rear of the bicycle.

(Response) Most freeway riding takes place during daylight hours. Those opting for night riding generally provide more lighting than legally required in order to give themselves maximum visibility. Ankle lights, flashing beacons, rear lights, etc., are currently available and usually used by night riders. Bicyclists would most likely restrict their riding on narrow shoulder freeways to daylight hours. Even with the best of bicycle headlights, it is difficult to see all of the hazardous debris that accumulates along the shoulders. The experienced bicyclists are well aware of this hazard and avoid night travel. Further, the visibility problems would be less on a freeway with wide shoulders than on an alternate local road with little or no shoulder.

APPENDIX 3. BICYCLE USE OF CONTROLLED ACCESS FREEWAY SHOULDERS

Assessment of Alternative Routes
Pima Association of Governments[17]

If an alternative to a controlled access freeway segment proves to be both safer and more reasonably convenient as a result of applying level one of this systematic evaluation procedure, then a more extensive level two investigation of that alternative route's safety and convenience for bicycle travel is warranted. If the evaluation so indicates, or if there is no alternate route, the freeway segment should be opened to serve bicycle travel needs.

METHODOLOGY FOR DETERMINATION OF REASONABLE CONVENIENCE

Reasonable convenience to the bicyclist will vary depending on the distance of the trip involved. Various cyclists with different levels of riding experience were interviewed to help determine and quantify acceptable additions to travel distances for alternate routes which are as safe or safer than a controlled access freeway segment being considered. The material in the chart below was developed to provide standards for the extent of route diversion acceptable while still providing for reasonable convenience.

Standards for acceptable route diversion

Interstate Trip Distance(miles)	Max. Ratio of Alt. Rt. Dist. of Interstate Rte. Dist.	Resultant Max. Added Trvl Time(min)*
0 - 25	1.20	25
26 - 50	1.15	38
51 - 100	1.10	50
101 or more	1.05	varies

* figured at 12 mph

It can be persuasively argued that people traveling by bicycle should be able to choose a travel route requiring the least travel time, as do motor vehicle operators. However, until more experience and data become available, and are analyzed, these standards can serve.

METHODOLOGY FOR DETERMINATION OF SAFETY

A quantitative method for defining the safety level of alternate routes complements the method described above for determining reasonable convenience, and together they will allow definitive recommendations regarding those portions of the rural Interstate Highway System in Arizona which should be opened to bicycle traffic.

According to work accomplished by the Colorado Department of Transportation there are a variety of measurable factors which directly influence highway safety for bicyclists. These include, in no particular order: sight distances, traffic mix, grades, conflicts with parked vehicles, lane width, traffic volume, miscellaneous hazards, (i.e. cattleguards), roadway and shoulder surface condition, cross traffic, and traffic speed. Another factor which is valuable in assessing highway safety for bicyclists is the rate for accidents which involve single vehicles (Cross' study found that 37.8 percent of all fatalities experienced by bicyclists occurred when an overtaking motorist struck the bicyclist from the rear -- mostly on rural roads). The single vehicle accident rate is the most effective quantitative indicator of how frequently drivers using a specific road tend to stray off the road, whether due to environmental or operator characteristics.

Level One Safety Evaluation: Of the eleven factors identified above, there are five which are available for all Interstate Highways in Arizona, as well as for virtually all potential alternate routes. These include traffic volume, speed, roadway width (including paved shoulder), lane width, and daytime single vehicle accident rate. These measures, either singly or in combination, represent the major roadway structural and operational elements affecting bicycle safety.

Of the 37.8 percent of bicyclist fatalities resulting from overtaking vehicles, more than 30% had characteristics which strongly suggest the significant influence of roadway lane width and traffic speed and volume, on safety, or lack thereof, for bicyclists. For this reason, and the ease of availability of these factors, values derived from them can provide simple, quick, and sound alternative route bicyclist safety evaluations. The three specific measures to be used include:

1. Daytime single vehicle accident rate.

2. Traffic volume per lane vs. roadway lane width.

3. Traffic speed vs. roadway lane width.

Direct comparison of the Interstate segment being considered with the identified alternate route(s) can take place, using the quantification of these three measures, as described below.

- *Daytime Single Vehicle Accident Rate:* Either available, or computable from available accident data. Expressed as the number of accidents per aggregate of distance of travel (i.e., 5.3 per 1,000,000 vehicle miles of travel). The route with the lowest rate would receive 0 points and the route with the highest rate 5 points. Any route between these two extremes would receive a proportional number of points based on its relative rate.

