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Bicycle Safety-Related Research Synthesis

Research and Development
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FOREWORD

The early 1970's saw the United States in the middle of an oil crisis, causing many Americans to look for alternatives to automobiles. Bicycling became popular, and thousands of miles of special bicycle facilities were constructed from coast to coast. Twenty years later, once again, interest in bicycling is high. New Federal legislation, such as the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) and the 1990 Clean Air Act Amendments, and publication of the National Bicycling and Walking Study create a favorable atmosphere for bicycling in the 1990's.

This report is a synthesis of bicycle safety-related research and applied research since 1981 in the United States. This report updates an earlier synthesis prepared for the Federal Highway Administration in 1981. This current synthesis should update researchers and practitioners with what has been tried, tested, and evaluated since the initial synthesis. This report also identifies the gaps in bicycle safety research and integrates experience from countries that have devoted a significant amount of research to increasing bicycle use and safety.

The information contained in this report should be of interest to design engineers, transportation planners, and transportation engineers involved in the design, construction, and/or reconstruction of facilities within the highway system.

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

NOTICE

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16. Abstract

This research synthesis is designed to summarize bicycle safety-related research and applied research since 1981 in the United States. The report has been developed for the benefit of researchers and practitioners in the field. The report updates an earlier synthesis prepared for the Federal Highway Administration in 1981.

The report reviews research into current levels of bicycle use, potential levels of use, and the benefits bicycling can bring to society; identifies the scale and nature of crashes related to bicycle use; discusses engineering countermeausres that have been tested to prevent crashes; brings readers up-to-date with current practices related to bicycle facility selection and design; highlights surface irregularities that endanger bicyclists as well as countermeasures to correct them; introduces readers to traffic-calming techniques; reviews bicyclists' equipment safety and helmet use; and reviews education programs and enforcement programs to improve safety. Conclusions on the current state of knowledge in this field are offered, and where possible, reference to current practices have been included.

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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		
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yards	0.836	square meters	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km²
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³
NOTE: Volumes greater than 1000 l shall be shown in m³.				
		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/m²	cd/m²
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in²	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		
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m³	cubic meters	35.71	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
		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/m²	candela/m²	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/in²

* 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)

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF FIGURES

Page

LIST OF TABLES

INTRODUCTION

Twenty years ago, the United States was in the middle of an oil crisis. Gasoline prices skyrocketed and supply was scarce. In the 3-year period of 1972 through 1974, more than 45 million bicycles were sold — mostly to adults looking for an alternative to their gas-guzzling automobiles.(1)

Dozens of State and local government agencies launched ambitious plans to make their communities more conducive to bicycling. Thousands of miles of special facilities for bicyclists were built on and alongside highways from San Diego, CA to Bangor, ME.

For most transportation planners and engineers it was the first time they had ever been called upon to think about bicycling — and for much of the 1970's, bicyclists, academics, legislators, police, traffic engineers, and planners debated and studied what worked best to safely and efficiently accommodate this new group of highway users.

Twenty years after the oil crisis, interest in bicycling is high once more. New Federal transportation and clean air legislation, and publication of the U.S. Department of Transportation's National Bicycling and Walking Study, make the 1990's a crucial time for bicycling.(2)

There are unique opportunities at the State and local level to influence the physical and political climate to make bicycling easier and safer. Every State and most major urban areas now have a bicycle and pedestrian coordinator and/or bicycle advisory committee.

We can look back on and learn from the 20-year history of experiments, studies, strategies, reports, videos, and programs that increased bicycle use and made the activity safer. Many of these resources are mentioned in this synthesis. Yet, there are still significant gaps in the literature. Debates still continue over the best way to accommodate bicyclists in certain situations. Research has not always been available to back up program activities. Evaluation of policies and programs implemented at the State and local level is still uncommon. In addition, little of the experience gained in Europe, Japan, Australia, and other parts of the world over the past 20 years has been disseminated or utilized in the United States.

Little more than a decade ago, a synthesis of bicycle safety-related research was undertaken by the Federal Government.(3) This report is designed to:

1. Bring researchers and practitioners up to date with what has been tried, tested, and evaluated during the 1980's and 1990's.

2. Identify significant gaps in research that are holding back efforts to increase bicycle use and bicycle safety.

3. Integrate experience from countries where a significant amount of research has been devoted to increasing bicycle use and bicycle safety.

The 1981 synthesis was focused specifically on reporting research work. In the 12 years since then, most of the literature in the field has been policy- and program-oriented, with very little pure research. Thus, the scope of this synthesis is broader than its predecessor, without attempting to be a complete program manual for State and local engineers, planners, and advocates. Where possible, references to current best practices have been included. As part of the development of this report, case studies were commissioned from the Netherlands, Great Britain, Australia, Japan, Germany, and Denmark to add international experience and perspective.

Practitioners and bicycle policy-makers and advocates should have access to the best information available as they work to integrate bicycling into the routine development, operation, and maintenance of the transportation system. This synthesis provides an overview of research, both pure and applied, that has been done in this area over the past 15 years.

SECTION 1.
BICYCLING IN THE UNITED STATES IN THE 1990's

INTRODUCTION

The 1990's have seen an explosion of interest in bicycling at all levels of government and among all sections of society. In February 1990, the U.S. Department of Transportation (DOT) issued *Moving America: A Statement of National Transportation Policy,* which explicitly endorsed bicycling as an important component of the transportation system:

> 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.[4]

Congress commended DOT on this statement in the 1991 Transportation Appropriations Act and allocated funds for the Federal Highway Administration (FHWA) to carry out a National Bicycling and Walking Study.[5] They said:

> 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.

Prior to passage of this legislation, the Federal Highway Administrator, Dr. Thomas Larson, committed his staff to "working with the States to encourage their [nonmotorized modes] use and make them safer."[6] In a subsequent memorandum to staff, he added:

> 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.[7]

Congressional and Federal agency support for bicycling culminated in 1991 with passage of the Intermodal Surface Transportation Efficiency Act (ISTEA).[8] ISTEA, together with the 1990 Clean Air Act Amendments, which include bicycling and walking programs as key implementation strategies, has ensured that bicycling safety and promotion will be considered by Federal, State and local agencies as an integral part of the transportation system.[9]

ISTEA makes all the major funding sources for Federal-aid transportation programs available to be used for bicycling improvements, and the planning process outlined in the legislation requires the development of long-range bicycle plans for every State and major urban area.

INCREASING BICYCLE SALES AND USE

Another reason for government agency interest in bicycling is the fact that so many people are now using bicycles. In the decade leading up to 1993, the number of bicyclists in the United States grew from 72 million to 99 million, according to the Bicycle Institute of America (BIA).[10] The BIA publishes an annual estimate of bicycle use in a variety of categories based on sales figures, demographics, and other sources in the bicycle industry (table 1).

Other indications of the growth in popularity of bicycling include annual sales figures. The Bicycle Manufacturers Association compiles data on shipments of bicycles made in the United States each year.[11] In the decade prior to 1993, an average of more than 11 million bicycles have been sold in the United States, ranging from a low of 9 million in 1983 to 12.6 million in 1987. Sales in the last 3 years were 11.7, 11.6, and 13.0 million units, respectively (table 2).

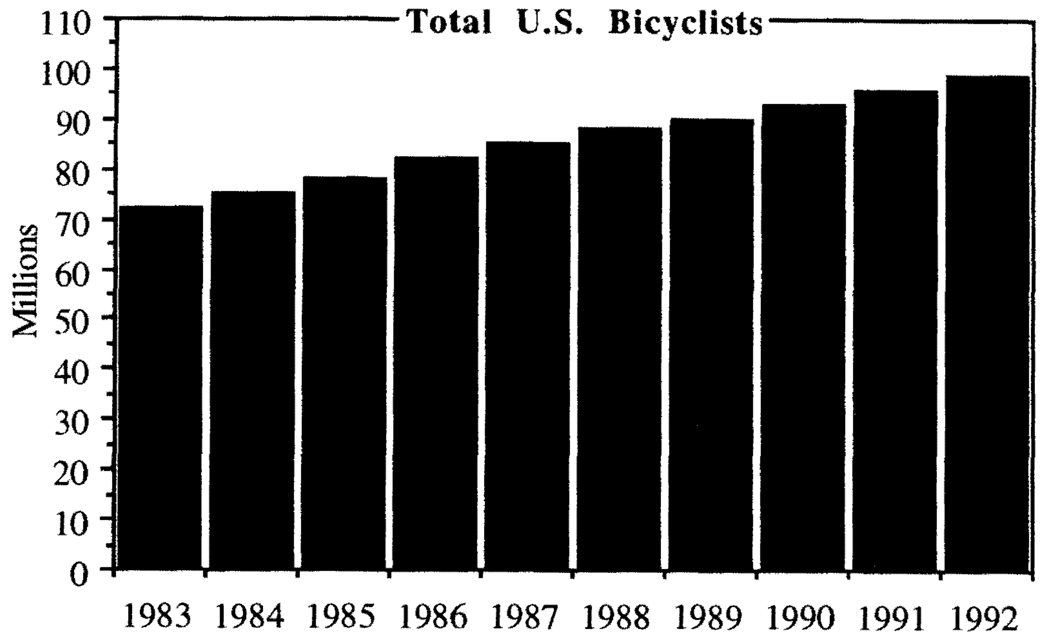
Among the most important trends hidden in these sales figures is the great popularity of mountain bikes or all-terrain bikes. Only 500,000 of these wide-tired, low-geared, easy-to-ride bicycles were sold in 1983, but they now represent close to 60 percent of the entire bicycle market with annual sales approaching 7 million units.[10] Mountain bikes are easy and comfortable to ride, and are very practical for utility riding.

Sales of mountain bicycles over the past few years have confirmed the general trend, noted in many studies, towards greater adult participation in bicycling. For example, the Department of Interior's 1982-1983 Nationwide Recreation Survey noted that:

> Bicycling has gained dramatically in the past 22 years on every available yardstick, more than tripling its population participation rate. Especially noteworthy is the increase in adult bicycling, which was practically insignificant in 1960. In the present survey, cycling is part of the free-time repertoire of 37 percent of the young adults (ages 25 to 39) and 22 percent of the middle-aged (40 to 55 years of age). This greatly exceeds the most sanguine predictions of the early 1960's.[12]

This growth continued in the 1980's. In 1990 and 1991, Rodale Press commissioned opinion polls from the Harris Organization. They found that in 1990, 42 percent of adults had ridden a bicycle at least once during the previous 12 months, and 54 percent of those ages 18 to 39 had ridden at least once. On average, adults had ridden four times in the previous month.[13] The 1990 figure represents more than 75 million adults. By the following year, the number riding at least once in the previous 12 months had risen to 82 million, or 46 percent of all adults.[14]

Table 1. Bicycle use in the United States, 1983-1992.



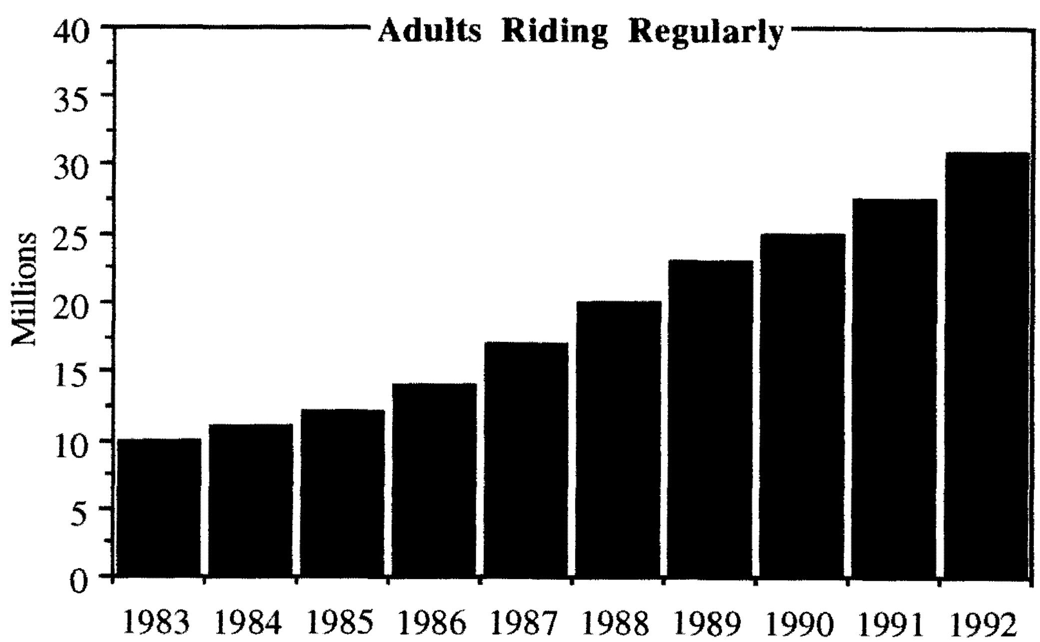
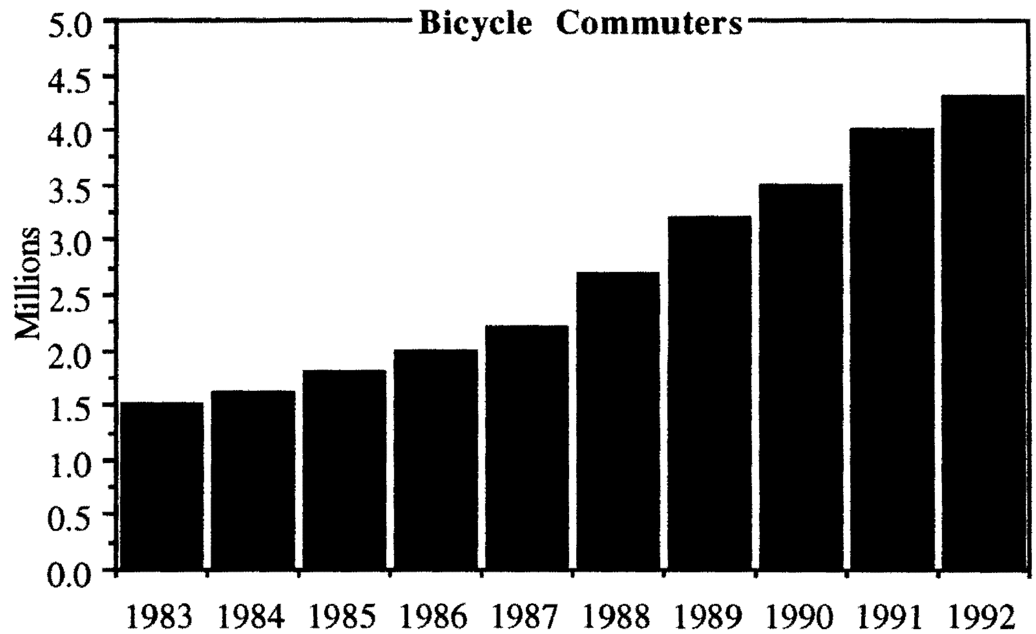


Table 1. Bicycle use in the United States, 1983-1992 (continued).



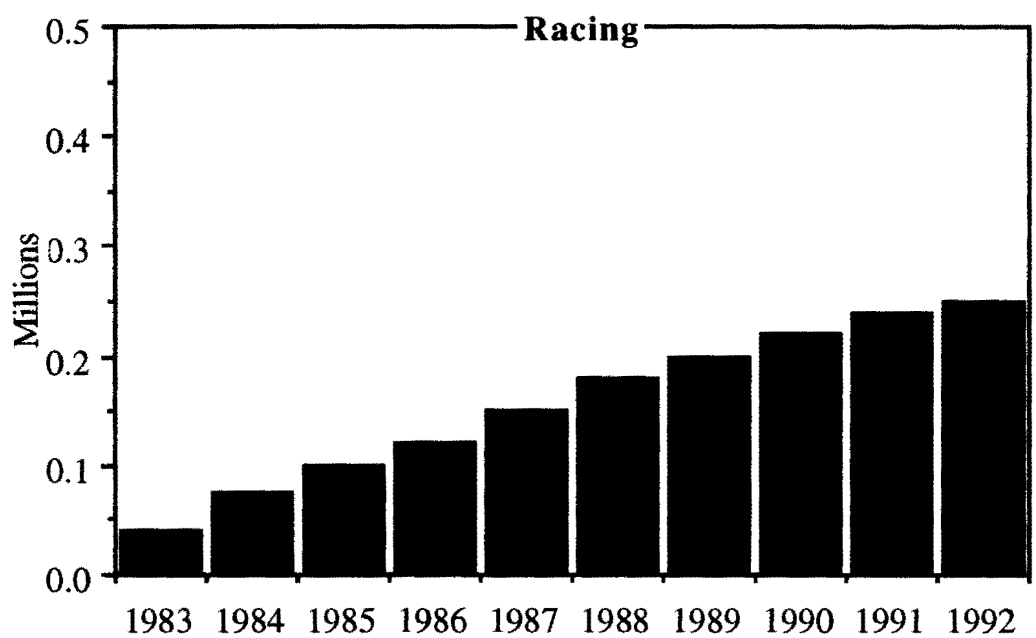
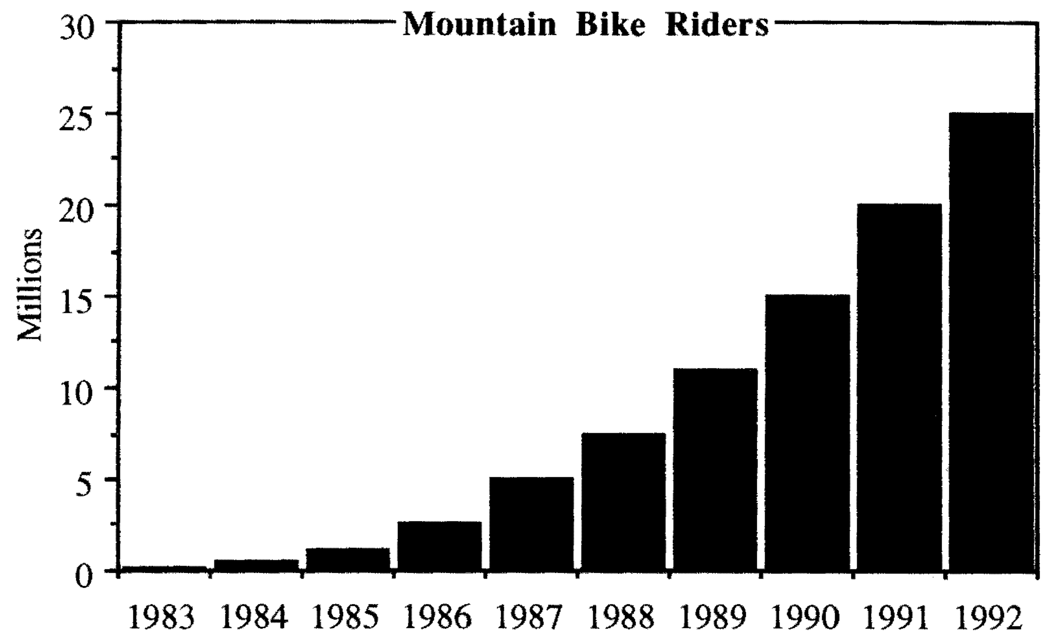


Table 1. Bicycle use in the United States, 1983-1992 (continued).



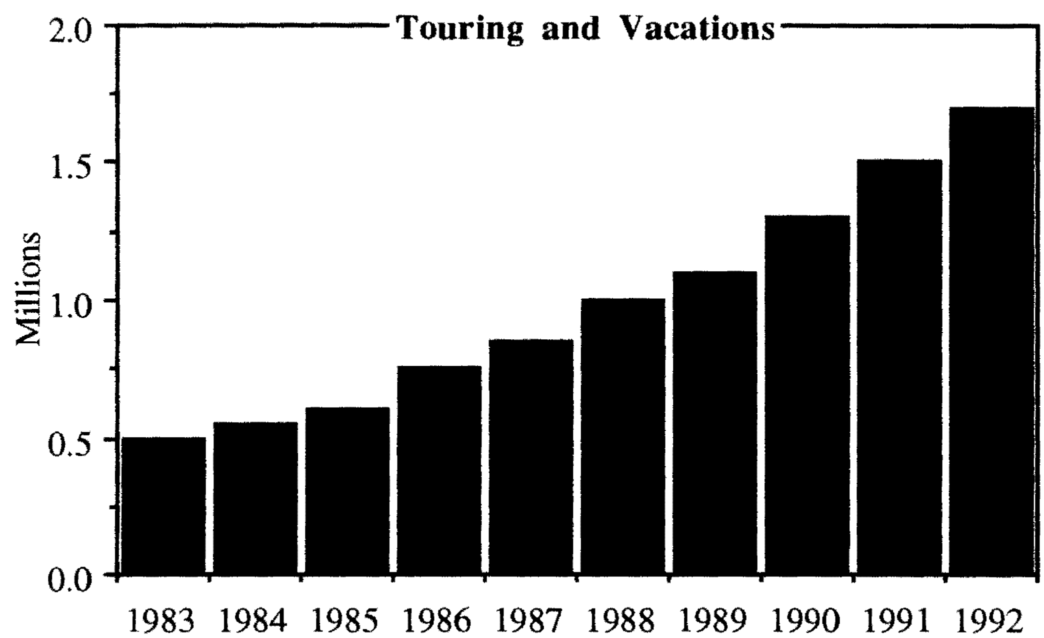
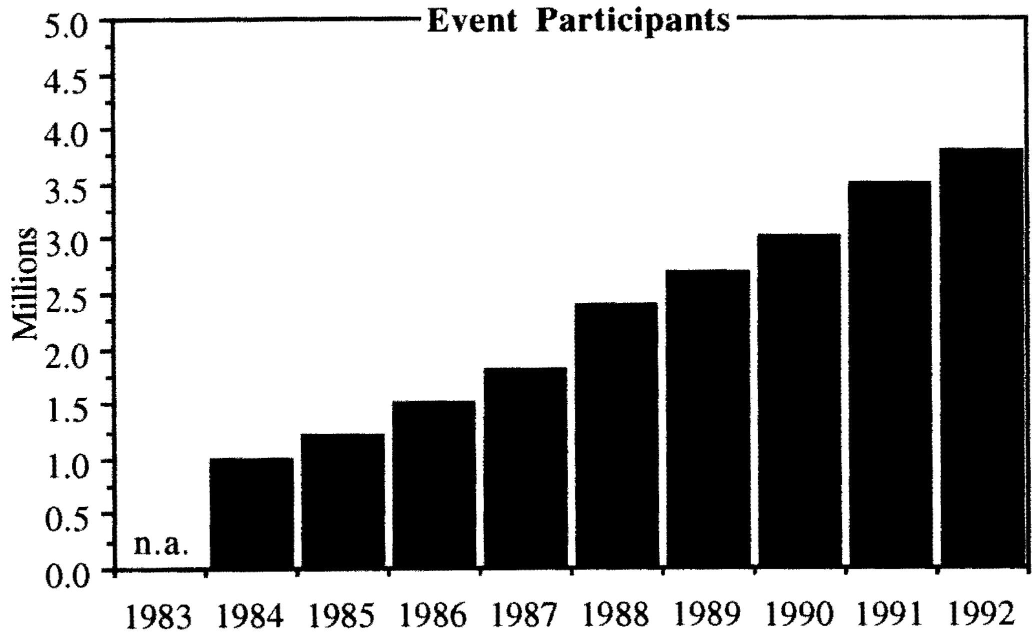


Table 1. Bicycle use in the United States, 1983-1992 (continued).