- *Traffic Volume Per Lane vs. Roadway Lane Width:* Each route being evaluated would receive a point score based on the chart shown in figure 7.

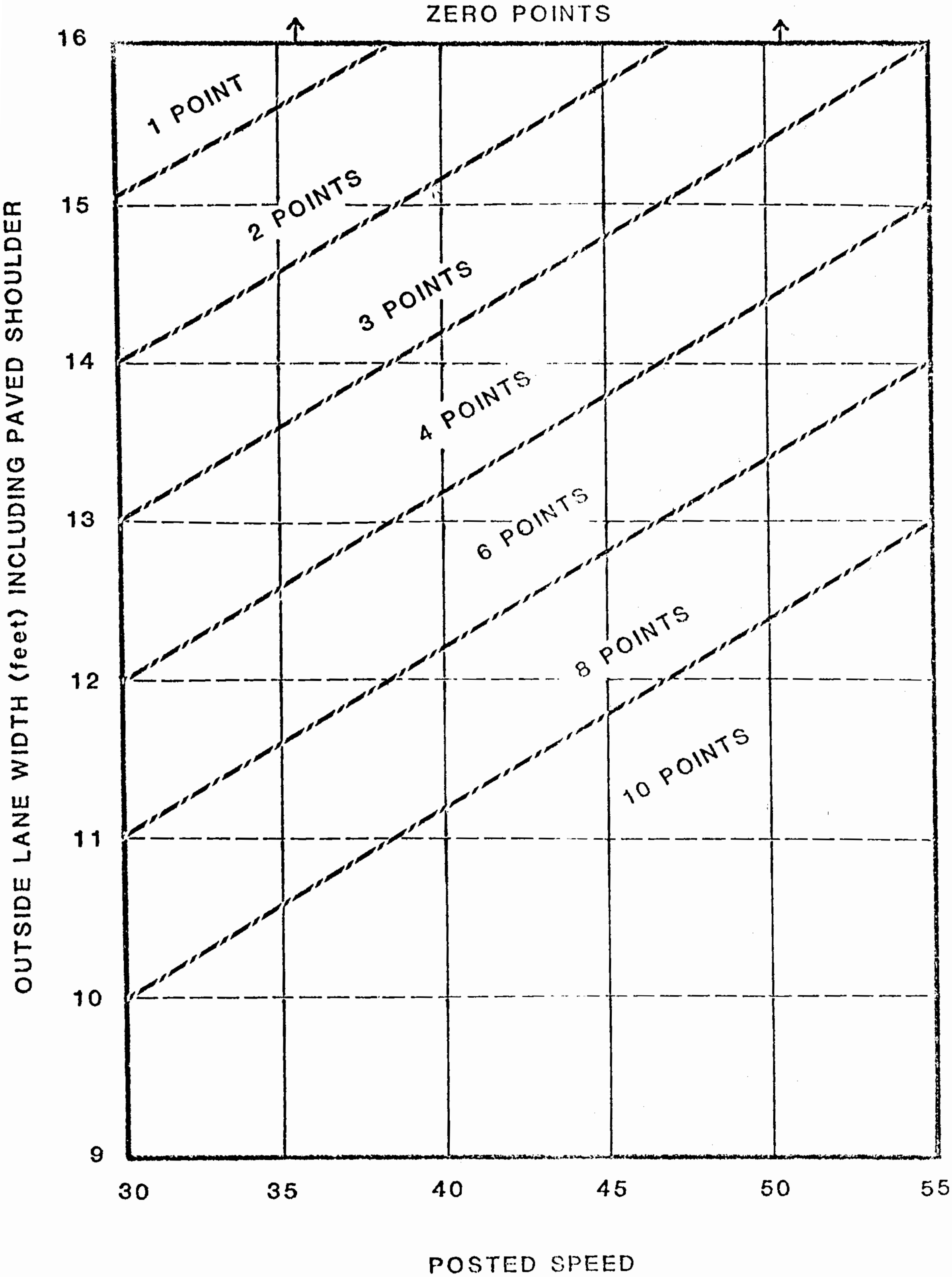


Figure 7. Traffic volume per lane vs roadway width.

- *Traffic Speed vs. Roadway Lane Width:* Each route being evaluated would receive a point score based on the chart shown in figure 8. The speed to be used would be the posted speed.