Source: Bicycle Institute of America

Table 2. Bicycle sales in the United States, 1983-1992 (in millions).

Year	Domestic Shipments	Imports	Total
1983	6.3	2.7	9.0
1984	5.9	4.2	10.1
1985	5.8	5.6	11.4
1986	5.3	7.0	12.3
1987	5.2	7.4	12.6
1988	4.5	5.4	9.9
1989	5.3	4.9	10.7
1990	6.0	4.8	10.8
1991	7.3	4.4	11.7
1992	7.4	4.2	11.6
1993	8.0	5.0	13.0

Source: Bicycle Manufacturers Association

Surveys at the national and local level confirm that for most people, recreational riding is still the primary activity, and that fitness, health, and fun are the primary motivational factors. In the 1991 Harris survey, for example, 18 percent (29.5 million) of those surveyed rode for recreation and 15 percent (25.3 million) rode to stay fit. Of the 82 million who rode in 1991 (reported in the 1992 publication), 82 percent did so for fun and 65 percent for fitness.

Similar studies at the State and local level have helped convince State agencies and others that bicycling was an activity that deserved attention. For example, in Texas, the State Parks and Wildlife Department discovered in 1989 that 5.5 million Texans (33 percent) rode a bicycle at least once a year, and that bicycling was the second most popular outdoor recreational activity in the State.[15] A second Texas study (Simmons, 1989) revealed that more than 6 percent of Texan adults (627,000 people) rode a bike at least 24 days per year.[16] Surveys done in conjunction with bicycling events and along specific bicycling facilities in many other locations have revealed similar trends.

EVERYDAY BICYCLING

Although bicycling has become a mainstream recreational activity for U.S. adults, bicycle use for everyday trips to work, school, and stores remains, according to most studies, relatively low.

There are two major data sources on transportation that are widely used by planners and engineers — the decennial Census and the National Personal Transportation Survey, which is carried out every 7 years. Data from these and other sources on national levels of bicycling are somewhat confusing as commentators note that each of the surveys has its own problems.[17]

The Census, for example, only asks respondents to note their primary mode of travel to work, and only asks people ages 16 years and older — 77 percent of the population. Thus, rides to transit, shopping, or social trips are excluded, as are any school-based trips by children ages 15 years or less. As journeys to work now account for only 20 percent of all trips, reliance on the Census for hard transportation data is becoming harder to justify.[18] In addition, the Census data is collected in March, which is still a cold month for some areas of the country, and this is likely to contribute to a lower number of people riding bicycles.

The National Personal Transportation Survey (NPTS) covers all trips made by respondents (48,000 people in 22,000 households) during a 24-h period, and asks about each segment of each trip.[19] The percentage of all trips made by bicycle has remained constant at 0.7 percent, since the 1977 survey. In addition, the NPTS breaks down the number of journeys to work made by different modes.

Table 3 summarizes the results of the two most recent Census and NPTS reports, and compares journey-to-work data with data collected for a 1980 report on bicycle promotion published by the U.S. Department of Transportation. The second half of the table shows the level of bicycle use for all trips, regardless of their purpose, collected as part of the NPTS.

Table 4 is taken from the NPTS and shows the purposes for which bicycle trips are made. A comparison is provided with the national breakdown for all modes and it reveals that bicycling is used predominantly for social and recreational travel.

A local survey of bicyclists in Seattle has shown that bicycling for non-work-related utilitarian trips is three times greater than bicycling for journey-to-work trips.[20]

The NPTS also reveals that more than 75 percent of bicycle trips are made by people younger than 30 years of age, and that men are three times more likely to bicycle than women.

In the 1991 Harris report, commuting information was specifically requested from respondents. Of the 39.4 million adults who had ridden in the previous month, only 7 percent (2.76 million) had commuted to work by bicycle during that time. A second survey reported the same percentage of commuting trips made by riders.[13]

Thus, while recreational bicycling has increased significantly, commuting and utilitarian bicycling is still a largely untapped market. According to the NPTS, the average length of all trips is less than 8 mi (13 km), and two out of every three trips are less than 5 mi (8 km) long. Fifty-four percent of workers live within 5 mi (8 km) or less of their place of work.[21] Thus, a major portion of the trips are within reasonable bicycling distance.

Table 3. Estimated levels of bicycle use in the United States.

Journey to Work		
Source	**# of Cyclists**	**% of Trips**
Bicycle Transportation for Energy Conservation, 1975[4]	475,000	
U.S. Census, 1980[25]	800,000	1.4
NPTS, Journey to Work, 1990		0.3
U.S. Census, 1990[22]	690,000	
All Trips		
NPTS, 1983[26]		0.7
NPTS, 1990[23]		0.7

Table 4. Bicycle trip characteristics, 1990.

Trip Purpose	% All Trips	% Bicycle Trips
To or from work	20%	10%
School/Church	11%	14%
Social/Recreational	27%	55%
Personal, Family Business	22%	10%
Shopping	18%	10%
Other	2%	1%

Source: National Personal Transportation Survey, 1990

THE POTENTIAL FOR BICYCLING IN THE UNITED STATES

Every survey of bicyclists and non-bicyclists reveals a tremendous latent demand for making everyday trips by bicycle (to the extent that two major studies, a decade apart, researching the potential for bicycling and walking trips have noted this phenomenon).

In 1981, the Federal Highway Administration noted that:

> Of all modes, bicycle is the only one for which preference is consistently greater than choice. This is true regardless of the current level of bicycle use or the purpose of the trip or the site surveyed.(24)

In a doctoral thesis published in 1993, Noland identifies a similar trend. People consistently express a much greater desire to bicycle than is actually the case at present, suggesting a great untapped potential pool of people who would ride, given the right circumstances. Noland writes:

> High levels of abstract support for bicycling belie the fact that in most places, only a small minority choose to use a bicycle for transportation on anything resembling a regular basis.(25)

The apparent latent demand for bicycling can be seen clearly in the Harris report findings. In both the 1991 (table 5) and 1992 reports, a representative sample of respondents — taken from the general public — were asked whether they would sometimes commute to work by bicycle if certain improvements were made.(13, 14)

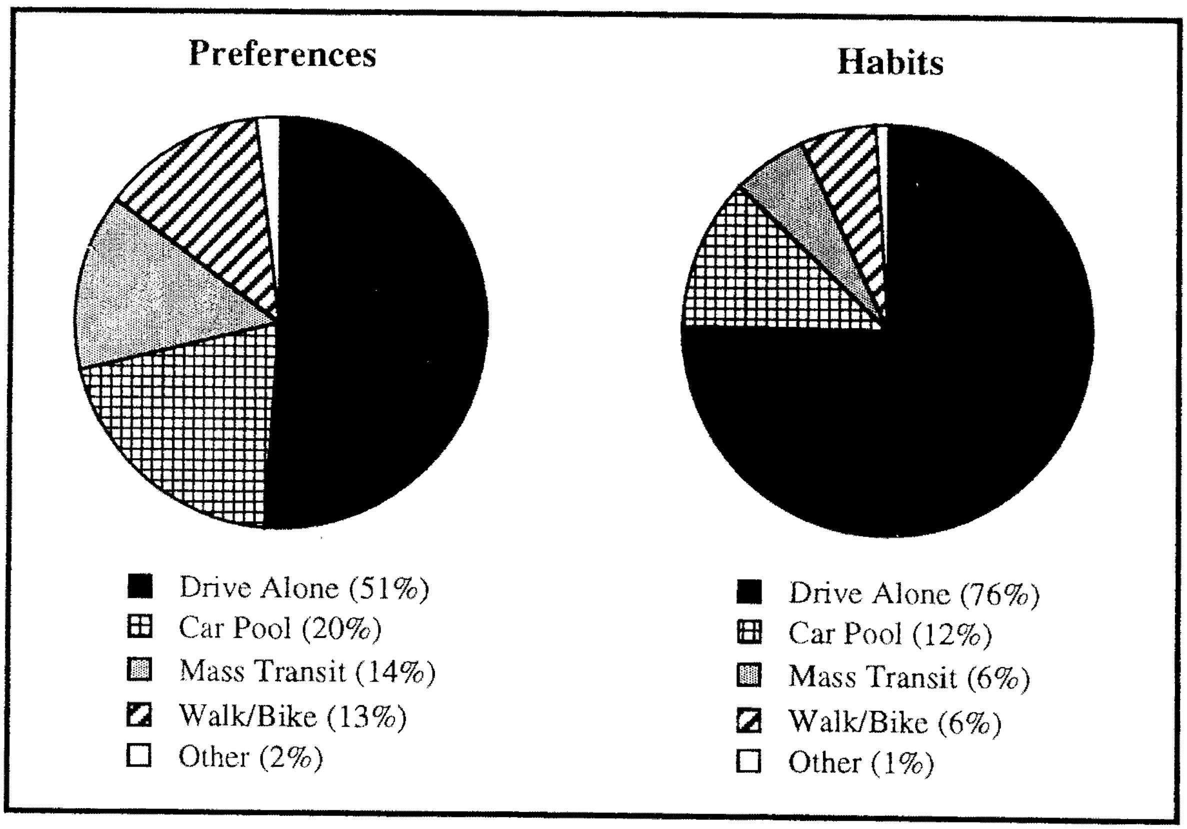
Table 5. Would you commute by bicycle if...

1991 Conditions	Yes	No
Safe bike lanes on roads and highways	49.3%	44.8%
Financial incentives from employer	44.5%	49.7%
Showers, lockers, and secure parking at work	43.5%	50.6%
Gas prices continue to rise	37.9%	55.8%

Source: Rodale Press.

The 1992 report includes questions on stated trip habits (actual use) vs. trip preferences, if all modes were equal. According to the survey, if people felt they had a real choice between modes, the percentage of trips made by bicycling and walking would increase from 5 percent of all trips to 13 percent. Driving alone would fall from 76 percent of trips to 51 percent. Transit and carpooling would both increase their share significantly (see table 6).

Table 6. Transportation habits and preferences if facilities existed.



Source: Pathways for People. A Louis Harris Poll commissioned by Rodale Press.

In a case study completed for the FHWA as part of the National Bicycling and Walking Study, Goldsmith (1993) reviews more than 10 national and local surveys that follow a similar pattern.[26] He reviews the subjective and objective factors that influence mode choice and concludes that:

- Current markets for bicycling have not been adequately tapped.
- Removing the perception of danger and lack of safe routes — and matching bicycle accessibility to the level of car accessibility — will increase utilitarian bicycling.
- Compact land-use patterns and development of a bicycle-friendly infrastructure must be achieved in the long run.
- The share of bicycling trips will not grow significantly as long as motoring remains relatively cheap and easy compared to every other option.
- Very little is known about non-commuting trip patterns and habits. This is an area that probably has tremendous potential.

Goldsmith's conclusions are matched by researchers both before and after his study. The 1981 FHWA study on demand incentives to promote bicycling and walking arrived at strikingly similar results, as did Noland (1993).[24,25]

Among the key findings of the FHWA (1981) report were:

- Current preference is a good indicator of current mode choice, but indicated preference levels underestimate actual car use and overestimate actual bicycle use.
- The greatest potential for increasing bicycle use may be in areas where it is already high.
- In order of effectiveness in shifting people from their cars, compact land-use patterns and higher driving costs are ranked above the provision of facilities for bicyclists.
- Special facilities can play a prominent role in increasing bicycle use, especially in the context of compact land-use patterns.
- "It appears that in order to accomplish even modest increases in the levels of walking and bicycling, a family of measures or incentives must be implemented. This is precisely what motorized traffic enjoys and takes for granted."[24]

Noland, whose study concentrates on the impact of risk on trip choice, concurs. He concludes that:

- It is possible to induce a large increase in the share of commuting trips made by bicycle in the Philadelphia region, but no single policy will achieve this goal.
- In denser urban areas, significant increases can be achieved through the provision of a network of bicycle lanes.
- In lower density suburbs, average commuting distances must be brought down.
- In all cases, disincentives to automobile commuting are necessary to achieve significant shifts from driving cars to alternatives.
- "From a policy perspective it would be questionable to only implement the anti-auto policies, which will cause shifts to bicycle transportation, without providing a safe transportation network for bicycling . . . However, only constructing bicycle lanes, without decreasing incentives to automobile commuting, will only achieve relatively minor reductions in automobile usage." [25]

Work in the broader field of transportation policy is beginning to reveal the extent to which automobile use is subsidized, and the degree to which these subsidies act as incentives to single-occupant vehicle use.[23] Increasing costs toward the true cost of driving, through higher gasoline prices, and parking, through parking fees, would act as a significant disincentive to drive.[22]

FACTORS INFLUENCING BICYCLE MODE CHOICE

The three studies by Noland, Goldsmith, and FHWA each reviewed an exhaustive list of factors that influence mode choice for the journey to work for both bicyclists and non-bicyclists, including distance, safety, time, convenience, climate, topography, and available facilities.

In considering individual factors, Goldsmith notes that age is the most significant demographic variable. Health and fitness concerns are the primary motivating factors and the primary disincentives are fear of traffic, lack of places to ride, and the weather. For utilitarian riding, however, distance, safety, and ancillary facilities are the greatest disincentives. Once again, no single program or policy change is going to attract all potential commuter and utilitarian bicycle trips. A comprehensive package of measures, especially at the local level, is required.

Goldsmith reviewed environmental factors by comparing bicycle-use levels in 20 urban areas against a number of objective factors, such as population, land use, and the existence of different facilities. The most significant variable noted was the presence of a university, where bicycle use is notably higher than in communities without a university. However,

> Even when university towns are excluded from consideration, cities with higher levels of bicycle commuting have on average 70% more bikeways per roadway mile and six times more bike lane miles per arterial mile.[26]

An interesting case study in Hawaii is documented by Willey, et al. (1991) as it confirms many of the general principles identified by Goldsmith.[27] The authors compared studies of bicycle and moped use by students at the University of Hawaii in 1978 and 1988. In the 1978 study, 8.2 percent of students used bicycles to get to school and 1.1 percent chose mopeds. In addition, 22 percent walked, 35 percent drove alone, and 15 percent were car passengers.

After 10 years, single-occupant car use had risen to 43 percent and moped use grew to 7.6 percent of the trips. In contrast, car passengers had fallen to 9.7 percent and bicycling fell to 5.8 percent of the trips. Respondents in the survey were asked if they had shifted from another mode to their present mode and a significant percentage had done so. In 1988, 22 percent of moped and bicycle users formerly walked to campus, 6 percent drove cars, and 3 percent traveled as car passengers. In 1978, only 2 percent of the drivers and 4 percent of the passengers had shifted to bicycling or moped use.

Lack of parking was cited as the major reason for drivers shifting to bike or moped use, and approximately 540 cars were removed from the streets as a consequence. Willey comments that a 6 percent reduction in car use is at the high end of the diversion range for transportation system management strategies. However, the authors also note that the long-term trends are for car driving and moped/bicycle trips to increase at the expense of walking and bus trips, with no net decrease in vehicle miles traveled as a consequence of increased bicycle and moped use. "Automobile disincentives would be needed to induce reductions in automobile use."[27]

Noland surveyed bicyclists and non-bicyclists in the Philadelphia metropolitan region to determine the relative importance of 16 factors to their decision not to commute by bicycle, or why they do not commute every day by bicycle (table 7). In correlating these answers to determine their significance, Noland identifies four main areas of interest.

Perceived Risk. Weather-related risks and the risk associated with the lack of a shoulder on the road are factors that did influence the choice of bicycling as a commuting mode, but a broader measure of perceived risk did not. However, he does suggest that reductions in the perceived risks of driving increase the probability of some people choosing that mode.

Perceived Convenience. Travel time, distance, land use, and density are important factors for all modes, especially for walking and transit. The availability of bicycle parking is significant and related to convenience.

Perceived Cost. Increasing the cost of automobile commuting reduces the probability of automobiles being chosen, and the cost of bicycling has a positive coefficient value. (Goldsmith points out that as drivers rarely pay the full cost of motoring and are never made aware of the full costs, this factor is little deterrence to driving.)

Perceived Comfort. Perceptions of comfort are significant in influencing mode choice. Noland determined also that the availability of showers, a frequent request of non-bicycle commuters, is of little or no significance to mode choice.

Table 7. Top five factors affecting bicyclists.

Negatives, Bicyclists	
Don't want to ride in rain/snow	75%
Sweat factor	62%
Too much traffic	60%
Too dangerous	53%
Takes too long	51%
Negatives, General Public	
Don't want to ride in rain/snow	85%
Takes too long	79%
Sweat factor	75%
Too much traffic	75%
Too dangerous	71%

Source: Noland[25]

Wright (1990) has developed a table depicting the qualitative performance of different transport modes based on the importance of different characteristics to the individual and to society (table 8).[28]

In terms of importance to society at large, bicycling scores above average in terms of space and energy consumed; visual, noise, and air pollution; public expense and healthfulness; and significantly better than cars. Only in the area of serious crashes does the bicycle option score poorly for society due to the cost of lives lost and injuries sustained. However, in terms of importance to the individual, bicycling falls short of the motor car in terms of comfort, the ease of carrying items; and trips longer than 1500 m (1 mi). From an objective standpoint, Wright argues, public policy "should be geared to improve the performance and attractiveness of the modes which have the least negative externalities and other attributes which run counter to the public interest."[28]

The literature suggests, therefore, that proponents of bicycling have a substantial task ahead of them to persuade motorists to leave their cars at home and choose the bicycle instead. Of more concern to those proponents is the possibility that advocates and professionals have devoted considerable resources and effort to factors that may not be decisive in the choice of modes.

Table 8. Qualitative performance of transport modes.

CHARACTERISTIC	ODE			
	Walking	Cycling	Transit	Car
Important to Society:				
1. > Capacity/Area	S	S	S	P
2. > Energy Efficiency	S	S	S	P
3. < Air Pollution	S	S	S-I	P
4. < Noise	S	S	S-P	P
5. < Public Expense	S	S	S-P	I-P
6. < Vulnerable System	S	S	P	P
7. < Visual Pollution	S	S	S-P	I-P
8. > Healthfulness	S	S	I-P	P
9. < Serious Accidents	S-P	S-P	S-I	P
Important Primarily to Individuals:				
10. < Costs to Users	S	S	S-I	P
11. > Personal Environment	S	S	P	S
12. > Flexibility	S	S	P	S
13. > Frequency	S	S	S-P	S
14. > Punctuality	S	S	S-P	S
15. > Comfort	S-P	S-P	S-P	S
16. > Ease of Carrying Things	I-P	S-P	I-P	S
17. < Total Travel Time				
a) Up to 400 m	S	S	I-P	I
b) 400-1500 m	I-P	S-I	S-P	S-I
c) Beyond 1500 m	P	S-P	S-I	S

1 m = 3.28 ft

Notes: (1) S = Satisfactory or Superior; I = Intermediate; P = Poor. Common variations depend on specific factors and are indicated by giving a range (e.g., S-P indicates that the mode's performance ranges from satisfactory to poor). Grades represent somewhat favorable circumstances for the modes but with no special compensation for disadvantages each typically faces. (2) ">" means "greater," "more," "better." "<" means "less" or "worse."

Source: Wright, 1990.

For example, a consumer survey by National Family Opinion (NFO), commissioned by Rodale Press, asked bicyclists of all backgrounds and levels of experience what would encourage them to ride more often.[29] The most popular response, by almost half of those surveyed, was somebody else to ride with, closely followed by more safe places to ride.