- *Composite Safety and Convenience Assessment:* Each route being considered will have a composite Safety Score, as a result of the above analyses, and a reasonable convenience determination. An alternate route will warrant a more detailed evaluation if two conditions are met: (1) the route is safer, based on its point score; and (2) the route's distance does not exceed the distance allowed as a result of applying the Standards for Acceptable Route Diversion.

Level Two Safety Evaluation: If the alternate route warrants further evaluation, such evaluation should include, in addition to the measures already used, those listed below. In each case, the points are assigned to the route as a whole, not on a per mile or similar basis.

- Roadway or Shoulder Surface 0 to 10 points

Surface condition of the roadway is important to bicyclists. A continuous, smooth asphalt surface is the most desirable and would rate a "0". Asphalt or concrete with cracking or raised seams which would cause an uncomfortable ride would rate 4 to 6 points. Severe cracking, numerous potholes, and conditions which could cause damage to the wheels of the bike, or cause the bicyclist to swerve excessively or to lose control of the bicycle, would rate 9 or 10 points. Freeway shoulder rumble grooves which run continuous to the shoulder edge would rate 6 to 8 points, grooves filled partially for bicycles would rate 2 to 4 points, and grooves installed according to a "bikeable" design would rate 0.

- Potential Conflicts with Parked Cars 0 to 5 points

These conflicts will typically be found in towns or cities. If there is no parking, or where parking is not a potential hazard, score 0. If there is parallel parking, score 2.5 points; score 5 points for diagonal parking.

- Grades 0 to 5 points

Grades may be a source of problems. Score as indicated on figure 9. If grades are unknown, estimate them.

- Sight Distance 0 to 5 points

Score 0 if sight distance is not a potential problem. Score up to 5 points, depending on the degree to which sight distance presents a problem.

- Miscellaneous Roadway Hazards 0 to 5 points

Railroad crossing, cattle guards, drainage grates, and areas which have excessive loose gravel on the paved surface (normally found where a gravel road intersects a paved