The provision of safe places to ride has usually focused on safety from motor vehicle traffic. Many potential riders, especially women, fear personal attack. Parents fear their children may be abducted. Traffic is not necessarily the primary fear factor.

Less than 1 percent chose bicycle education as something that would encourage them to ride more often. Yet, one of the basic elements in a lot of bicycle promotion programs is education for adult bicyclists.

Similarly, we have seen that the journey to work now accounts for just 20 percent of trips and that social and recreational trips account for a greater percentage, and shopping trips are almost as prevalent. Despite this, many advocacy groups and public agencies focus exclusively on bike-to-work promotions.

Bicycle promotion programs have also concentrated heavily on persuading motorists to give up their automobiles for some or all trips. There is a massive potential population of non-drivers who currently do not bicycle either. For example, in Florida, 37 percent of the population does not drive.[30]

COSTS AND BENEFITS ASSOCIATED WITH BICYCLING

A review of the costs and benefits associated with bicycling confirms that bicycling has many positive aspects for both society and the individual that make it worth promoting. However, there are also costs associated with bicycling, principally death and injuries sustained while bicycling.

Section 2 covers the costs associated with bicycling in more detail. For now, it is enough to know there are 600,000 crashes involving injury to bicyclists treated in hospital emergency rooms each year. Of these, an average of 850 to 900 are fatal and 70,000 (about 12 percent) are reported to the police as traffic crashes. The economic cost of these crashes is estimated at $3 billion annually.[31]

This section summarizes some of the main benefits of bicycling. A lot has been written over the last decade about the many benefits of bicycling to the environment, economy, individual, and quality of life in urban areas.

<u>Economic Benefits.</u> A report from Hillsborough County, FL, analyzed the economic impact of the extensive provision of wide curb lanes and paved shoulders for bicyclists.[32] A shift of 1.8 percent from car trips to bicycle trips was assumed, producing an annual savings of up to $3.95 million for Hillsborough County (table 9).

Table 9. Economic benefits of bicycle-friendly roads.

Gasoline use (2,644 gal)	$1.21 million
Fatal injury (2.15 fatals prevented)[1]	$2.15 million
Other injury (12 prevented)[1]	$0.12 million
Tax Revenue (increased bike sales)	$0.46 million
Total, 1 Year	$3.95 million

[1]Bicyclist fatalities and injuries 1 gal=3.8 L

Source: Hillsborough County Bicycle Program[(32)]

Recreational bicycling has a tremendous potential to generate spending and other economic activity. A number of studies of individual facilities, such as trails, have attempted to quantify this effect.

Elroy-Sparta Trail, WI. In 1988, trail users spent $1,257,000 in the area of the trail on trip-related expenditures, almost one-half coming from out-of-State visitors. The average per person expenditure was $25.14.[(33)]

Sugar River Trail, WI. A 1986 survey estimated the local economy in the trail area benefited by between $400,000 and $600,000 per year.[(34)]

A study by the National Park Service of three trails in different surroundings revealed that users spend between $4 and $11 per person as a result of trail visits, boosting the local economy by more than $1.2 million in each location.[(35)]

Bicycle events are also big business. Waring (1991) reports that major bicycling events in Texas benefit local towns significantly.[(36)] For example, the Hotter'n Hell Hundred event pumps $860,000 into the economy of Wichita Falls, and Tyler receives approximately $760,000 from an annual bicycle ride.

Environmental Benefits. Komanoff et al. determined the current and potential impact of actual and projected bicycling and walking trips on vehicle emissions and energy consumption.[(37)] Table 10 shows the emission reduction potential of a range of levels of bicycle use. Table 11 shows the potential impact on U.S. petroleum consumption of this range of levels of bicycle use. Up to 2.67 percent of current fuel use could be saved, given a shift from car to bicycle travel.

Since the passage of ISTEA in 1991, government agencies have been working to identify the emissions reduction potential of different transportation control measures, including bicycling. No definitive model for estimating the impact of bicycling has yet been developed, but a number of agencies have made a valuable start.

Table 10. Emissions savings, percentage of U.S. emissions of different pollutants produced by passenger vehicles.

	CO_2	CO	NO_X	VOC
Bicycle use, 1990-1991 high level	0.68	2.13	0.51	0.92
1990-1991 low level	0.12	0.39	0.09	0.17
Bicycle use, 2000 high level	2.90	9.00	2.18	3.91
2000 low level	0.32	1.00	0.24	0.43

Source: Komanoff, et al.[37]

Table 11. Fuel savings, portion of U.S. petroleum consumed by passenger vehicles.

Bicycle use, 1990-1991 level	0.1 - 0.6%
Bicycle use, 2000	0.3 - 2.67%

Source: Komanoff, et al.[37]

The City of Seattle, WA, has been able to justify the expenditure of significant amounts of Congestion Mitigation and Air Quality (CMAQ) program funds on the basis of a calculation that a certain number of car trips will be made by bicycle.[38] Similarly, the Delaware Valley Regional Planning Commission has developed a model that assumes a potential shift of 5 percent of the trips under 5 mi (8.1 km) from car to bike. Under this model, bicycle projects only rank behind increased parking fees in their effectiveness in reducing the air quality impact of driving.[22]

Savings to the individual. A New York City study estimates an annual average savings of $575 for each transit user and $1,100 for each motorist if they switched to bicycling. A ten-fold increase in bicycling in the city would release $0.5 billion of additional discretionary income from this source. A further $300 million savings to the city government is estimated from such a shift to bicycling.[39]

Health benefits. Bicycling is recognized by the medical and sports worlds as one of the best forms of exercise available. Numerous studies have shown a positive link between exercise and health in a wide range of areas, notably cardiovascular health, weight control, mental health, cholesterol, hypertension, stress, and other diseases. These are summarized in a number of more detailed reports.[40]

A detailed study of the health of 17,000 Harvard University graduates serves as an example of the kind of potential bicycling has to improve health and longevity. A study of the link between mortality rates and physical activity of 17,000 Harvard University graduates ages 35 to 84 found that those who had cycled 60 mi (97 km) per week from the age of 35 could add 2-1/2 years to their life expectancy.[41]

The United States spends in excess of $400 billion annually on health care costs. Absenteeism and low productivity caused by ill health and lack of exercise add to this cost. Although no dollar figure has been estimated for the impact higher levels of bicycling could have on this expenditure, the potential for savings to the national economy and to individuals is clearly significant.

INTERNATIONAL COMPARISON

Table 12 compares the extent to which bicycling is an everyday mode of transportation in the countries from which case studies were commissioned as part of this report. The U.S. experience, in terms of bicycle sales, gasoline prices, and other economic trends over the past 20 years is very similar to that of other countries studied as part of this report. The oil crisis of the seventies caused sales and use to grow fast in Germany, the Netherlands, the United Kingdom, Denmark, Japan, and Australia.

Table 12. Percentage of all trips made by bicycle.

Netherlands	29%	Sweden	10%
Denmark	18%	Norway	less than 10%
Finland	12%	United Kingdom	2.5%
Germany	11%	United States	0.7%

Sources: Laursen, Mathew, and Clarke.[42-44]

Bicycle sales have remained strong in these countries, and yet many of them report that use has not kept up with sales — especially among the adult population in the case of Denmark. In each of the foreign case studies comissioned for this report, a significant suppressed demand for bicycling was identified.

The greatest distinction between cycling in the United States (and Australia) and the European countries and Japan is the predominance of recreational riding in the former, as opposed to utilitarian riding in the latter. Bicycling is not a significant everyday form of transportation in the United States.

CONCLUSIONS

Although bicycling has experienced a recent increase in popularity in the United States, the United States lags behind most other developed nations in terms of overall levels of bicycle use and over-reliance on the automobile. U.S. transportation system consumers do not have the same choice of modes available to them as do those in the Netherlands, Denmark, Japan, Australia, and the United Kingdom.

On the plus side, this also means that the United States probably has the greatest potential for increasing the number of trips made by bicycle over the coming years. If this can be achieved, the United States will reap significant environmental, economic, and social benefits that our international partners have enjoyed for decades.

Useful Resources

(a) Bicycle Federation of America (BFA), 1990. *Mountain Bikes on Public Lands: A Manager's Guide to the State of the Practice.* Washington, DC.

Summary of the history of mountain bicycling and the issues facing the activity in 1990. Available for $20 from the BFA, 1506 21st Street, NW, Suite 200, Washington, DC 20036.

(b) Bicycle Institute of America, 1993-1994. *The Bicycling Reference Book.* Washington, DC.

Full-color media guide on all aspects of bicycling. The 1993-1994 issue is a special transportation issue. Available for $8 from the Bicycle Institute of America, 1506 21st Street, NW, Suite 200, Washington, DC 20036.

(c) Federal Highway Administration, 1994. *National Bicycling and Walking Study,* Final Report.

See also a number of the case studies commissioned as part of the National Study, in particular:

> *Reasons Why Bicycling and Walking Are and Are Not Being Used More Extensively as Travel Modes.* Case Study 1.
>
> *Benefits of Bicycling and Walking to Health.* Case Study 14.
>
> *The Environmental Benefits of Bicycling and Walking.* Case Study 15.

The final report and case studies are available from FHWA, HEP-50, 400 Seventh St., SW, Washington, DC 20590.

(d) Federal Highway Administration, 1992. *Bicycle and Pedestrian Provisions Under the Intermodal Surface Transportation Efficiency Act of 1991.* Washington, DC.

A 10-page summary of relevant provisions of ISTEA. Free from FHWA, HEP-50, 400 Seventh St., SW, Washington, DC.

(e) Lowe, M. 1990. *The Bicycle: Vehicle for a Small Planet.* Worldwatch Institute, Washington, DC.

Global picture of the importance of bicycling as a means of transportation. Available for $4 from Worldwatch, 1776 Massachusetts Ave., NW, Washington, DC 20036.

(f) Seattle Engineering Department (SED), 1991. *The Seattle Bicycle Program Video.* Seattle, WA.

A 12-min video detailing the successful City of Seattle bicycle program. Available from SED upon receipt of a blank VHS tape. SED, 708 Municipal Building, 600 4th Ave., Seattle, WA 98104.

(g) Transportation Alternatives (TA), 1993. *Bicycle Blueprint: A Plan to Bring Bicycling into the Mainstream in New York City.* New York, NY.

Detailed action plan for making New York City bicycle-friendly provides a unique insight into the comprehensive actions required. Available for $15 from TA, 92 St. Mark's Place, New York, NY 10009.

SECTION 2. BICYCLE CRASH EXPERIENCE

INTRODUCTION

Safety is an important topic with respect to bicycling. Numerous surveys have shown, for example, that fear of injury is a significant deterrent to bicycling for many people. This fear is well-founded. Studies have shown that annually many Americans are injured or killed while riding bicycles (table 13). The better we understand the particulars of those unfortunate incidents, the better we will be able to design countermeasures to improve bicycling safety. But we still have a lot to learn.

Table 13. Bicycle-motor vehicle fatalities, 1980-1992 by sex.

Year	Male	Female	Total
1980	782	183	965
1981	748	181	936*
1982	720	144	864
1983	700	130	830
1984	684	153	838*
1985	732	137	869
1986	789	140	929
1987	826	115	941
1988	781	129	910
1989	695	126	831*
1990	734	122	856
1991	720	121	841
1992	632	89	722*

*includes sex unknown

Source: Fatal Accident Reporting System, NHTSA

Each year, the overall success of our national traffic safety effort is measured by the number of fatalities per 100 million mi (161 million km) traveled. Unfortunately, this means of determining progress, while perhaps useful in reporting the safety of motoring, is woefully inadequate when applied to bicycling. We simply do not have adequate information on the amount of bicycling being done. We know little about the actual number of people who ride, the time they spend on their trips, the distance they travel, as well as the number of trips they take in the course of a year.

Some limited data from the Nationwide Personal Transportation Survey (NPTS) gives an indication of the level of bicycle use; however, the amount of detail is insufficient to help in providing the needed exposure data for estimating crash or injury rates.[45] Even this data is of limited value in trying to determine exposure rates, as different age categories are used for the comparison of data. For example, the Cross study differentiates between three age groups below driving age (under 6 years old, between 6 and 11 years old, between 12 and 15 years old) while the NPTS combines them into one age group (5 to 15 years old).[46] The difference is significant because, as Cross has shown, different age groups have different crash problems.

In addition to these limitations, much remains to be learned about the relationship between crash problems and the bicyclist's age and level of expertise. One early study suggested a relationship between the amount of bicycling a person had done and the risk of a bicycle-related crash.[47] However, the data came from a mail-out survey of members of a national bicycle organization and, hence, its application to other groups is difficult to assess. The type of facilities being used is another factor that needs to be addressed. There is little data, for instance, regarding crashes on separate bicycle/pedestrian trails.

Another topic concerns the relationship between time of day, darkness, and crash problems. Some data sources give time of day vs. number of fatalities, but the data is not correlated with the seasonal changes in the time of sundown and sunrise. Motorist's behavior is another important area for research. This is most acutely obvious in the fatal crash picture where police reports may be based largely on the motorist's perspective.

Furthermore, the impact of impaired driving and bicycling among those involved in bicycle-motor vehicle crashes needs more attention. An analysis of 1987-1991 data from the Fatal Accident Reporting System (FARS) showed that 63 percent of bicyclists 15 years of age and older who were killed in bicycle-motor vehicle crashes were tested for alcohol and 31 percent of those tested were positive.[48] However, little information is available regarding the proportion of bicyclists who ride after drinking and, as a result, it is difficult to assess the seriousness of the risks of riding and drinking.

Some other factors that limit the amount and breadth of information available include:

- One of the main data sources, the National Electronic Injury Surveillance System (NEISS), is an emergency room reporting system that relies on the injured party to provide the data. As a result, there is little reliable information available regarding the circumstances of the crash.[49]

- Only a fraction of all bicycle-related crashes are ever reported to the police. For example, a study of bicycle injury cases treated in North Carolina emergency rooms concluded that only 10 percent of crashes serious enough to require emergency room treatment were actually reported to the police.[50] Sixty percent of the bicycle crashes in which a motor vehicle was involved and virtually none of those cases not involving a motor vehicle were reported to police.

- Many law enforcement agencies have a limited amount of expertise in bicycle crash investigation and reconstruction. As a result, the accuracy of police reports, both in terms of description and in terms of coding can be questionable. One Canadian study, for example, found inaccurate descriptions of collisions in 60 percent of police reports and coding that was inconsistent or absent.[51]

- There is a common perception among bicyclists of an institutional bias against bicyclists that results in an inappropriate assignation of blame. This is caused by an undervaluing of motor vehicle threats to bicyclists, bicycle crashes, injuries, and fatalities by law enforcement officials and within the judiciary. (See section 9.)

- As alluded to above, different studies and data sources use different approaches to describing bicycle populations, crash locations (e.g., urban vs. rural), and crash type. This makes comparisons difficult.

Despite these data limitations, there is much we can say about bicycle crashes. Furthermore, new studies are now being conducted that may well shed light on the situation. For example, a forthcoming study conducted by the Consumer Product Safety Commission (CPSC) attempts to analyze the risk of injury among a random bicyclist population. The results of this study, tentatively called "An Analysis of Surveys of Bicycle Use and Injuries and Injury Reduction Strategies," have not yet been approved for distribution. Two populations were surveyed. In a random-digit-dialed telephone survey, 1,250 bicyclists were asked their age, the amount and type of bicycle use, where they rode, and what type of bicycle they rode.

A parallel survey among 400 bicyclists treated in emergency rooms asked the same questions in addition to injury scenarios. An analysis has been conducted to compare those who had been injured with the general bicyclist population surveyed. Factors considered included age, level of bicycle use, riding location, and helmet use. Conclusions have identified the role of human factors in injury. Bicyclist training is a recommended countermeasure.[52]

In addition, there have been some significant changes in the U.S. bicycle scene in the past decade that may have influenced the crash situation. The following points are worth noting:

- The population of the United States has grown by 10 percent since 1982, but the number of motor vehicles on the road has grown by 17 percent and the amount they are driven has increased by 40 percent.[53]

- The number of bicyclists in the United States has grown 37.5 percent since 1983.[10]

- Unlike a decade ago, there are now more adult bicyclists than child bicyclists. In 1992, 56 percent of bicyclists in the United States were over 16 years of age.[10]

- Not only are more adults riding bicycles, but they are riding more often. Since 1983, the number of adults riding regularly (at least once a week) has increased 210 percent, the number commuting by bicycle has increased 187 percent, and the number taking bicycling vacations has grown 240 percent.[10]

- Mountain bikes have come to dominate the bicycle market in the past 12 years. In 1992, 6.7 million of these more upright, more stable bikes were sold in the United States.[10] Mountain bikes tend to be more stable and easier to ride than sports and racing bikes.

BICYCLE CRASHES IN GENERAL

Bicycle-related crashes happen in a variety of ways. One convenient way to categorize such crashes is: (1) those involving motor vehicles, and (2) those not involving motor vehicles. There are two primary reasons for using this distinction. First, injuries suffered in bicycle-motor vehicle crashes tend to be more severe than those suffered in all other kinds of bicycle crashes. This is most clearly shown in the FARS fatality statistics; over 90 percent of all bicycling deaths involve collisions with motor vehicles.[54] By contrast, non-motor vehicle-related bicycle crashes tend to be relatively minor. Second, while non-motor vehicle-related bicycle crashes tend to be less serious than bicycle-motor vehicle crashes, they account for a tremendous number of incidents.

Data from the National Electronic Injury Surveillance System (NEISS) suggest that, for example, in 1992, 649,808 people were treated in hospital emergency rooms for injuries they reported as bicycle-related.[49] Of those treated, more than 90 percent had been involved in non-motor vehicle-related bicycle crashes.

Clearly, the sheer numbers point to a significant problem in non-motor vehicle-related crashes. And, since prevention of injuries is a common goal of bicycle safety programs, it is worth focusing on non-motor vehicle-related crashes.

Interestingly, bicyclist fatalities have decreased by 22.2 percent since 1982, yet the number of bicycle-related injuries treated in hospital emergency rooms increased 12 percent between 1990 and 1992.[49,53] A comparison of fatal versus injury crashes over the same period of time is not possible because of a change in the definitions used by the CPSC for the NEISS data after 1990.

BICYCLE-MOTOR VEHICLE CRASHES

Overall, bicycle-motor vehicle crashes account for between 700 and 1,000 deaths per year. For example, in 1992, 722 bicyclists were killed in bicycle-motor vehicle crashes, the lowest figure in the past 15 years. (See table 13.) Those 722 deaths represented approximately 94 percent of all bicycle-related deaths and 2 percent of all traffic deaths.[53]

In terms of injuries, the data are often more difficult to come by. Several sources point out that between 40 percent and 80 percent of all bicycle-motor vehicle crashes are never reported to the police.[46,50] The discrepancy between police reports and actual crashes has come to light through comparisons between emergency room data and police files as well as through user surveys. Nationally, NEISS data suggests that, in 1992, 61,223 people were treated in emergency rooms after being involved in bicycle-motor vehicle crashes. This represents 9.4 percent of the total number of bicyclists treated.

CRASH CAUSES

Just how those bicycle-motor vehicle crashes happen is a topic that has been studied closely. Probably the best example is the Cross study mentioned above. Their crash typing system has been copied in local studies by many communities and has been the basis for determining the goals and objectives in most bicycle safety programs and materials produced since the late 1970's.[3] This pivotal study was initially published by the National Highway Traffic Safety Administration (NHTSA) in three volumes, and a brief version was produced by the American Automobile Association (AAA) Foundation for Traffic Safety.[55]

The Cross study identified common bicycle-motor vehicle crashes, and classified them into 37 types within 7 major categories. (See table 14.) An average percentage of fatalities and injuries and the median age of the bicyclists involved were determined for each crash type. This study determined the relationship between age and crash type, thus allowing educational objectives to be targeted to the age group most affected.

Subsequent studies such as those conducted in Missoula, MT and Madison, WI, have identified local variations from the national averages reported by Cross.[56,57] Both studies were conducted in cities where university students account for approximately 22 percent of the total population.

In the 16 years since the Cross study was completed, its data have obviously become dated, but its approach has aged remarkably well. There are some aspects of the authors' typing system that could use modification. For instance, there are several important bicycle-motor vehicle crash types that were not identified by the study. These include bicyclists hitting opening doors of parked cars, among other things.

In Boston, for example, this type accounted for 5.3 percent of crashes.[58] In addition, changes such as the proportion of adult-to-child bicyclists and the amount of riding they do, and the increase in the number of motor vehicles and their use have created a markedly different environment than the one Cross and Fisher studied. Future research must not only consider bicycle-non-motor vehicle crash types, but also the severity of all types of crashes.

Table 14. Bicycle-motor vehicle crash types, including percentage of injuries and fatalities, and median age.