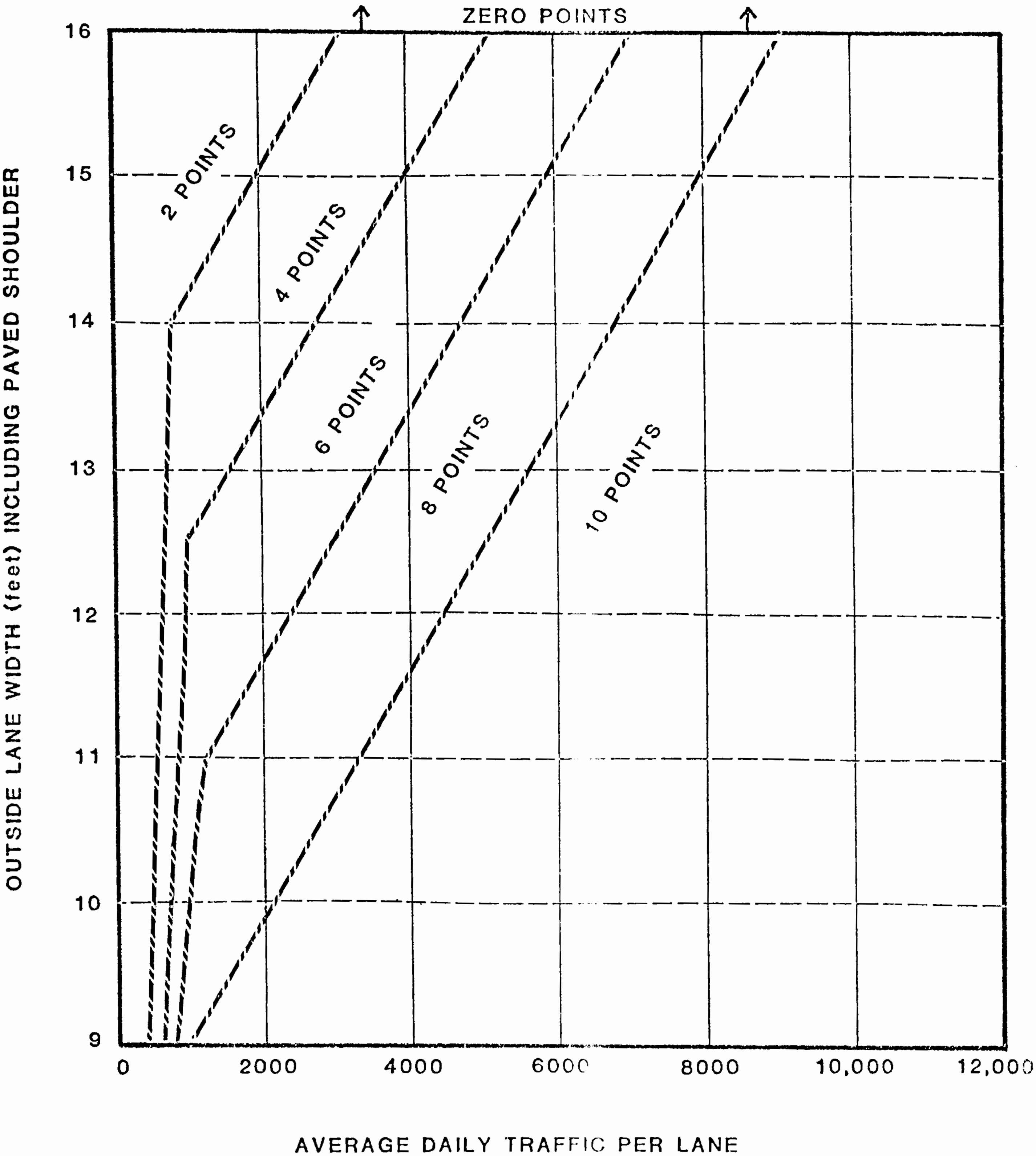


Figure 8. Traffic speed vs roadway lane width.