Class/Type		Injuries	Fatalities	Median
Class A:	Bicycle ride-out from driveway, alley, and other midblock location	13.9%	15.1%	
Type 1:	residential driveway ride-out	5.7	6.7	9.8
Type 2:	commercial driveway ride-out	3.2	2.4	13.8
Type 3:	parallel direction driveway ride-out	2.5	3.6	11.5
Type 4:	ride-out over curb or shoulder	2.5	3.6	11.5
Class B:	Bicycle ride-out at controlled intersection	17.0	12.0	11.8
Type 5:	stope sign or yield sign	10.2	7.8	16.1
Type 6:	cyclist caught in signal phase change	3.1	0.6	15.2
Type 7:	multiple-threat at intersection	2.0	2.4	
Class C:	Motorist turn/merge/drive-through/drive-out	18.7	2.4	
Type 8:	motorist drive-out from commercial driveway/alley	5.3	0.0	15.4
Type 9:	motorist failure-to-yield at stop/yield sign	10.2	1.2	16.3
Type 10:	motorist failure-to-yield at signal	1.0	0.0	13.3
Type 11:	motorist backing from driveway	0.8	0.0	-
Type 12:	motorist didn't slow or stop for signal	0.5	1.2	-
Class D:	Motorist overtaking/overtaking threat	10.5	37.8	
Type 13:	motorist overtaking/cyclist unseen	4.0	24.6	18.1
Type 14:	motorist overtaking/out of control	0.7	4.2	-
Type 15:	motorist overtaking/counteractive evasive action	1.7	2.4	12.3
Type 16:	motorist overtaking/misjudged spaces required to pass	2.0	1.8	15.0
Type 17:	motorist overtaking/cyclist's path obstructed	2.0	0.6	16.3
Class E:	Bicyclist unexpected turn/swerve	14.2	16.2	
Type 18:	bicyclist unexpected left turn/parallel paths same direction	8.4	8.4	12.7
Type 19:	bicyclist unexpected left turn/parallel paths opposite direction	3.2	3.0	13.8
Type 20:	bicyclist unexpected left swerve/parallel paths same direction	1.5	3.0	11.5
Type 21:	wrong-way bicyclist turns right/parallel paths	1.1	1.2	-
Class F:	Motorist unexpected turn	14.5	2.4	
Type 22:	motorist unexpected left turn/parallel paths same direction	1.3	0.6	15.9
Type 23:	motorist unexpected left turn/parallel paths opposite direction	7.6	0.0	20.1
Type 24:	motorist unexpected right turn/parallel paths same direction	5.6	1.8	16.8
Class G:	Other	11.2	13.8	12.4
Type 25:	uncontrolled intersection/orthogonal paths	2.8	0.6	12.9
Type 26:	head-on/wrong-way bicyclist	3.6	2.4	-

Table 14. Bicycle-motor vehicle crash types, including percentage of injuries and fatalities, and median age (continued).

Class/Type		Injuries	Fatalities	Median Age
Class G:	Other (continued)			
Type 27:	bicyclist overtaking car	0.9	0.6	-
Type 28:	head-on/wrong-way motorist	0.8	1.8	-
Type 29:	parking lot	0.8	0.6	-
Type 30:	head-on/counteractive evasive action	0.1	0.0	-
Type 31:	bicyclist cuts corner when turning left	0.0	0.6	-
Type 32:	bicyclist swings wide when turning right	0.3	0.0	-
Type 33:	motorist cuts corner when turning left	0.4	0.0	-
Type 34:	motorist swings wide when turning right	0.1	0.0	-
Type 35:	motorist drive-out from on-street parking	0.3	0.0	-
Type 36:	weird (everything else)	1.1	-	-
Type 37:	insufficient information to classify	-	7.2	-

Source: Cross and Fisher[46]

BICYCLIST BEHAVIOR

The potential for bicyclist behavior to cause a crash varies according to the behavior. A Canadian study in Winnipeg observed 900 bicyclists' actions and compared them to 2,300 crashes over 13 years. Bicyclist failure to stop or yield was rare in observations, but when it did occur, it was more likely to cause a collision. Less than 3 percent of bicyclists observed had failed to obey a red light or a stop sign, and yet this behavior accounted for 11 percent of crashes. Conversely, nearly 25 percent were observed riding on the sidewalk or in a crosswalk, which was a factor in 14 percent of crashes.[54] (see table 15)

Various studies have found most crashes were primarily due to some form of human error and very few were due to environmental conditions.[50,59] Nationally, police reported one or more bicyclists errors that may have contributed to 64.6 percent of the bicycle-motor vehicle fatalities in 1991. The most common were bicyclist failure to yield (21.8 percent), improper crossing of roadway or intersection (12.6 percent), and failure to obey traffic signs, signals, or a police officer (8.6 percent).[60]

Studies in Oregon, Arizona, and Kansas found bicyclist errors contributed to 21 to 64 percent of the crashes in which they were involved.[61-63] Taken at face value, these data may mask the failure of motorists to search for and yield to bicycle traffic, as well as the low level of police training in investigating bicycle-motor vehicle crashes. An Ontario, Canada study reported bicyclist fault as a function of age: 5- to 14-year-old bicyclists were at fault in 77 percent of the crashes, while bicyclists 15 years of age and older were at fault in 39 percent of the crashes.[64] Table 16 summarizes the specific bicyclist behavior cited as having caused crashes in some recently conducted studies. Similar results have been noted in other countries.[43]

Table 15. Bicyclist behavior and incidence of crashes.

Cyclist Action	% of Observations	% of Accidents
Disobeyed stop sign/red light	2.4	11.1
Failed to yield right-of-way	0.2	15.1
On sidewalk/in crosswalk	23.8	14.3
Improper left turn	8.9	5.1
Proceeding from right-turn-only lane	8.1	0.3
Too close to parked cars	0.5*	4.7
Overtaking between traffic and curb	3.2	2.9
Weaving	1.7	4.4
In bus bay	10.1	0.0
Riding wrong way	2.4	7.6*
Lack of night-time equipment	None Made	10.0
Sample size	900	2,293

*Only 10 observations made.
**Includes wrong-way riding on a sidewalk or in a crosswalk.

Source: Thom and Clayton[51]

MOTORIST BEHAVIOR AND OTHER FACTORS

Bicyclist safety can be significantly compromised by motorist behavior. Drinking or using drugs before driving or traveling at speeds in excess of posted limits or what is appropriate for conditions lead to a significant number of crashes. Other factors include motorist inexperience, fatigue, night vision impairment, inattention, and failure to search for nonmotorized traffic. The threat each of these behaviors pose to bicyclists has not been adequately quantified.

In addition, the opportunity for motorist distraction grows with the increased use of in-car technology not related to the driving process, such as cassette decks, telephones, FAX machines, and computers. For instance, the effect of motorist use of cellular phones while actually driving has been shown to have a potentially threatening impact on bicyclists. An estimated 12 percent of motorists placing a call on a cellular phone go out of their lane while doing so. Complex, intense conversation increases the likelihood the motorist will fail to respond to traffic situations or will do so with an increased response time.[65,66]

Table 16. Sample bicycle-motor vehicle crash causes: national; Oregon (statewide); Denver, CO; and Winnipeg, Man. (Canada).

Behavior	**FARS[1]**	**OR[2]**	**Denver[3]**	**Winnepeg[4]**
Bicyclist failure to yield	21.8%	6.0%	-	15.0%
Bicyclist improper crossing, crossing roadway/intersection	12.6%	-	-	-
Failure to obey traffic signs, signals, or officer	8.6%	8.0%	12.8%	11.0%
Bicyclist inattention	7.5%	-	-	-
Bicyclist erratic, reckless, careless, negligent	5.6%	-	-	-
Bicyclist rideout-driveway	-	-	5.3%	-
Bicyclist enters/leaves midblock	-	10.0%	-	-
Bicyclist on sidewalk, wrong-way riding	-	-	-	13.0%
Bicyclist wrong way	-	14.0%	-	-
Bicyclist no nighttime equipment	-	-	-	10.0%
Motorist driving too fast	21.0%	-	-	-
Motorist inattentive (talking, eating, etc.)	16.0%	-	-	-
Motorist vision obscured	14.0%	-	-	-
Motorist failure to yield	-	17.0%	-	20.0%
Motorist failure to yield at signal	-	-	16.6%	-
Motorist failure to yield at stop sign	-	-	14.3%	-
Motorist driveout-driveway/alley	-	-	11.7%	-
Motorist improper right turn	-	-	-	5.0%
Motorist improper overtaking	-	-	-	3.0%
Motorist enters/leaves midblock	-	13.0%	-	-

[1] NHTSA, 1993[(60)] (Note: FARS contains information on fatal crashes only. Other sources include injury crashes as well).
[2] Oregon DOT, 1991 and 1992[(61)]
[3] City of Denver, 1992[(59)]
[4] Thom, 1992[(54)]

This distraction is two to three times greater among drivers over 50 years of age. The consequences of these distractions place bicyclists at risk while narrow lanes or narrow shoulders offer little margin for evasive action by either road user.

Bicyclists' safety can also be compromised by accommodations designed to facilitate motor vehicle traffic. Legislation to permit motorists to make a right turn on a red traffic signal after a stop was enacted as a means to reduce traffic congestion and air pollution from idling vehicles. However, in practice, often only the second half of this two-step process is executed — right turn on red. Theoretically, the "after-stop" first step was to have provided a level of safety similar to that of a motorist turning right at a green traffic signal. In most urban areas a majority of motorists fail to stop before turning and sometimes barely even seem to decrease their speed. Even the accepted shorthand references to this modification of the traffic code omit the critical first step — stop.

Preusser et al. studied "The Effect of Right-Turn-on-Red on Pedestrian and Bicyclist Accidents" following the adoption of right-turn-on-red (RTOR) legislation.[67] They found immediate 72- to 123-percent increases in crashes where bicyclists were hit by motorists turning right at signalized intersections. Among all types of bicyclist crashes, those involving RTOR increased 99 percent from 1.40 to 2.79 percent. Few fatalities were noted in these types of crashes due to slower motorist speeds.

Three-quarters of RTOR crashes involved bicyclists riding the wrong way or on the roadway or sidewalk coming from the motorist's right. In the 1980's, confusion continued as to which side of the road a bicyclist should be riding on — throughout the 1970's, bicyclists were still being taught by the police and others to ride against traffic, and this was a difficult habit to break. The Preusser research was conducted between 1973 and 1978 when some bicyclists were still being taught to ride against traffic. Subsequent education of bicyclists regarding the correct direction of travel may have reduced the incidence of wrong-way riding.

Absent from suggested RTOR-accident countermeasures is the role of traffic enforcement in monitoring compliance with this two-step process or any mention of motorist education to stop, and to search for both bicyclists and pedestrians before proceeding.

The type of motor vehicle involved also appears to be a factor in fatal bicycle-motor vehicle crashes although no research was found to explain why or provide driver profiles. Nationally, light trucks represent 20 percent of all registered motor vehicles and yet, in 1991, they were involved in 31 percent of bicyclist fatalities. Passenger cars, which represent 74 percent of registered motor vehicles, were involved in 53 percent of these fatalities.[60] Parts of the United States are tracking and reporting on this phenomena. In King County, WA, light trucks are involved in 21.6 percent of the crashes and yet, account for only 15 percent of registered vehicles in the county. Crashes between bicyclists and motorists driving heavy trucks or buses were in proportion to the number of these vehicles registered in the county.[68] In Arizona, light trucks and vans are involved in 50 percent of the bicycle fatalities, but only 12.2 percent of them are registered in the State.[62]

ALCOHOL INVOLVEMENT

The role of alcohol consumption in bicycle-motor vehicle crashes is important enough to deserve more attention. While less than 1 percent of emergency room-treated bicycle-related injuries are reported to involve alcohol on the part of the bicyclist, alcohol consumption —

either by the motorist or the bicyclist — is a factor in one-third of bicyclist fatalities.[49,53] Less than two-thirds of fatally injured bicyclists are tested for alcohol, and what motorist testing is conducted is further limited by the 12 percent of fatal crashes that are "hit and run."[48]

A Wisconsin DOT study reported 201 crashes involving alcohol-impaired bicyclists who were either injured or killed between 1987 and 1991.[69] Male bicyclists were involved in 70 percent of all crashes during this period, but were involved in 88 percent of all alcohol-impaired crashes. These crashes typically involved males 21 to 34 years old, riding on urban streets between 8 p.m. and 4 a.m. during summer weekends.

The biggest difference between drinking bicyclists involved in crashes and crashes with non-drinkers is age. Fifty-nine percent of drinking bicyclist crashes involve adults 21 to 34 years old, compared to the 56 percent of non-drinking bicyclist crashes that involve children 5 to 15 years old. Fifty-two percent of drinking bicyclist crashes happen at night, compared to 10 percent of non-drinking bicyclist crashes that happen at night.[69]

Observations reported in the Wisconsin study offer suggestions for targeted countermeasures. The study made the distinction between "a [bi]cyclist riding drunk" and the perhaps more likely scenario of "a drunk riding a bike." It also found 63 percent of these drinking crashes occurred in urban counties, suggesting the possibility that those involved may tend to rely on a bicycle as a means of transportation. Whereas drinking and driving are against the law and the target of safety campaigns, the focus has been on driving a motor vehicle. For a motorist with a suspended license or too impaired to drive, walking and bicycling continue to be widely accepted alternatives.[69]

Nationally, over one-third of motorists and/or bicyclists involved in fatal bicycle crashes were alcohol-impaired. In King County, WA, only 40 percent of drunk drivers were issued citations.[68] Only one-quarter of all traumatic brain injured 15- to 19-year-old bicyclists were tested in one study, but over one-half of them had a positive blood alcohol test.[70]

BICYCLIST AGE

While the overall number of bicycling fatalities has decreased over the years, the proportion of adult bicyclists killed has continued to increase and has become the majority. To understand the significance of this trend, consider that in 1977, just 22 percent of bicyclists killed were 21 years of age or older. Fifteen years later, this proportion has grown to 51 percent of bicyclists killed, and 58 percent of bicyclists killed were over 16 years of age.[71,72]

Some researchers have attempted to assess risk for different age groups by comparing the fatality statistics with the overall populations within each group. However, this approach is unlikely to provide reliable data. For example, the death rate per million population is highest among 11 to 14 year olds; this age group accounted for approximately 25 percent of the fatalities in 1992. However, a majority of the 11- to 14-year-old population rides bicycles. At the same time, nearly 26 percent of the bicycling fatalities involved bicyclists between 25 and 44 years of age. The proportion of people in this age group who ride bicycles is lower than that of people between 11 and 14 years of age.[72]

A potentially useful approach was taken by Baker et al. who used NPTS trip data for different age groups and compared it with injury data from NEISS and fatality information from FARS.[48] In this way, they were able to estimate overall injury and death rates for bicyclists of different ages. However, much more needs to be done on this topic, including research on the kinds of crashes involved, their severity, and the specific ages involved.

The demographics of those injured has remained constant despite the continued aging of the fatally injured bicyclist population. Seventy percent are children under 15 years of age with those between 5 and 14 years of age accounting for 61 percent of the emergency room visits. One hypothesis for children being over-represented in this data is that injured children may be more likely to be brought to the emergency room to be checked out whereas similarly injured adults may treat themselves at home or wait to visit a personal physician. NEISS only tracks emergency room visits and does not include treatment by others such as personal physicians, college and workplace health clinics, or school nurses.

Numerous cities have conducted crash studies in which the typical bicyclist ages have varied significantly from those found in the Cross study. Two such communities, Madison, WI, and Missoula, MT, are well-known "bicycle towns" with large university student populations. In the Madison crashes, only 12.4 percent of bicyclists involved were under 15 years of age vs. Cross's national finding in the mid-1970's of 63.3 percent under 16 years of age. One-third of the bicyclists in the Madison crashes were 20 to 24 years old, and as might be expected, they were involved in crashes typically associated with adults. For example, "motorist left turn, bicyclist approaching from the opposite direction" accounted for over three times as many crashes in Madison than had been found in the Cross study (23.3 percent vs. 7.6 percent).[57]

GENDER

Gender consistently plays a role in bicycle-related crashes. Male bicyclists continue to be the most likely victims of fatal crashes. On average, for the past 10 years, 85 percent of the bicycle-motor vehicle fatalities have involved male bicyclists. The 1992 FARS data showed that 88 percent of the fatality victims were male (table 13).[53]

With respect to non-fatal crashes, 71 percent of the injured bicyclists in the Cross study were male.[46] This figure compares well with more current data. For example, over the years, approximately 69 percent of bicyclists in the NEISS data have been male.[49] This proportion carries across all age groups, except for those over 65 years of age where females account for nearly 50 percent of those injured.

In a study conducted in Madison, WI, researchers found that nearly twice as many females were involved in reported bike crashes as was the case in the Cross study (32.6 percent vs. 17.5 percent).[57]

TIMING

While fatal bicycle crashes occur throughout the year, the week, and the day, there are some clear patterns. Sixty-one percent of fatalities occur between May and September, and the majority of these occur in June, July, and August. Forty-four percent are killed on Friday, Saturday, or Sunday; but the highest single day for deaths is Monday.[60]

Nearly half of the fatal crashes happen between 3 and 9 p.m. Of those crashes, 52 percent occur between 3 and 6 p.m. and 48 percent occur between 6 and 9 p.m. Logically, these periods are also times of heavy bicycle and motor vehicle use. However, the role of darkness and the impact of low-light glare are also likely to be a significant factor. Many observers suggest that bicycle use falls off at night, but there are still a relatively large number of bicycling deaths occurring during the hours of darkness. Unfortunately, definitive data are unavailable because the time at which dusk occurs varies throughout the year and throughout the country. These changes have not been factored into the picture.

Even so, some limited data are available. According to Cross and Fisher, about 17 percent of the crashes they studied occurred during darkness.[46] They also found a significant difference between the proportion of fatal crashes occurring after dark (30 percent) and the proportion of non-fatal crashes occurring at that time (10 percent). Since the Cross study was completed in the mid-1970's, more study is needed to understand the current situation.

LOCATION

In terms of general land use, more fatal bicycle-motor vehicle crashes occur in urban areas than in rural areas (61 percent vs. 39 percent). When considering non-fatal crashes, the difference between urban and rural areas is even more pronounced. The Cross study suggested that 89 percent of non-fatal crashes occurred in urban areas, while 11 percent happened in rural areas. Several considerations are likely to influence the greater proportion of fatal crashes happening in rural areas. First, many rural roads have high posted speed limits and, as a result, the crashes that do occur tend to be more serious. Second, the time between the crash and the start of trained emergency medical treatment is an important factor in the victim's likelihood of survival. In rural areas, an injured bicyclist may have to wait longer for aid to arrive and may have farther to travel to reach an adequately equipped medical facility than a bicyclist injured in an urban area.

Proximity to the bicyclist's home is another aspect of bicycle-motor vehicle crashes worth considering. The typical crash happens within 1 mi (1.6 km) of the bicyclist's house. In the Cross study, for instance, the median distance between the crash site and the operator's home was 0.6 mi (0.97 km).[46] In a 6-month study of emergency room-treated bicyclists under 19 years of age, researchers in Philadelphia, PA, found that 84 percent of these crashes had occurred less than 5 blocks from home.[73]

Overall, 50 to 60 percent of bicyclist crashes resulting in injuries occur at either roadway or driveway/alley intersections. The percentage of intersection crashes is lower for fatal bicycle crashes that most commonly occur on major roads (54 percent) and at locations other than intersections (68 percent).[60] A study of police-reported crashes in North Carolina between 1988 and 1990 found that bicyclists over 20 years of age were more likely to be involved in a crash at an intersection than were younger riders.[53,74]

ECONOMIC IMPACTS OF BICYCLE-MOTOR VEHICLE CRASHES

The total economic impact of motor vehicle crashes in 1990 was $137.5 billion. Bicycle-motor vehicle crashes account for $3 billion. These economic impacts include medical, property, lost productivity, premature funeral, emergency services, vocational rehabilitation, lost household productivity, workplace costs, insurance administration, legal and court costs, and travel delays for both the bicyclist and the motorist involved.[31]

In Florida, the cost of bicyclist injuries is estimated at $13.9 million, and the cost of bicyclist fatalities is $49.1 million.[75]

NON-MOTOR VEHICLE-RELATED BICYCLE CRASHES

Sources for detailed data on non-motor vehicle-related (NMV) bicycle crashes are very limited. Non-motorized crash types have not been systematically identified and yet 83 to 91 percent of emergency room-treated injuries are due to non-motorized crashes. Harborview Injury Prevention Research Center in Seattle, WA, for example, estimates 50 percent of crashes producing serious injuries do not involve motor vehicles.[68] While emergency room data may give the overall magnitude of the problem and the severity of the injury, it does not tell how the crashes happened. For example, there is nothing comparable to the Cross study for NMV crashes. In the absence of such information, surveys conducted in various jurisdictions can provide a tentative understanding of the problem. These are the source for the following information. Changes in bicycling since they were conducted must be kept in mind.

The vast majority of bicycle crashes involve a lone bicyclist losing control and falling or hitting an obstacle. Typically, surveys conducted by Barton-Aschman Associates in 1974 and 1975 and reported on in the Cross study showed that such scenarios account for between 80 percent and 90 percent of all NMV bicycle crashes.[46] Other crash types are significantly less common. Bicycle-bicycle collisions typically account for between 9 percent and 11 percent of NMV crashes. And bicycle-pedestrian collisions result in approximately 1 percent of all NMV crashes.