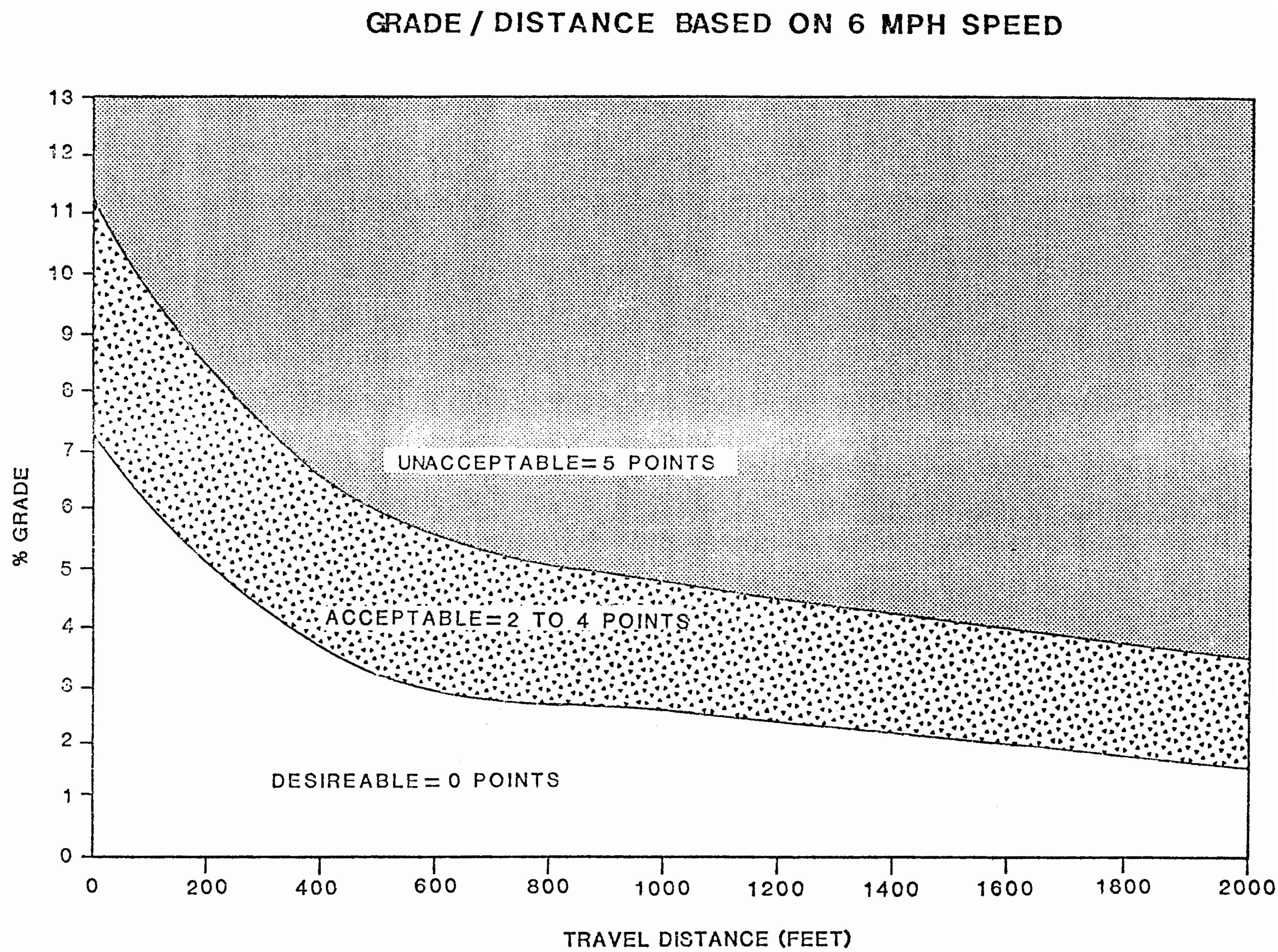


Figure 9. Roadway grades.

road). Identify the specific hazard and its location. Cattle guard score 5. Railroad crossing 3 to 5 depending on condition. Drainage grate, score 5; if bicycle proof, identify and score 0; if striped to indicate grates presence, score 1. Loose gravel, score 3 to 5 points.

- Traffic Mix 0 to 5 points

The percentage that trucks represent of the total average daily traffic (ADT). Less than 1% score 0 points, 1 to 5% score 1 point. 6 to 10% score 3 points, and over 10% score 5 points. Include Recreational Vehicles (including pickups with campers, cars pulling trailers) as trucks in your estimate. This will occur most frequently near camp grounds, points of interest, and recreational attractions.

- Potential Cross Traffic Conflicts 0 to 5 points

Assign an estimated point value to this potential safety hazard. This will result from an intersection with a high volume street, several intersecting streets, or a commercial area.

- Secondary Composite Safety and Convenience Assessment: The same evaluation should then be applied to the Interstate segment. The point score can then be compared, with the route having the lowest point score being indicated as the most appropriate route for bicycle travel. If the two routes score within 5 points of each other, they should be considered equal, and the route with the shortest distance identified as the most appropriate route for bicycle travel.

If a freeway segment has no parallel alternative route, then no evaluation is required. Such segments should be opened to bicycle travel without delay.

APPENDIX 4

FEASIBILITY OF PAVING SHOULDERS ON LOW ADT ROADWAYS

(AD-75)

CORRESPONDENCE/MEMORANDUM — STATE OF WISCONSIN

Date: October 29, 1986 *File Ref:*

To: D. L. Strand, P.E.
State Design Engineer for Hwys.

From: C. E. Solberg, P.E.
Chief Methods Development Engineer

Subject: Feasibility of Paving Shoulder on Low ADT Highways

Recommendations

It is recommended that the present shoulder paving policy be revised such that 3' paved shoulders would be required on any state trunk highway with an ADT of 1000 or more. This recommendation is based on the result of an economic analysis of paved shoulders and review of the opinions of the District personnel. Although the results of the económic analysis indicate that benefit/cost ratio is less than 1.00 for 1000 ADT roads, the values which did result coupled with intangibles, such as the overwhelming support of District personnel and the general public, indicate that this position is responsible.

District Opinions

It is the unanimous opinion of the District personnel who responded that paved shoulders on highways with ADT's of 1000 or more is a good idea. The most common items mentioned with regard to the benefits of paved shoulders are improved safety and reduced maintenance costs. Also commonly mentioned is the overwhelming positive response from the public. This factor cannot be measured on a monetary scale but is an important factor.

Economic Analysis

SUMMARY: An examination of the effectiveness of paved shoulders in reducing accidents and maintenance costs has been completed. The results indicate that 3-foot paved shoulders are cost effective when initial ADT is higher than 1640 for virgin mixes (initial cost = $12,700/mile) and 1085 for recycled mixes (initial cost = $7,800/mile).

A summary of the results of the analysis appear below:

Virgin Mix:

Initial ADT	Initial Cost	Accident Benefits*	Maintenance Benefits*	Total Benefits*	B/C
1000	$12,700	$ 5,545	$1,500	$ 7,045	0.55
1500	$12,700	$ 9,975	$1,305	$11,280	0.89
2000	$12,700	$14,400	$2,145	$16,545	1.30

Recycled Mix:

Initial ADT	Initial Cost	Accident Benefits*	Maintenance Benefits*	Total Benefits*	B/C
1000	$7,800	$5,545	$1,500	$7,045	0.90
1500	$7,800	$9,975	$1,305	$11,280	1.45
2000	$7,800	$14,400	$2,145	$16,545	2.12

All cost values are per mile of highway.
*Benefits converted to present worth.