It is important to note, however, that these relative proportions may be more applicable in large statewide surveys than in particular communities, especially those with college or university campuses. Another study reported on by Cross found that in Santa Barbara, CA, 52 percent of the NMV crashes involved falls or collisions with objects, while 42 percent involved bicycle-bicycle crashes, and 6 percent involved bicycle-pedestrian crashes.[46]

BICYCLING INJURIES

As mentioned earlier, the demographics of fatal bicycle-motor vehicle crashes are different from those of non-fatal crashes. A non-fatal crash is much less likely to have involved a motor vehicle and is much less likely to cause serious injury. Studies of bicycle-related injuries treated in hospital emergency rooms have found between 9.4 and 17 percent of these patients had been hit by a motor vehicle.[49,73] Some of the other causes of non-fatal injuries include collisions with other bicyclists, fixed objects, pedestrians, or animals; falling on slippery or uneven surfaces; becoming caught on some part of the bicycle; riding too fast; and to a lesser extent, mechanical problems with the bike.[76]

In 1992, the National Electronic Injury Surveillance System (NEISS) estimates that there were 649,808 people treated in hospital emergency rooms for injuries they reported were related to bicycles. This includes those who had been riding a bicycle, had been hit by a bicycle, and even those who had tripped over a bicycle in the garage.[49]

Only data collected since 1990 can be used to note historical trends as the NEISS hospital emergency room sample was updated at that time. Between 1990 and 1992, the estimated number of bicycle-related emergency room visits increased 12 percent (see tables 17 and 18.)

Of the 649,808 bicyclists who sought emergency room treatment, less than 4 percent were hospitalized. In 1992, 89 percent of bicyclist injuries were coded in the the lower four of eight injury severity categories. These first four categories represent injuries ranging from no injury (2 percent) to such injuries as crushed fingers, lacerated head, or punctured eye (21 percent). [It must be noted here that the examples of injuries in each category are drawn from all NEISS product-related injuries and, as such, each may not necessarily be present in the bicycle-related injury subset.] Bicyclists under 15 years of age tend to be better represented in the least severe injury categories and somewhat less represented in the three most severe categories.[51] In a study of 10 North Carolina hospital emergency rooms, the most severe injuries were sustained by those bicyclists 45 years of age and older.[50]

Sixty-nine percent of bicycle injuries occur between May and September, with 45 percent occurring in June, July, and August.[49] A more comprehensive study of emergency room bicycle-related injuries conducted by the Consumer Product Safety Commission found 60 percent of these bicyclists' falls and crashes occurred between 3 and 9 p.m. Crashes involving children under age 15 and adults over age 65 were more likely to occur in the evening between 6 and 9 p.m. Crashes involving those between 15 and 64 years of age were more likely to occur in the afternoon between 3 and 6 p.m.[76]

The character of bicycle-related injuries is, in part, defined by the NEISS information; however, little can be inferred about injuries that are not treated in emergency rooms. During a 2-year period in New York, SHASIRS (Scholastic Head and Spine Injury Reporting System) monitored 83,000 children in grades K-12 and found only 55 percent of any type of

Table 17. Bicycle-related hospital emergency room visits - 1990 to 1992 by age.

Age	1990	1991	1992
Unknown	34	275	85
0-4	49,981	53,474	59,050
5-14	333,352	350,793	394,135
15-24	94,954	87,906	85,184
25-44	73,581	78,936	78,802
45-64	21,928	21,800	23,780
65+	6,289	7,988	8,772
Total	580,119	601,172	649,808

Source: NEISS[49]

Table 18. Bicycle-related hospital emergency room visits - 1990 to 1992 by sex.

	1990	1991	1992
Male	398,493	413,701	448,736
Female	181,421	187,306	201,037
Total	580,119	601,172	649,808

Source: NEISS[49]

head and spine injury were seen in a hospital emergency room.[77] Although many of these injuries involved some type of less-serious general trauma, such as lacerations and abrasions, they were serious enough to keep the child out of school a portion of 1 or more days.

In the SHASIRS study, a head injury was defined as any injury to the head that resulted in lost time from school. This included anything from minor abrasions to death. The authors chose this inclusive definition because they found no standard definition of head injury and no generally accepted diagnostic criteria, methodology, or severity index to quantify the head injury.

Four percent of all injured children in SHASIRS had a bicycle-related injury and 92 percent of them were not wearing a helmet at the time. Three percent of head and spine injuries to children 10 to 19 years of age were bicycle-related.[77]

EXPOSURE

Currently, there is no agreement as to just what constitutes an appropriate measure of exposure. At the same time, exposure measures could answer some very important questions — such as the relationship of crashes to the amount of time spent riding, the number of trips taken, a bicyclist's age, the amount and type of bicycling experience, and the traffic context. Crashes involving elementary school children, college-age adults, and adult bicycle club members have been studied at different times between 1969 and 1976, and the resulting crash rates determined through the number of miles traveled varied from a low of 0.109 per 1000 mi (1600 km) for male bicycle club members to a high of 1.79 per 1000 mi (1600 km) for female elementary school students.[46,47,78]

More recently, other authors have used a measure based on the number of crashes per million bicycle trips.[47] This 1993 study of 1991 data found that bicyclists suffered 296.2 injuries and 0.54 deaths per million trips. The authors differentiated between bicyclists of different ages, genders, and between trips taken at different times of day. The results of studies such as this give an indication of what could be discovered.

CONCLUSIONS

Attempting to base conclusive statements on the available bicycle-crash research is difficult and tentative at best. National data sources, while useful, seldom provide sufficient detail from which to create programs and countermeasure strategies. This is true for both fatal and non-fatal crashes, as well as for bicycle-motor vehicle crashes and non-motor vehicle-related crashes. Some studies, while based on a sound research approach, are sadly dated; the world has changed significantly since the mid-1970's. Others use different approaches to crash categorization or age differentiation, making comparisons difficult. Even so, the importance of studying bicycle crashes can hardly be denied. And, it is hoped that improvements in both the quantity and quality of future research will improve significantly.

SECTION 3. INTERSECTION COUNTERMEASURES

INTRODUCTION

Based on the statistics and trends presented in section 2, it is clear that intersections are a significant source of conflict and potential danger for bicyclists. This section is designed to identify available countermeasures to these common bicycle-motor vehicle conflicts that have been implemented and evaluated in recent years. Sections 4, 5, and 6 are designed to address not only crash avoidance, but also the need to promote bicycling through the elimination of barriers and environmental disincentives.

> The *Minnesota Bikeway Design Manual* (1983) has one of the most complete sections covering intersection treatments for bicyclists, and comments that:
>
> It must be remembered that there is no single measure that will provide a primary solution to the intersection problem. Each intersection must be studied individually.[79]

By way of example, the Manual lists some of the potential causes of conflict at intersections:

- Poor visibility to the right rear of a motor vehicle.
- Driver lacks expectation of encountering a through vehicle — the bicyclist — to their right, or left-turning bicycle "in the middle of the road."
- Poor driver perception of bicyclist's speed.
- Pre-occupation of the motorist with other motor vehicle traffic, pedestrians, etc.
- Motorist's expectation that bicyclist will yield to "bigger" vehicle.
- Failure to signal for the turn.

These sources of conflict can be influenced by lane markings, warning signs, speeds, driver and cyclist behavior, signaling, and traffic controls.

For bicyclists, intersections are often the most threatening of locations, as well as the most likely place for a crash to occur. They can also be the most confusing, and the place where they are offered the least assistance by roadway planners and engineers. In addition, many suburban intersections have been built wider to accept more motor vheicle capacity and this has increased bicyclist exposure to traffic. This section of the synthesis will review research and other reports related to a number of specific problems and issues that arise at intersections and driveways.

STOP SIGNS

Anywhere between 2 percent (Boston, MA) and 12 percent (King County, WA) of crashes involving bicyclists identify failure to stop at a stop sign as a primary cause.[58,68] Children are particularly vulnerable to this kind of crash. A significant number of crashes are also caused by motorists failing to stop at stop signs or yield at intersections (for example, 14 percent of crashes in Denver, CO).[59]

Thom (1992) observed less than 3 percent of bicyclists disobeying stop signs at selected sites in Winnipeg, Canada, yet this action contributed to 11 percent of car-bicycle collisions, suggesting "that when a bicyclist does disobey a traffic control device, the probability of a collision is high." [54]

Bicyclists do not like to stop and lose their momentum. Some bike route networks are criticized for being too circuitous and having too many stop signs, which render them unpopular with riders and may encourage bicyclists to ignore the stop signs altogether.

The city of Palo Alto, CA has experimented with the development of bicycle boulevards to help overcome these problems. The Bryant Street Bicycle Boulevard is a 3.5-mi (5.6-km) residential street that parallels two major arterials in the city. Stop signs along the route have been repositioned to give priority to traffic on Bryant Street over other residential streets, and crossings of major roads are signalized. Through-access to motor vehicles has been closed-off by five barriers, and the street is passable only on foot or bicycle. The result has been a significant increase in the numbers of bicyclists using Bryant Street, and a reduction in the number of bicyclists using the parallel arterials.[80]

The same effect can be noted in the development of trails along independent rights-of-way (e.g., abandoned railroad rights-of-way) where intersections with major highways can be grade-separated and frequent stops avoided.

CONCLUSION

Where the potential exists to develop trails and bicycle boulevards, the number of stop signs can be diminished, giving bicyclists using these facilities a significant incentive to use the facility over other parallel routes that may be slower. Where this cannot be done, education and consistent enforcement of bicyclist violations are likely to be the best solution to reducing bicycle-motor vehicle crashes at intersections controlled by stop signs.

Useful Resources

(a) City of Palo Alto, 1982. *Bicycle Boulevard Demonstration Study — Evaluation*. Dec. 9, 1982, Staff Report to City Council. Palo Alto, CA.

Description of the bicycle boulevard when first introduced as an experimental project. Available from the City of Palo Alto, CA 94303.

TRAFFIC SIGNALS

Crash studies in Oregon, Denver, CO, and Boston, MA, all record 6 percent of bicycle-motor vehicle crashes occurring as a result of bicyclists failing to stop at a traffic signal.[58,59,61] In addition, motorists failing to yield to bicyclists in the intersection at traffic signals account for 16 percent of crashes in Denver (an urban setting) and 2 percent in Oregon (a more rural setting).

Shields identifies traffic signals as an important issue for bicyclists:[81]

> One of the most frustrating and irritating aggravations a bicyclist experiences is being forced to wait long minutes for a traffic signal to change. Often, if no automobile comes along to trigger the light, the cyclist will run it, taking chances with the law and perhaps endangering his/her own life.

Bicycle club and advocacy group newsletters frequently discuss this issue and pass on advice to readers on dealing with signals that do not detect bicycles and how to trip signals.[82] They often contain detailed technical information about the types of signal detectors that do detect bicycles.

Most articles refer to San Diego's Traffic Signal-Bicycle Detection Study that provides design drawings and installation instructions for D-pole and quadrupole loops, and for helping bicyclists get old loops to work for them.[83]

FHWA identifies the North Carolina facility guideline manual as summarizing the preferred options for loop detectors:[84]

- Quadrupole loops for bicycle lanes or trails, where the position of the bicycle is predictable and consistent.
- Diagonal quadrupole loops for shared roadway conditions where the exact location of the bicycle cannot be easily predicted (figure 1).
- Standard loops are the least desirable. Some jurisdictions identify the most sensitive part of the loop with a pavement marking (figure 2).
- Loops should be kept to less than 40 ft (12 m) in length to increase their sensitivity.

Grigg (1993) reports that "bicycle detection at traffic signals is always advancing," and that the city of Palo Alto has developed a quadrocircle — a circular loop with a diagonal cut to detect bicycles (figure 3).[85] The city has also made significant efforts to educate bicyclists about the correct way to make traffic lights turn green by enclosing literature in city utility bills (figure 4).

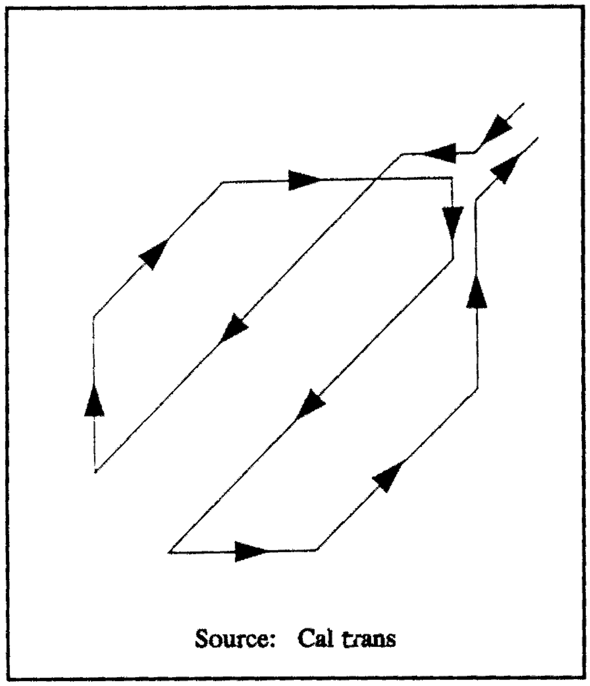


Figure 1. San Diego (CA) installation of Caltrans Type D modified quadrupole detector loop.[83]

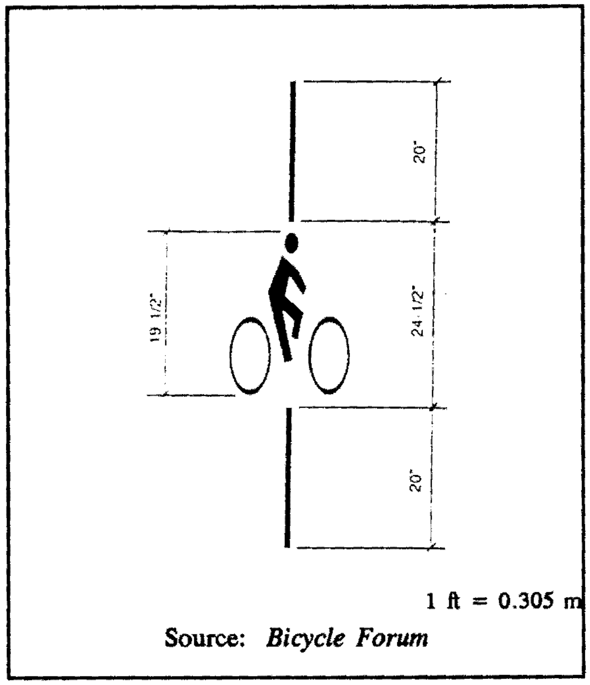


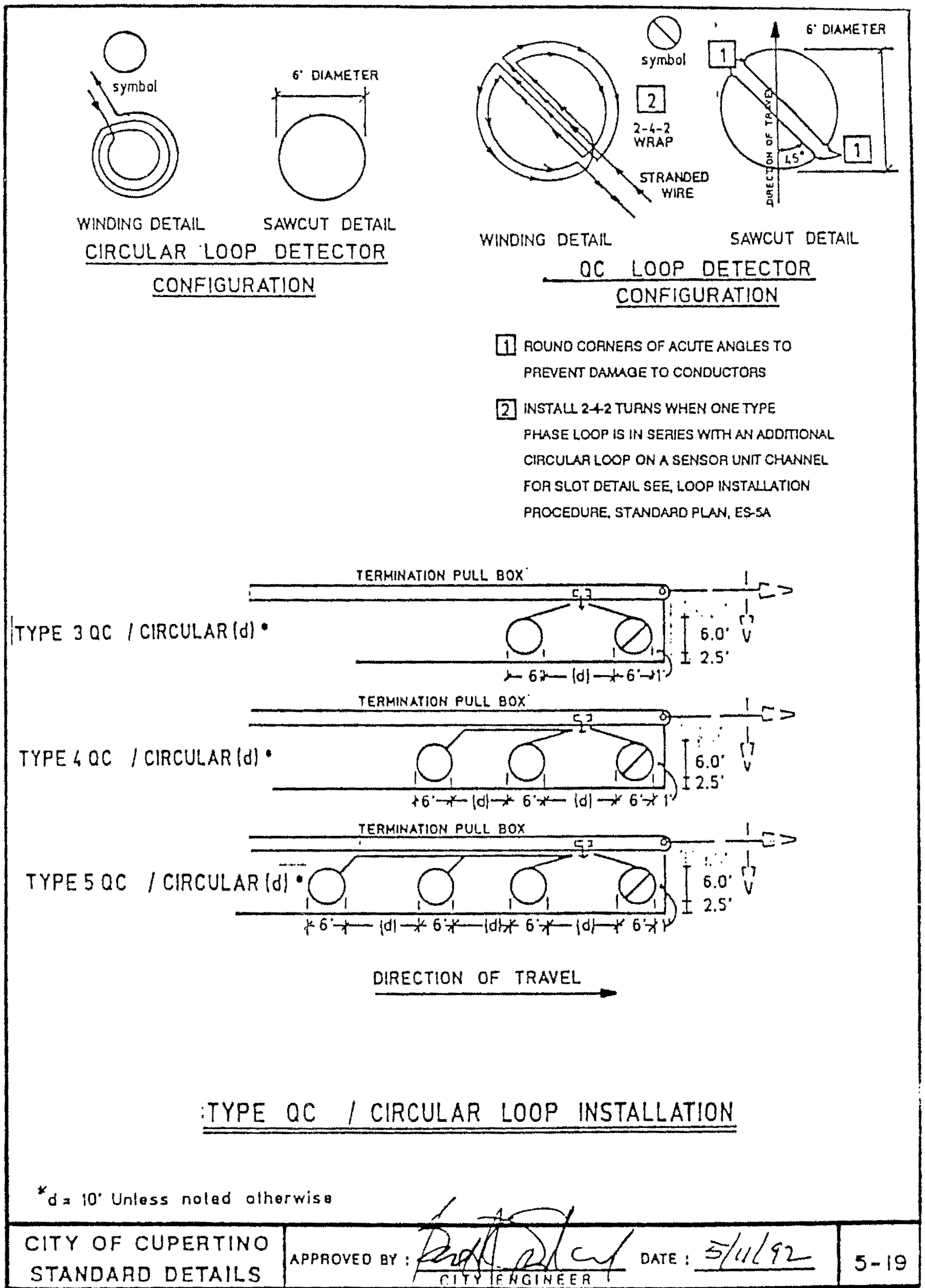
Figure 2. San Diego's pavement marking for standard square detector loops.[83]

Some agencies have recommended the use of pedestrian-style push buttons for bicyclists. However, this practice is not recommended by many advocates and engineers in the field as it can result in bicyclists — especially those seeking to turn left — being in the wrong place in the traffic flow. In addition, as the *Washington State Department of Transportation Design Manual* points out, "the use of push button actuators at bikeway intersections are not preferred by bicyclists as they must stop to actuate the signal."[86] This is certainly not an option that would be provided for automobile drivers.

If such push buttons are to be used, however, Chao et al. (1976) recommends using a cyclist push button — "a traffic signal push-button designated for bike rider use only, usually located on or near the curb line so that a cyclist can reach it while on a bicycle in the street. It is also known as a curb-mounted push-button."[87] These have a higher level of acceptance and use by bicyclists than standard pedestrian push buttons.

The timing of signals is also an issue of concern to bicyclists. Wachtel (1993) reports that "insufficient clearance time between conflicting green phases of traffic signals causes 5.9 percent of urban car-bike collisions (Forester, Bicycle Transportation, p. 265, using data from Cross)."[88] A similar phenomenon is reported in Denmark, where up to 15 percent of cyclists injured in signalized intersections had insufficient time to clear the intersection.[41]

Wachtel provides an analysis and recommendations that can be used to set and adjust signal timing at intersections where bicycle clearance-time accidents are likely, and to set timing for



Source: City of Cupertino, CA

1 ft = 0.305 m

Figure 3. Quadrocircle loops.

BICYCLING IN PALO ALTO

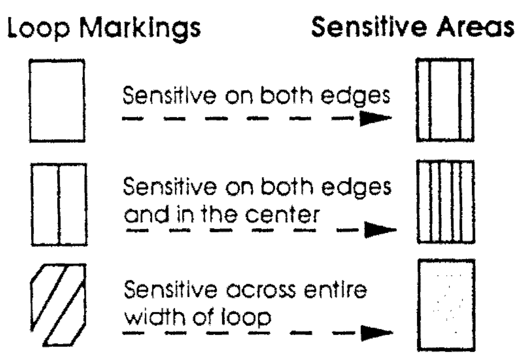
Making Traffic Lights Turn Green

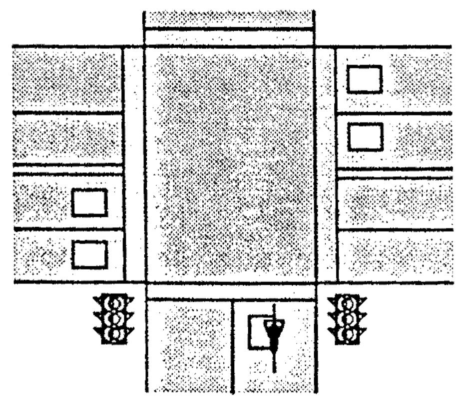
There are two types of traffic lights. **Traffic-actuated** lights are programmed to respond to changes in the flow of traffic. The length of the green light varies accordingly; heavier traffic movements receive proportionately longer green time. **Fixed-time** lights change from red to green at preset intervals. The majority of traffic lights in Palo Alto are traffic-actuated. Downtown traffic lights are fixed-time signals.

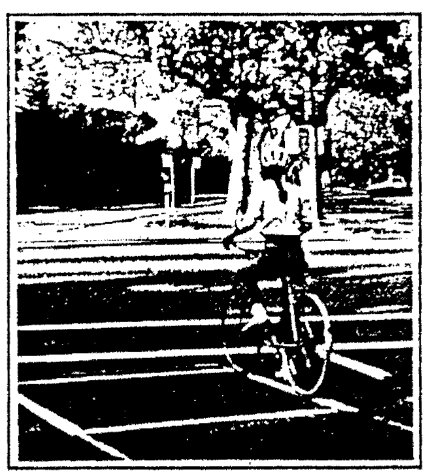
To recognize a traffic-actuated light

In most cases, loops of wire are buried in the traffic lanes before the intersection. The loops detect metal on the road above, and send a signal to a control box beside the street. Loops in Palo Alto are set to **detect small amounts of metal in a bicycle.**

There are several types of loops. The patterns used in Palo Alto are shown below. Some appear as white, painted squares or rectangles, others as thin black lines or cut marks in the pavement. The loops are **most sensitive to metal over the highlighted areas.**







To make a traffic light turn green

Stay on the sensitive area with the two wheels of your bike as shown until you get the green light. Don't leave the loop until you have a clear space in the intersection.

When riding with a group of cyclists, ride over the loop about a bicycle length apart to extend the green light. When metal is over the point of detection, the light will stay green up to a preset maximum length of time.

If you can't find the loop or the light won't change

Call the City of Palo Alto Transportation Division at 329-2520 to report the location and problem.

Source: City of Palo Alto, CA

Figure 4. Utility bill insert.

separate bicycle signal phases where they exist.[88] Currently, no standards exist for doing this, although Minnesota (1987) and Grigg provide detailed recommendations.[89]

CONCLUSION

Bicycle-sensitive traffic signal detectors are available and are being used quite extensively in California and other States. There are appropriate and effective methods of guiding bicyclists to the most sensitive part of older loop detectors to aid their detection. An appropriate formula for determining signal timing has been developed.

Useful Resources

(a) Wachtel, A. 1993. *Proposed Signal Timing for Bicyclists.* Paper to the California Bicycle Advisory Committee, Signal Timing Subcommittee.

Provides detailed formulas for setting signal timing at different types of intersection and signal configurations. Available from Caltrans, c/o Rick Blunden, 1120 N St., Room 4500, P.O. Box 942874, Sacramento, CA 95814.

(b) *Bicycle Forum #6.*

Contains discussion guidelines for signal placement in Cupertino, CA. Available from Adventure Cycling Association, P.O. Box 8318, Missoula, MT 59807.

RIGHT TURN ON RED

There are two major research studies from the early 1980's that attempted to determine the impact on bicyclists and pedestrians of right-turn-on-red (RTOR) laws.

As noted above, while the percentage of RTOR crashes involving bicyclists is small, Preusser et al. (1981) found that right-turn accidents at signalized intersections doubled after implementation of RTOR.[67] In the three States studied, the increases ranged from 73 to 123 percent for bicycle crashes. As a percentage of all bicycle crashes, right-turn crashes at signalized intersections went from 1.4 percent to 2.79 percent, an increase of 99 percent.

In their research, Preusser et al. found that 75 percent of bicyclists were coming from the drivers' right side, on the roadway and/or sidewalk — and thus were wrong-way riders. Seven percent of bicyclists were struck when proceeding with the light, coming from the left of the driver.

Zador et al. (1982) confirmed these results and also identified that the adoption of RTOR leads to larger increases in crashes in urban areas than in other areas, and that under adverse weather conditions, bicyclist crashes increase more than under normal weather conditions.[89]

CONCLUSION

Right-turn-on-red laws have had a negative impact on the safety of bicyclists. At intersections with high crash records and/or significant levels of bicycle use, RTOR prohibitions should be considered.

As a significant number of crashes in this category involve wrong-way riders, education and enforcement campaigns to discourage this activity may help reduce the incidence of this crash type. In addition, wrong-way riding (on the sidewalk) occurs because riders do not feel safe riding on the roads in traffic. Better provision for bicyclists, as outlined in the following sections, may help overcome this factor.

LIMITED-ACCESS (FREEWAY) INTERSECTIONS

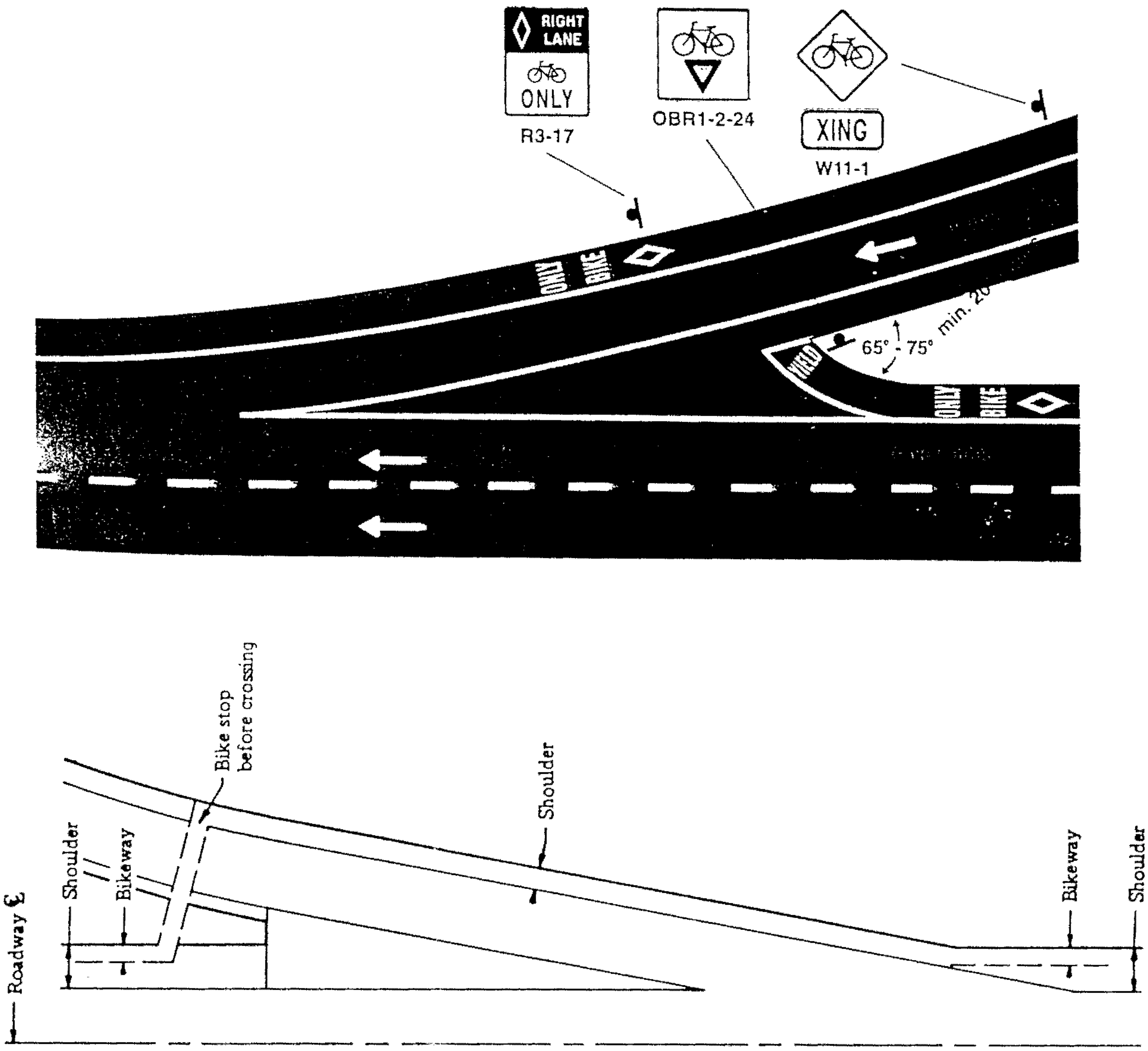
Because of the high speed differentials and length of exposure to turning and merging traffic, bicyclists are particularly intimidated by high-speed, right-lane merge intersections such as those commonly found at the entrance and exit of freeways and limited-access roads. This type of crash is not identified in any studies as a separate type as the actual number of incidents are quite small. However, these crashes are often fatal because of the high speeds involved. Although bicyclists are prohibited from riding on interstates and other limited-access highways in many States, they will eventually encounter them at road crossings. The high level of intimidation may be a significant deterrent to bicyclists using roads with these intersections.

There is still some disagreement about the best way to accommodate bicyclists in these locations. In most instances, bicyclists will either be riding on a shoulder or in the travel lane as they approach this type of intersection. The cyclist must merge with and/or cross traffic exiting and entering the freeway before continuing in the shoulder or travel lane. Where bike lanes are marked and they cross high-speed merge lanes, most manuals suggest directing bicyclists in the bike lane to a point where a crossing can be made at right-angles to the traffic, and where sight distances are good (figure 5).

Bike-lane markings do not exist at most intersections of this type. More commonly, the rider will be on a shoulder or in the travel lane. Some commentators advocate that the bicyclist remain in the travel lane and follow the motor vehicle path, regardless of whether there is a bike lane or shoulder present.

Forester (communication, 7/11/92), for example, writes:

> To make any pretense of safety, the cyclist must yield to the traffic on the on-ramp before crossing it. Yielding means looking and waiting until no traffic is coming so close as to constitute danger. Since the cyclist in the bike lane must sometimes wait to preserve his life, while he never has to do so on the vehicular route, it is clear that the bike lane route is more dangerous.[90]



Source: Oregon Department of Transportation

Figure 5. Bicycle lane at on/off ramp.

Later in the same discussion, Forester acknowledges the bike-lane route has one advantage over the vehicular route — it reduces the bicyclists' exposure to motorist error. "The question then becomes the extent to which cyclists should delay themselves by taking routes that provide greater protection from mistakes by motorists."

An experimental bicycle lane across a "slip road" in the United Kingdom and other innovative projects do not indicate any improvement in the safety of bicyclists. There was a 40-percent reduction in crashes at one sample of sites, but there were insufficient crashes to make the reduction significant.[91] The experiment led the Cyclists Touring Club (1992) to conclude that increased entry angles and narrower exit gaps are useful and that the key element is to decrease vehicle speeds.[92]

Layfield estimates the level of risk for bicyclists at these intersections is considerably higher than at other types — about 30 crashes per million bicycle movements.[93] He also notes that for every crash at the point where vehicles leave the roadway for the ramp, there are three at the point where motorists join the roadway from the ramp.

Many of these types of intersection are in suburban and rural areas where marked bike lanes are much less common than shoulders, wide curb lanes, or no special treatment at all. In these instances, the rider has little option but to choose the vehicular route and "permit judgment by the bicyclist to prevail."[86]

CONCLUSION

Where bike lanes and/or shoulders exist, bicyclists can be channeled to visible crossing points where their exposure to fast-moving motor vehicle traffic is minimized. In either case, motor vehicle speeds should be carefully controlled to ensure the safety of bicyclists. Where bike lanes and/or shoulders do not exist, engineering techniques do exist to lower the speed of entering and exiting motor vehicle traffic, for example tighter turning radii and more channelization.

Signing can be used to warn motor vehicles of the potential presence of bicyclists through the intersection.

Advice for bicyclists on negotiating this type of intersection is available, and can be adapted based on the confidence and experience of the rider. However, these intersections remain intimidating to most bicyclists, especially for the less confident and infrequent rider, and are increasingly common in suburban and rural areas. Further research could be useful to continue the development of better designs for these intersections.

Useful Resources

(a) Oregon Department of Transportation (ODOT), 1992. *Bicycle Master Plan.* Salem, OR.

Contains numerous drawings and design information for dealing with bike lanes at intersections. Available from ODOT, Technical Services Division, Transportation Building, Salem, OR 97310.

(b) Cyclists Touring Club (CTC), 1992. *Cyclists and Major Roads*. Godalming, U.K.

Combines research and practical information on dealing with bicyclists on major roads in the United Kingdom, including at freeway-style intersections. Available for £10 from the CTC, 69 Meadrow, Godalming, Surrey GU7 3HS, England.

RIGHT-TURN-ONLY LANES

The problems identified in the previous section are also often encountered where free-right-turns and right-turn-only lanes are provided at non-freeway intersections. The King County, WA, and Boston, MA, studies of bike crashes put the percentage of crashes involving right-turning vehicles at between 16 percent and 20 percent of all crashes. Neither study separates out those crashes involving right-turn lanes.[58,68]

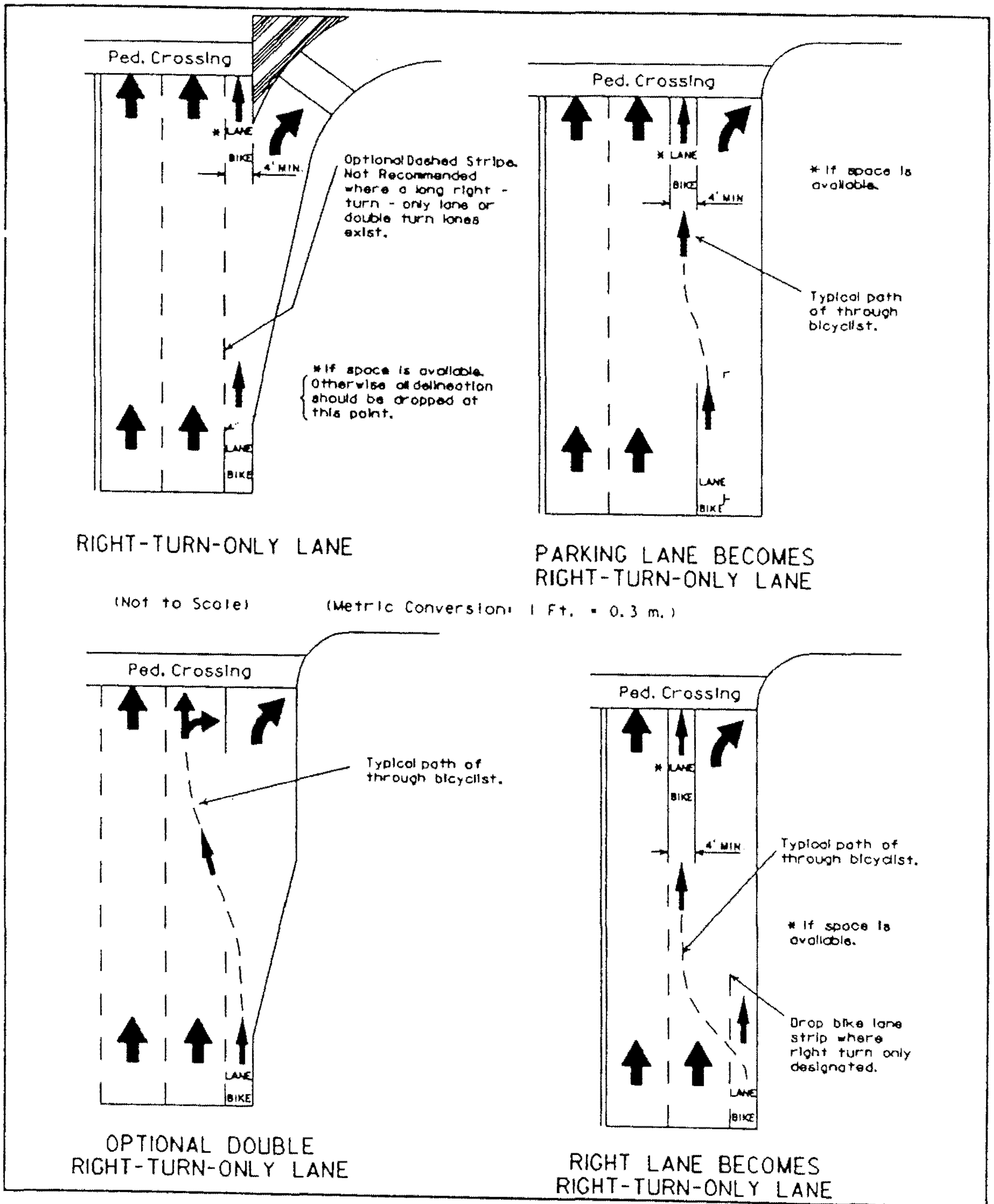
In their comparison of observed behavior and crash statistics, Thom and Clayton (1992) determined that right-turn movements were responsible for 13.3 percent of all collisions and the majority of these involved a straight-through bicyclist being hit by a right-turning motor vehicle.[54] While 8 percent of observed bicyclists proceeded straight ahead from a right-turn-only lane (two-thirds of all the bicyclists passing through the two observed intersections with right-turn-only lanes), this action contributed to only 0.3 percent of crashes. The authors note that "many cyclists either find changing lanes difficult or choose to ignore signage and pavement markings."

The essential conflict is identified in the Minnesota guide (1983):

> Minnesota State law requires the bicyclist to keep as close as practicable to the right-hand curb on the edge of the roadway. Therefore, the bicyclist should be on the right edge of the right-turn lane. This is not a desirable position, especially if the bicyclist is intending to go straight ahead.[79]

Much of the advice for highway designers in dealing with these situations is only given where bike lanes or trails already exist, or are planned in the future. The AASHTO Guide recommendations have been adopted by most agencies, and they recommend breaking bike-lane markings ahead of the intersection and then marking a bike lane again at the intersection itself, to the left of the right-turn lane at the stop bar.[94] This positions bicyclists going straight ahead away from any conflict with right-turning vehicles, and allows a merge area for right-turning vehicles to get into the right-turn lane (figure 6).

When this option is utilized, some jurisdictions (e.g., Boulder, CO) end the bicycle lane ahead of the intersection and then post signs saying "Right-Turn Vehicles Yield to Bicycles." The 1983 Minnesota manual provides this method, but also shows an example of dealing with bicyclists at these locations that is now considered inappropriate and even dangerous. They suggest channeling bicyclists onto a sidewalk or bike path and having them behave as pedestrians.[79] Crash records from Germany, Denmark, Sweden, and Japan suggest this approach is seriously flawed, especially as it can encourage wrong-way riding.[42-44]



Source: AASHTO

Figure 6. Bike lanes at intersections.

The cities of Cupertino and Davis (CA) have both modified the design shown in figure 7 for left-turning bicyclists. The bike-lane marking is striped to the right of the left-turn pocket for motorists.[89] Where there are no special facilities for bicyclists on the roadway, riders must negotiate their own way through intersections with exclusive right-turn lanes. As in the previous section, this may be feasible for confident and experienced riders, but can be intimidating for less experienced and potential bicyclists.

In a limited number of places, bicyclists in European cities may have their own traffic signal phase to separate their movement from other vehicles. At one signalized intersection in Cambridge, England, where there were heavy flows of left-turning automobiles conflicting with straight-ahead bicyclists, a unique signal-phasing was utilized to separate the different movements. Bicyclists arriving at the intersection have their own lane, separated by a curb and with a traffic signal that holds them on red until left-turning motorists are stopped by a red light.[95] A Finnish research report suggests that such arrangements can lead to a 90-percent reduction in crashes involving younger cyclists.[96]

CONCLUSIONS

On streets with bike lanes, there are appropriate designs to ensure straight-through bicyclists are well-positioned to the left of the exclusive right-turn lane. On streets with no provision for bicyclists, bicyclists and motorists must make essentially the same maneuver as if separate lanes were marked — but without the guidance offered by the bike lane marking, and without the same amount of space available to share the road at the intersection. In both instances, there are important design features to remember.

First, as the length of the right-turn lane increases, so does the exposure of the bicyclist to traffic driving on either side of them. In addition, the speed of vehicles in the right-turn lane may be greater. Thus, exclusive right-turn lanes should be kept as short as possible.

Second, continuous right-turn-only lanes should not be constructed. These leave the bicyclist exposed on both sides to fast-moving traffic and merging traffic for long periods.

Finally, as both motorists and bicyclists passing through these intersections are concentrating on their own position on the road and traffic in the intersection, there should be no driveways (e.g., into gas stations) in the intersection area.

Useful Resources

(a) AASHTO, 1991. *Guide to the Development of Bicycle Facilities*. Washington, DC.

Guide has design details for intersections with bike lanes crossing exclusive right-turn lanes. Available for $8 plus $3 postage and handling from AASHTO, 444 North Capitol St., NE, Suite 225, Washington, DC 20001.

(b) Oregon Department of Transportation (ODOT), 1992. *Bicycle Master Plan,* Salem, OR.

Contains numerous drawings and design information for dealing with bike lanes at intersections. Available from ODOT, Technical Services Division, Transportation Building, Salem, OR 97310.

ADVANCED STOP LINES

Concern over the incidence of crashes at intersections controlled by traffic signals, and the desire to encourage motorists and bicyclists to make the appropriate maneuvers from the appropriate place in the roadway, have led to a number of innovative intersection designs. This is especially true in European countries.