PROCEDURE: The initial data set used in this analysis included only 1984 data (it is planned to check this procedure using 1985 data when it becomes available). This data set was built by Mike Maierle (Planning and Data Processing) using the Accident File, Event File, and Deficiency File. These files do not always agree with one another. Therefore, much of the data had to be deleted due to internal inconsistencies between the files. The data set represents 90% of the pavements being examined and defines the characteristics of non-animal accidents on rural two-lane highways (excluding intersections).

Initially, it was planned to examine individual segments (typically 1-2 miles) of highway with similar geometrics in an attempt to create an accident prediction model. Approximately 20 models were examined. The results of this analysis indicated that total shoulder width, the width of paved shoulder, and ADT were most important in defining accidents. However, an accurate prediction model could not be built due to the wild variability of accidents in a single segment of highway.

The next step was to combine segments with similar levels of ADT. Groups of ADT had a range of ±125 and included data on highway segments between 125 and 5125 ADT. Since shoulder width was found to significantly influence accident rate only pavements with a 6' to 10' shoulder were examined. Two regression models were created, one for unpaved shoulders and one for 3' paved shoulders, which predicted accidents/mile of highway.

The final step was to examine the costs and benefits associated with paved shoulders. An examination of accident severity indicated that there were approximately 30% more fatal accidents on highways with unpaved shoulders; therefore, the average cost per accident was different ($9,160 for unpaved, $7,455 for 3' paved). The number of accidents/mile was determined using the regression models. The total number of accidents was multiplied by the cost/accident in order to get an annual cost for accidents. These values were subtracted resulting in annual benefits on highways with 3' paved shoulders, due to accident reduction. These values were then converted to present worth.

Maintenance benefits were calculated based on data provided by C. O. Maintenance. These values were also converted to present worth. Summing the annual benefits for accident reduction and maintenance cost reduction resulted in total benefits.

Initial cost data for paved shoulders was collected from District Offices and the Pavement Design Engineer, Gerry Burns. These values were $12,700/mile for virgin mixes and $7,800/mile for recycled mixes. The data gathered from the Districts is summarized below:

District	Virgin Mix	Cost Per Mile Recycled Mix
1	$ 5,925	$ 4,300
2	$12,000	$12,000
3	$11,200	$8,700
4	$10,050	$6,325
5	$13,300	$9,000
6	$16,000	$11,600
7	$ 9,700	$ 8,700
8	$11,160	$9,800
Average	$11,170	$8,803

It should be noted that these values are extremely variable. This complicated the decision as to what value to use for initial cost. It was decided to use the values provided by Mr. Burns rather than using those provided by the Districts since this data would be more representative of the state as a whole. Furthermore, this data was based on a consistent design for the shoulder.

Other assumptions made in this analysis include a 2% annual increase in traffic; an annual interest rate of 5%; a 15 year design life; and accident cost of $200,000/fatal accident, $8,000/injury accident and $1,090/PD. accident.

During the course of analysis, it was thought that perhaps a policy could be derived based solely on achieving a B/C of 1 or more. This idea was rejected. If it were adopted, there would be no consistency statewide for paving shoulders. This would result in adding a degree of complexity to the design and programming process which would be intolerable.

System Impact

Initially, the estimated annual impact on the highway program was $1.63 million annually (assumes completion in 20 years). This estimate was based on an initial cost of $14,000/mile for the paved shoulders. With additional data, it has been found that an average initial cost of $9,270/mile is more reasonable (assumes 70% recycled mix and 30% virgin mix). Using this revised estimate, and the recommendation of paving shoulders on all highways with 1000 ADT or more, the total annual impact on the program is $1.08 million.

If we assume that the average cost of a new pavement is $640,000/mile or resurfacing is $145,000/mile, the impact of paving shoulders would result in a reduction of 1.7 miles of new pavement or 7.5 miles of resurfacing.

Summary

It is recommended that the shoulder paving policy be revised such that highways with ADT's of 1000 or more include paved shoulders. This recommendation is economically justified to a point (1640 ADT for virgin mixes and 1085 for recycled mixes). However, the overwhelming support of highway users for paved shoulders should be considered. Impact on the highway program would be approximately $1.08 million annually.

CES:DAF:e0226
Attachments

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