The Dutch, Germans, and British have all tried and tested the Advanced Stop Line intersection and variants on this basic design (figure 7). The intent with this design is to allow bicyclists to get to the front of the line of traffic at a signalized intersection and move off first — sometimes with a delayed green for motor vehicles — so that:

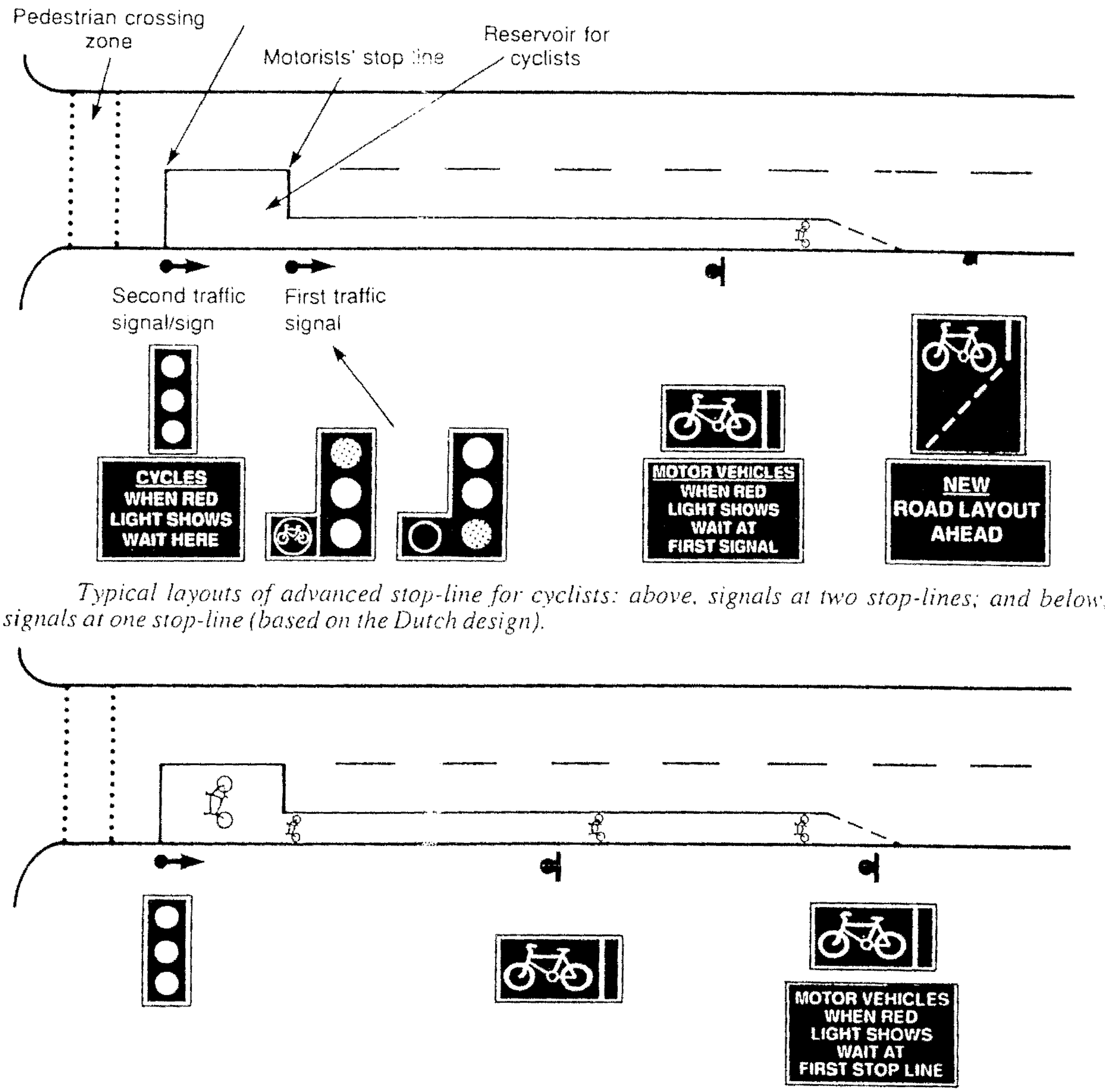
- They can avoid potential conflicts with right-turning vehicles.
- They can get into position to make a left turn.
- They have time to clear the intersection.
- The bicyclists are positioned where the motorists can clearly see them.
- The bicyclists are kept away from vehicle exhaust.

In the Netherlands, this type of intersection design is often employed simply to give bicyclists an advantage over motor vehicle traffic, and to prevent a long backup of bicyclists.

The design of these facilities is such that the maximum benefit comes when a bicyclist arrives at a red light. When the rider approaches the intersection and the light is green, the bicyclist behaves as if the intersection were a regular signal-controlled facility.

Experience with these facilities has been good. A review of five locations with intersections of this type in the United Kingdom found that the lanes and reservoirs were used satisfactorily by most bicyclists, red-light violations by bicyclists were not evident, the majority of motorists kept out of the bicycle lanes and reservoirs, and intersection capacity was not decreased. With regard to safety, the researchers could only report that "no obvious problems have arisen with the schemes studied."[97] The authors conclude that:

> The evidence so far is that advanced stop lines can be used satisfactorily on junction approaches with one or two lanes and with vehicle flows of up to 1,000 vehicles per hour.



Source: Traffic Engineering and Control, U.K.

Figure 7. Advanced stop line designs, U.K.

Further research is necessary to determine the impact of variations on the designs used so far. Similar results are reported in Denmark and Germany.[42,44]

CONCLUSIONS

Advanced stop lines and other innovative intersection designs and road markings have not been utilized in the United States despite their growing use in other countries.

Advanced stop lines should be tested at various locations in the United States to determine their applicability. In particular, attention should be given to determining traffic volumes at which advanced stop lines become desirable, the impact of RTOR, and appropriate roadway signs and markings necessary to make them effective.

Useful Resources

(a) Center for Research and Contract Standardization in Civil and Traffic Engineering - The Netherlands (C.R.O.W.), 1993. *Sign Up for the Bike: Design Manual for a Cycle-Friendly Infrastructure*. Ede, Netherlands.

A 330-page design manual, including intersection designs. Available for Dfl. 50 from C.R.O.W., P.O. Box 37, NL-6710, BA Ede, Netherlands.

(b) Wheeler, A.H. et al., 1993. *Advanced Stop-Lines for Cyclists*. Traffic Engineering and Control (TE&C), Feb. 1993. London, England.

Article describing evaluation of recent experimental advance stop-line designs at five intersections in the United Kingdom. Available from TE&C Subscription Bureau, Queen St., March, Cambs. PE15 8SN, England.

ROUNDABOUTS AND TRAFFIC CIRCLES

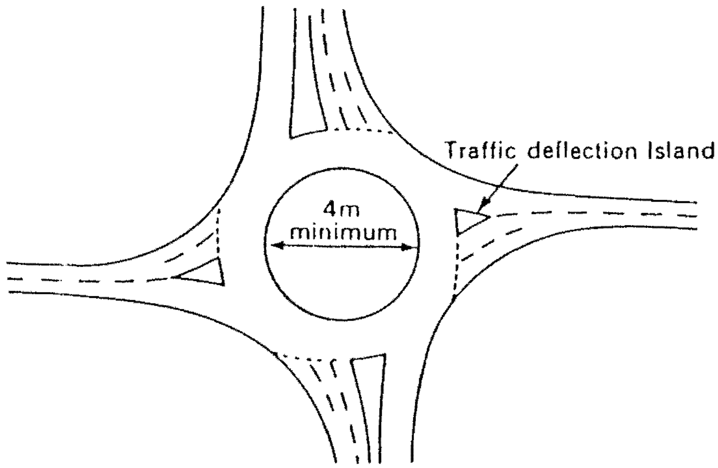
Roundabouts and traffic circles are still relatively uncommon roadway features in the United States. Crashes at these locations do not appear as a separate classification in any crash surveys and studies. However, transportation agencies do experiment with their use in a variety of locations.

There is some potential confusion about the terminology relating to roundabouts and traffic circles, and the differences between their design, function, and impact on bicyclists. In the following discussion, a definition used in this report is provided for each type of facility.

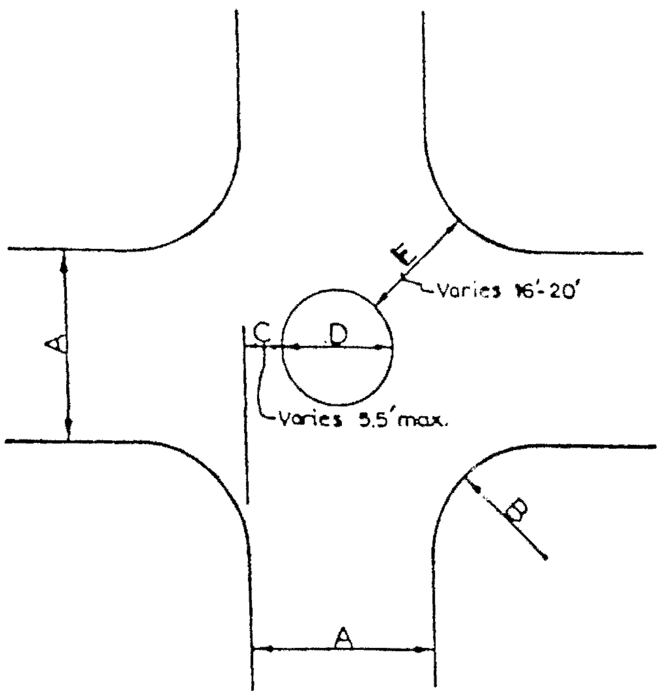
ROUNDABOUTS

Roundabouts, for the purposes of this report, have large radii and are installed at the intersection of multi-lane highways as a means of increasing capacity and traffic speeds through the intersection. A typical design for a roundabout is shown in figure 8. Their use is most common in Great Britain, where much of the research into their safety and practicality for bicyclists has been undertaken.

For example, a study by the U.K. Cyclists Touring Club (CTC) revealed that cyclist accident rates at roundabouts are up to 15 times those for cars and 2 to 3 times those for bicyclists at traffic signals.[98] Seven percent of all bicycle crashes occur at roundabouts and as many as 45 percent of crashes at roundabouts involve bicyclists or motorcyclists. The threat of



Normal Roundabout[1]



Legend:
- A Street Width
- B Curb Return Radius
- C Off-Set Distance
- D Circle Diameter
- E Opening Width

OPTIMUM CRITERIA

Off-Set Distance	Opening Width
5.5' max	16' min
5.0'	17'
4.5'	18'
4.0'	19'
3.5' or less	20'

1 ft = 0.305 m

Traffic Circle[2]

Sources:
[1] Roads and Traffic in Urban Areas, U.K. Department of Transport.
[2] Seattle Engineering Department.

Figure 8. Comparison of roundabouts and traffic circles.

roundabouts is significant. The CTC survey of their members — mostly experienced bicyclists — revealed that 28 percent choose routes that deliberately avoid roundabouts.

The study identified differences in the crash rates for different types of roundabouts, concluding that small roundabouts are the most dangerous, followed by conventional roundabouts and mini-roundabouts. Accident rates are not available for the large roundabouts.

A number of experimental designs have been tried to assist bicyclists using roundabouts, and none has been found to have general applicability. The U.K. Department of Transport has suggested in its official guidance to local authorities that where many bicyclists use (or would use) an intersection, the special requirements of bicyclists should be taken into account, and they note that no satisfactory method has been found for reducing the risk to cyclists once they have entered the circulatory system of a roundabout.(99)

Mathew notes that "there has been an appreciation with recent years that the most effective means of improving safety, especially at grade and in residential areas, is the installation of traffic signals. Early results tend to suggest significant casualty savings for cyclists."(44)

Nordic countries have been going through a similar discussion, and have been unable to determine an appropriate design for bicycle facilities through roundabouts. It is still uncertain whether roundabouts or signals are safer for bicyclists.(43)

TRAFFIC CIRCLES

Traffic circles, for the purposes of this report, are smaller devices than roundabouts and are designed to slow motor vehicles down at intersections (figure 8). They are commonly used in residential and low-volume roads as a traffic-calming technique. In Australia, these are known as "modern roundabouts" and in the United Kingdom as "mini-roundabouts."

The impact of traffic circles on bicyclists is very different to that of the roundabout. In Australia, there are more than 12,000 of these facilities and there have been too few bicycle crashes — despite significant levels of use — to make the results statistically significant. In the Netherlands, similar devices have been used to control intersections and have led to a 30-percent reduction in bicycle crashes.

In the United Kingdom, Mathew has highlighted the important distinction between roundabouts and mini-roundabouts or traffic circles. "Mini-roundabouts, with a diameter of 4 meters (12 feet) or less have been found to be effective at improving cycle safety. However, they start with the advantage of having their application restricted to junctions with approach speeds limited to 30 mph (48 km/h)."(44)

U.S. experience with traffic circles is growing fast. Cities such as Seattle, WA, and Portland, OR, have been installing traffic circles in residential areas for a number of years, and the practice is growing in other communities.

The city of Seattle installs about 30 traffic circles each year, based on citizen requests, and has built a total of close to 400 at a cost of about $5,000 to $6,000 each. The design and construction of the circles is done with the cooperation of the emergency services and allows for access of larger vehicles such as buses.

Two studies have evaluated the impacts of the circles. In one study of 14 "problem" intersections, collisions (between all types of vehicle) dropped from 51.6 per year to just 2.2 after installation of a circle, and within a one-block radius crashes also fell from 101 to 33. A second study of 15 locations found an average drop in collisions at each circle from 1.94 to 0.18 in a before and after period.[100]

CONCLUSIONS

Bicycle safety is not well-served by the use of large roundabouts designed to increase vehicle speed or capacity through intersections. No method has been found to reduce the vulnerability of bicyclists in the roundabout.

Traffic circles, however, show great potential for calming traffic in residential areas and in reducing the speed of vehicles to the benefit of bicyclists.

Useful Resources

(a) Cyclists Touring Club, etc., 1991. *Cyclists and Roundabouts: A Review of Literature.* Godalming, U.K.

Detailed discussion of bicycle safety at different types of roundabouts and traffic circles. Available for £10 from the CTC, 69 Meadrow, Godalming, Surrey GU7 3HS, England.

(b) Seattle Engineering Department (SED), 1993. *Neighborhood Traffic Circles.* Seattle, WA.

Video describing the traffic circle program in Seattle. Available for $20 from Jim Mundell, SED, 6th Floor, Municipal Building, 600 4th Ave., Seattle, WA 98104.

(c) Dornfeld, M. and Clarke, A. 1993. *Traffic Calming, Auto-Restricted Zones and Other Traffic Management Techniques: Their Effect on Bicyclists and Pedestrians.* FHWA, Washington, DC.

Case Study 19 from the National Bicycling and Walking Study case study series. Available from FHWA, HEP-50, 400 Seventh Street SW, Washington, DC 20590.

(d) Florida Department of Transportation staff have developed a training program to introduce traffic engineers and planners to traffic circle and roundabout design and implementation. Contact: Dan Burden, Florida DOT, 605 Suwannee St., MS-82, Tallahassee, FL 32399.

MID-BLOCK CROSSINGS AND RIDE-OUTS

Crashes at mid-block locations — where the bicyclist or motorist enters the roadway from a driveway, alley, or trail — are a significant percentage of the total number of bicyclist crashes.[46] Cross attributed up to 32 percent of crashes to this type of event, and local crash studies since then put the range between 17 percent (Denver, CO), 23 percent (Oregon), and 32 percent (Boston, MA). Both the Cross and Boston studies include some motorist drive-outs from uncontrolled intersections in the total.[58,59,61]

In the case of mid-block ride-outs by bicyclists, the majority of bicyclists are under the age of 14 (90 percent in Boston, MA) and are exiting driveways, the sidewalk, or alleys without stopping and looking for motor vehicles. Many of the motorist drive-outs involve wrong-way bicyclists (49 percent in Boston) and wrong-way bicyclists riding on the sidewalk. In other parts of Europe, traffic-calming techniques are used to slow vehicles down to a speed where they have time to react and stop in response to dart-out actions by children, and to prevent the parking of cars close to alleyways and trails where walkers and bicyclists cross busy roads.

Specific engineering solutions are difficult to identify for many of these crashes as the fault is most often with the person entering the roadway and failing to stop or yield. Education and enforcement are key to this effort.

In the United Kingdom, extensive use is made of metal railings and barriers to physically prevent ride-out and mid-block pedestrian crossing — especially close to intersections and around schools.

Many of the problems of wrong-way and sidewalk bicyclists are avoided in European countries because the roadway environment is conducive to riding on the roadway or bicycle facility in accordance with the vehicle code.

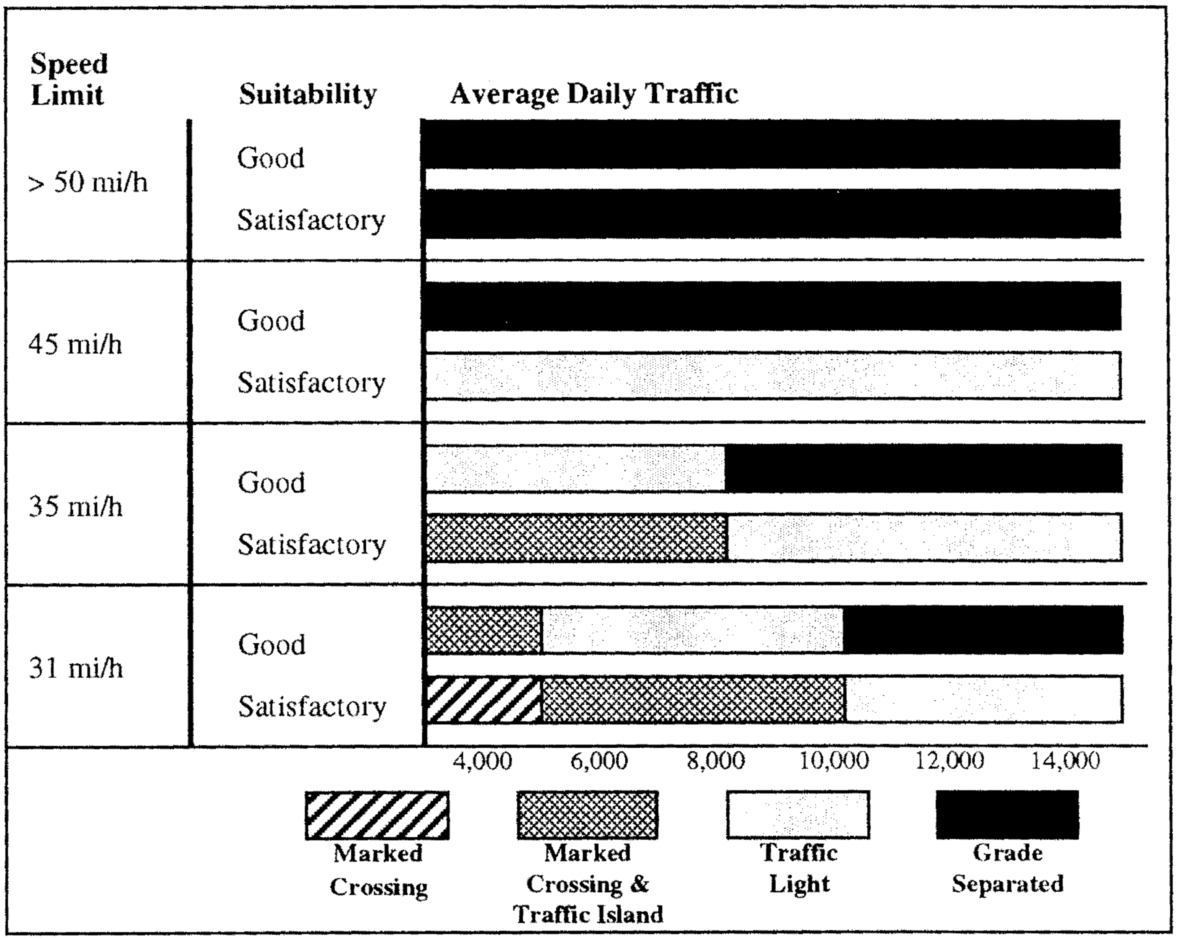
A different situation exists with respect to mid-block crossings where trails cross streets and highways, and where bicyclists and motorists are entering the roadway mid-block from a commercial or residential driveway.

The development of trails in rights-of-way independent of, or parallel to highways often requires mid-block crossing of roads. Except where these intersections are grade-separated, bicyclists are often required to stop or yield to traffic on the road, regardless of whether it is a residential street or a major arterial that the trail facility is crossing.

This is not always the case, however. Two recent publications identify situations, primarily where the trail carries more traffic than the street that it crosses, where traffic on trails have priority over street traffic.[101]

The city of Seattle, WA uses a combination of consistent trail markings and warning signs to alert riders approaching intersections with the highway system, and wide medians to provide trail users with a refuge when crossing busy streets.[20]

Minnesota has developed two useful models for determining when to provide signals or grade separation at these types of intersections.[102] The first model is in the revised edition of their bicycle design manual and will probably include a table showing thresholds for the installation of different types of crossings for trails (figure 9).



1 mi/h = 1.61 km/h

Source: Minnesota Department of Transportation

Figure 9. Thresholds for separations at trail/highway intersections.

The second model, appendix E of the Minnesota State bicycle plan, estimates the number of bicyclists per mi required to justify investment in different types of bicycle facilities.[102]

The Florida Department of Transportation has just begun a major research project to determine and evaluate successful designs for trail/roadway crossings.[30]

Crossings of major roads in the United Kingdom have been the subject of considerable investigation in two particular areas: underpasses shared with pedestrians and special traffic signals and signalized crossings. A number of experimental designs have been tried to retrofit existing pedestrian underpasses for joint use by bicyclists, and Mathew notes their use "has been of considerable benefit to cyclists." Special Department of Transport technical notes have been developed to help local authorities design shared underpasses, and three traffic advisory unit leaflets report on experiments at different locations in the United Kingdom.[103] Where the underpass is less than 9 ft (2.7 m) wide, the U.K. DOT recommends no segregation between pedestrians and bicyclists. A white line is recommended where the underpass is up to 11 ft (3.4 m) wide, and separation by grade and/or barrier is recommended where widths exceed 11 ft.

In the United States, the AASHTO Guide and other State manuals do not recommend signing or designating shared facilities such as these as bikeways unless there is at least 8 ft (2.4 m) of width and 2 ft (0.61 m) of clear space on each side of the underpass.[94]

The U.K. DOT has also reviewed a number of experimental projects where bicycle routes and trails intersect with major routes, and the intersections are signalized with lights featuring bicycle logo signal-heads. Many of these are mid-block crossings or adapted intersections between residential streets and major arterials. Some of these designs may be appropriate for use in the United States.

CONCLUSIONS

Drive-out and ride-out actions, and wrong-way riding are best tackled through education and training, particularly among school students and new bicyclists.

Engineering solutions are available to tackle these specific problems. In particular, the reduction of motor vehicle speeds in residential areas and around schools and important locations can reduce both the likelihood of collision and the severity of injuries should a collision occur.

In addition, controlling the number of driveways, limiting turning movements, provision of medians, and, in some cases, the elimination of two-way left-turn lanes on multi-lane highways can all help prevent crashes occurring away from intersections.

Engineering solutions also exist to take trails and bicycle routes — such as bicycle boulevards — across streets and highways in mid-block locations.

Useful Resources

(a) Rails to Trails Conservancy (RTC), 1993. *Trails for the 21st Century: A Planning, Design, and Management Manual.* Washington, DC.

A 245-page design manual, including sections on trail crossing of roads. Available for $24.95 plus $4 postage & handling from RTC, 1400 16th Street, NW, Suite 300, Washington, DC 20036.

(b) AASHTO, 1991. *Guide to the Development of Bicycle Facilities*. Washington, DC.

Guide has design details for trails. Available for $8 plus $3 postage & handling from AASHTO, 444 North Capitol St., Suite 225, Washington, DC 20001.

SECTION 4.
BICYCLE ACCOMODATIONS AND FACILITIES

INTRODUCTION

Considerable effort has gone into the development of guidelines for developing bicycle facilities in the United States over the past decade, in part, as public agencies have sought protection against law suits from road users injured in highway and trail crashes.

Clarke (McClintock) charts the development of guidelines in the 1970's, led by the California Department of Transportation.(104) Their pioneering work was adopted by the American Association of State Highway and Transportation Officials (AASHTO) and culminated in 1981 with the publication of *A Guide to the Development of New Bicycle Facilities*.(105)

Two other important reports were published at about the same time as the AASHTO Guide.(24) *The Feasibility of Demand Incentives for Non-Motorized Transportation and Bicycle Transportation for Energy Conservation*, together with the AASHTO Guide, culminated an intense period of 6 or 7 years of experimentation and research into many aspects of bicycling.(106)

During that period, the Kaplan Study, the Cross/Fisher accident-typing report, and the first bicycle design manuals were developed.(46,78) There was a significant body of research into the impact of bike lanes, shoulders, and other design features. New comprehensive bicycle education programs were developed for adults and children.

Much of this interest and activity ceased quite abruptly in 1980-1981. The 1980's are notable for the paucity of new work that was commissioned and initiated at the Federal, State, and local levels. Many of the reports and studies done in the 1970's have not been replicated or developed — despite changing circumstances, differing priorities, and a decade more experience.

There were, however, some important exceptions. Forester's highly influential *Effective Cycling* was published in 1984.(107) The book is both a manual on effective bicycling techniques and maintenance, and a polemic on the virtue of a vehicular-style of riding and philosophy that eschews any "special" and especially "separate" facilities for bicyclists.

Effective Cycling holds that bicyclists fare best when they behave like motor vehicles and that bicyclists should not venture onto the roads until they can ride this way. Bike paths and special facilities are demanded by people with a "cyclist's inferiority complex" about riding on the road, and by people with ulterior political and environmental motives for encouraging bicycling. The book has a hard core of followers drawn predominantly from the ranks of experienced and club bicyclists across the country, and there are equivalents in other countries. However, less than 3,000 bicyclists are estimated to have passed an Effective Cycling course — a training program teaching the principles in the book.

In 1986, the Federal Highway Administration published *Selecting and Designating Bicycle Routes*.[108] The report is a thorough review of the literature on bicycyle facility design and implementation, and has especially valuable sections on liability and bicycle route designation and selection.

The report has a strong inclination towards the attitudes and philosophies of *Effective Cycling*, showing a preference for facilities such as wide curb lanes that integrate confident bicyclists into the traffic flow. As such, it was probably an accurate reflection of the mood of the mid-1980's, and the reality of what was feasible at that time.

Throughout the 1980's, some State agencies developed their own bicycle facility design standards and guidelines, notably Minnesota, Washington, and Arizona.[79,86,109] While each of them was based on the 1981 AASHTO Guide, modifications and adaptations to suit local conditions and more recent experience prompted greater changes and a general call for a revision to the Guide. This was done in 1991.

While the new AASHTO Guide covers much the same ground as the 1981 edition, there were some important changes made. These reflected the research and experience gained during the 1980's.[94] Examples include:

- Shoulders. A sentence was added to say, "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." Previously, no distinction was made between rural and urban areas.

- Wide Curb Lanes. A paragraph was added to say, "Restriping to provide wide curb lanes may also be considered on some existing multi-lane facilities by making the remaining travel lanes and left-turn lane narrower. This should only be performed after careful review of traffic characteristics along the corridor."

This advice was offered after many comments from traffic engineers – although the Guide did not adopt the recommendation of many to use 15 ft (4.6 m) as the desirable width for a wide curb lane.[110] The change was also made based on a Maryland DOT study of lane widths, one of the few genuine research studies of the 1980's.[111]

- Separation Between Bicycle Paths and Roadways. A substantial new section was added to the Guide listing eight reasons why problems occur with bike paths located immediately adjacent to roadways. This new section acknowledges the serious problems these facilities have caused, notably by encouraging wrong-way riding and increasing the number of intersections bicyclists and motorists have to negotiate.

Two other additions to the 1991 Guide stress the need for caution when ending a bike path at an existing roadway, and discourage the designation of sidewalks – even very wide sidewalks – as bicycle facilities. These are both further examples of the problems identified in the above paragraph.

For the rest of the Guide, most of the advice on lane widths, speeds, superelevations, and other important design elements remained unchanged from the 1981 edition. This reflects the fact that little additional research was carried out during the 1980's that would warrant any other significant changes. It also suggests that although many different facility designs have been used for many years in some European countries, more formal research is needed to evaluate the effectiveness of different designs under a variety of traffic and roadway conditions.

FACILITY SELECTION

However, something else has changed. The detailed design of facilities has emerged as only one of two major issues for those involved in providing for bicyclists. The second factor is facility selection. The changes made in the 1991 Guide hint at the importance of this question, and the introduction to the Guide states:

> Research is currently underway to develop additional criteria for the design of bicycle facilities. Specifically, additional information is needed regarding the selection of an appropriate type of bicycle facility. The selection of a bicycle facility may depend on vehicular and bicycle traffic characteristics, adjacent land use, and expected growth patterns as well as other factors.

The selection may also be affected by the type of bicyclist being served. Mathew notes that, "the whole issue is complicated by increasing realization of how diverse cyclists are, ranging from children and timid novices to the experienced commuter and the hardened racer."[44]

In 1981, publication of the AASHTO Guide marked the end of a period of intense activity and discovery. The 1991 Guide was released as a new era of policy changes was ushered in. This has had a profound impact on the question of whether special bicycle facilities should be used, and should be the subject of research studies during the 1990's.

In February 1990, the U.S. Department of Transportation released *Moving America*, a statement of national transportation policy. The policy committed the Federal Government 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.[4]

This simple statement has had a dramatic impact at the Federal, State, and local levels. For the first time in a decade, there was overt support for bicycling at the national level. More importantly, there was support for increasing use, not just accommodating existing users and making them safer.

The distinction, according to Wilkinson (1992), is crucial. He offers the following definitions to explain this:

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 provision 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.[112]

Wilkinson argues that the sales approach adopted by bicycling advocates over the previous 15 years (including his own 1986 report) has not been effective. Potential or infrequent riders who are uncomfortable riding in traffic have not been won over by the opportunity to become "effective cyclists" through a rigorous training and education program. Instead, he suggests a marketing approach — find out what those potential and infrequent users say would encourage them to ride more often and start to offer them that product. This does not mean abandoning the engineering principles for the design of different facilities; it does mean taking a close look at who is best served by different facility types.

Wilkinson's report is the "current research" referred to in the introduction to the AASHTO Guide. The basic principles adopted in that report are:

- There are three classes of design bicyclist: group A (advanced), group B (basic), and group C (child).

- A policy goal of increasing use implies a supply-driven approach — "if you build it, they will come."

- Every street and highway should be designed and maintained for shared use by motor vehicles and bicycles.

- Facilities for group B/C cyclists can be identified through a planning process and design decision.

- Special facilities provided for B/C cyclists are additions to the existing system, not substitutes for shared use of the roadway.

This approach enables the practitioner to first identify the type of user to be accommodated on a particular street or along a particular corridor, and then choose and design an appropriate facility. The whole range of treatments is available, from shared lane and signed bike route to separate trails. Each has their place in the system.

A series of tables provided in a user manual offers guidance on which facility should be used in a series of given situations and when accommodating either group A or group B/C cyclists.[112]

SEPARATION VERSUS INTEGRATION

One significant point of Wilkinson's report is that it diminishes the purpose and value of the age-old debate about the merits of separating bicyclists from motor vehicles vs. integrating them into the traffic flow and training them to ride in a vehicular style.

This debate has rumbled on in the bicycle community throughout the past 20 years in all of the countries studied in this review. In the United States, the debate has primarily been waged between a relatively small number of participants who fall into two extreme camps.

- Elite Cyclists Syndrome: Proponents of integration contend that bicyclists fare best when they behave as motor vehicles and are part of the traffic system. They believe all bicyclists can be trained to ride confidently in all traffic situations. Much of the literature stems from the 1984 book, *Effective Cycling*.[107]

Although this position was formulated and hardened in response to requirements to use separate bike paths, many of the proponents equate any special facility for bicyclists with a diminution of a bicyclists' right to the road, and a call for such facilities as evidence of a "cyclist's inferiority complex."

- Bicycling is Dangerous Syndrome: Proponents of separation contend that bicycles and motor vehicles do not mix because of speed differentials, operator skill, visibility, and other factors. Therefore, they believe bicyclists should use facilities separated from the traffic flow by a curb or in a separate right-of-way altogether.

In the United States, proponents point to their perception of a Dutch style of bicycle facility as a model. They seek a complete network of trails and paths on separate rights-of-way and doubt the value of any on-street facilities except on the most quiet streets.

Both sides of the debate have used "safety" as the cornerstone of their argument, believing that their approach will make bicycling safer and prevent crashes. For example, Forester uses the Kaplan study data to argue that separate paths are more dangerous for experienced bicyclists. In the Kaplan survey of regular adult bicyclists, bike paths were calculated to be 2.6 times more dangerous per million bicycle miles (1.6 million bicycle kilometers) traveled than major or minor highways.[78]

According to Wilkinson (1992), "based on this single source, Forester articulated the theory that separate bicycle facilities are less safe than vehicular-style riding on the roadway."[112] Proponents of Forester have subsequently extended his theory to include bike lanes, even though the Kaplan study actually found bike lanes to be slightly over half as dangerous as major and minor highways and approximately five times safer than separate bike paths.[113] Wilkinson concludes that:

> 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."[112]

The statistical basis of the safety argument for separate bicycle paths has also been called into question. In particular, critics point out that separate facilities do not address the majority of car/bike crashes, which occur at intersections or are due to mid-block ride-outs. Separate facilities address the kinds of collisions caused by overtaking or passing maneuvers where a motorist strikes a bicyclist. These are the types of crashes most likely to cause death and serious injury, however, according to Cross and other crash studies, the incidence of these crashes is relatively low.

Cross[46]	10.7 percent (7th of seven major types)
Oregon[61]	4.0 percent (6th of seven major types)
Boston[58]	3.4 percent (8th of eight major types)

In addition, a significant proportion of the crashes that are never reported to the police — and many that are — involve no other vehicle. The bicyclist simply loses control and falls or hits a pedestrian, dog, or fixed object. Many of these crashes have little to do with the type of bike facility.

Commentators seeking to understand the debate between these different sides have also noted that much of the fear of special bicycle facilities is based on designs developed and implemented in the early 1970's. The Kaplan study, for example, was carried out in 1974 at a time when, according to Clarke,

> ... almost every jurisdiction in the nation embarked on cycle plans and projects with little or no experience or knowledge of what to do to help and encourage cyclists. The result was a plethora of badly designed, poorly maintained, isolated bicycle routes and paths that quickly fell into disrepute and low use. In many states, this was compounded by laws requiring the use of such facilities.[104] (See figure 10.)

During the past 20 years, much has been learned about the planning, design, operation, and maintenance of many bicycle facility types. Much of this is reviewed in the 1992 FHWA report, *The Effect of Bicycle Accommodations on Bicycle/Motor Vehicle Safety and Traffic Operations*, and is reflected in design manuals being developed by State agencies (North Carolina and Minnesota are examples).[84,112]

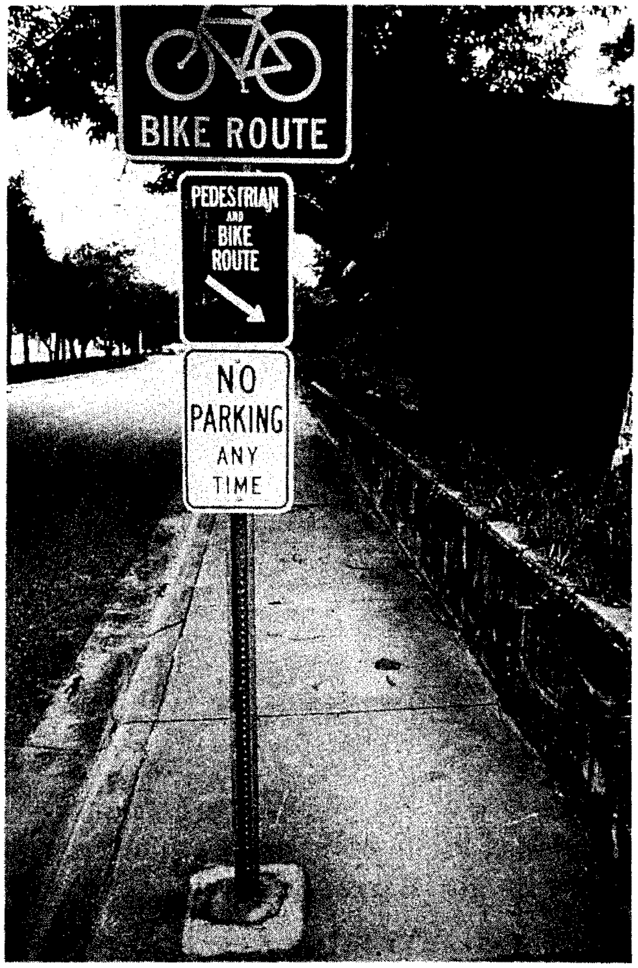


Figure 10. Compulsory sidepath.

For many people, therefore, the debate between separation and integration is looking increasingly contrived. Planners and engineers are rejecting the notion that all special bike facilities are unnecessary and dangerous, as some believe, or that any type of bike facility is good, as others contend. There is a substantial middle ground in the debate.

DESIGNING AND SELECTING FACILITIES

There is growing recognition in the literature, both at home and abroad, that a range of potential facilities can be used to accommodate bicyclists, and that the major issues are those of design and selection. The safety of bicyclists is influenced more by the design of a particular facility than the decision to use that type of facility. This is true regardless of whether the facility is designed primarily for bicycles or for cars, a principle identified in the 1991 *AASHTO Guide for the Development of Bicycle Facilities*:

> 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 by bicyclists.[94]

After a discussion of ways to ensure that all highways are designed, operated, and maintained so as to allow safe bicycle use — e.g., through the elimination of such potential hazards as drainage grates, railroad crossings, and poor pavement quality — the AASHTO Guide describes the following on-street and off-street facility types available to the traffic engineer and planner:

- Shoulder.
- Wide Curb Lane.
- Bicycle Route.
- Bicycle Lane.
- Bicycle Path.

Other documents include a more extensive range of facilities including those shown above and:

- Shared Lane.
- Bicycle and Bus Lane.
- Bicycle Boulevard.
- Traffic Calming.

Each of these facilities can accommodate bicyclists without compromising their safety. Each of these facilities can also enhance the safety of bicyclists and/or increase bicycle use, depending on where and how the facility is used. The results will depend on appropriate facility design and selection.

The 1992 FHWA report has comprehensive coverage of these issues in relation to wide curb lanes, bike lanes, shoulders, and trails.[112] Separate chapters in the final report summarize the advantages and disadvantages of each facility type, and also identify which type of bicyclist — group A or group B/C — the facilities serve best.

SHOULDERS

The AASHTO Guide identifies shoulders as the most appropriate treatment for bicyclists in rural areas, as do a number of State agencies, such as Oregon, Washington, and Minnesota. (See references 79, 86, 94, and 114.) Wilkinson provides an extensive review of the appropriate widths and other design issues based on the experience of these agencies.[112]

The 1992 FHWA report says that shoulders, in good condition and with a surface similar to the roadway, will be used by both group A and group B/C riders. Group A riders gain some benefit from almost any additional width provided by shoulders, but most agencies either do not mark shoulders as bicycle facilities until they are at least 5 to 6 ft (1.5 to 1.8 m) wide, or do not sign them as such at all.[112]

Noland (1992) reports that lack of adequate shoulder widths is one of the prime causes of a perception of risk that dissuades potential bicycle commuters from riding.[25] The paving of a shoulder is "the most frequent request from area bicyclists received by the King County [WA] Roads Division."[115]

According to McHenry (1985), a shoulder, rather than a raised curb, can reduce the optimum lane width necessary for mode-sharing and may eliminate the need for a wide curb lane if the shoulder is paved to the same quality as the roadway.[111]

In a policy memorandum in 1986 (feasibility study), the Wisconsin DOT evaluated the costs and benefits associated with paving shoulders on rural highways. The study does not refer to bicycling, and yet still finds ample justification for the construction of 3-ft (0.92-m) shoulders on all State trunk highways with more than 1,000 vehicles per day.[116]

A similar report published by the Texas Transportation Institute (1989) concluded that wide paved shoulders (6 to 10 ft [1.8 to 3.0 m] wide) are cost beneficial for average daily traffic (ADT's) above 1,500 vehicles per day — once again, with no reference to the benefits conferred on bicyclists by the provision of such wide shoulders.[117]

A Virginia Transportation Research Council report (Cottrell, 1992) found that "the literature review generally supported the notion that paved shoulders are economically justifiable under certain conditions."[118] However, there was no consensus on the specific conditions. This study concluded that 2-ft (0.61-m) paved shoulders are economically justifiable under certain ADT volumes for new two-lane roads, but not existing two-lane roads. Shoulders that are 2 ft (0.61 m) are reportedly justifiable on four- and six-lane roads when new, and under certain ADT volumes on existing roads of this type. As with the previous studies, no specific reference to bicycling was made in this report. While 2-ft (0.61-m) shoulders may be better than nothing for bicyclists, especially group A riders, this width is certainly not enough to warrant designating the road as a bikeway.

The benefits of shoulders for bicyclists are explicitly noted in a number of documents.[119,120] Burden (1989) argues that "both bicyclists and truck drivers should continue to urge highway departments to provide adequate lane widths and especially paved shoulders on all principal roadways, and especially those with higher average daily traffic counts where lane changing is difficult."[121]

Williams identifies the use of rumble strips by highway agencies as a potential threat to the value of shoulders for bicyclists.[122] Potential solutions to overcoming this problem range from not using rumble strips to innovative designs to not installing them on highways that bicyclists can use, locating them only in part of the shoulder, and using narrower (18-in [457-mm]) rumble strips rather than having them extend all the way across the shoulder. (See references 86, 110, 114, and 123.) The FHWA has also developed design guidelines for the use and location of rumble strips, recommending that they be placed in the middle one-third of the shoulder.[124]

Useful Resources

(a) Federal Highway Administration, 1992. *The Effects of Bicycle Accommodations on Bicycle/Motor Vehicle Safety and Traffic Operations*. Washington, DC.

Technical report that complements *Selecting Highway Design Treatments to Accommodate Bicycles*, and that has a chapter on shoulder design and policies. Available from FHWA, HEP-50, 400 Seventh St., SW, Washington, DC 20590.

(b) Florida Department of Transportation, 1993. *Interim and New Construction Typical Sections*. March 3, 1993, Memorandum. Tallahassee, FL.

Drawings and explanatory notes of the 14 typical sections adopted by the Florida DOT for all new highway construction. Available from Florida DOT, 605 Suwannee St., MS-82, Tallahassee, FL 32399.

(c) Florida Department of Transportation, 1984. *Policy for Incorporation of Bicycle Facilities in Design — Wide Curb Lanes, Bicycle Lanes and Paved Shoulders*. Tallahassee, FL.

List of justifications for the construction of shoulders. Available from Florida DOT, 605 Suwannee St., MS-82, Tallahassee, FL 32399.

(d) Oregon Department of Transportation, 1992. *Oregon Bicycle Master Plan*. Salem, OR.

Detailed design information for shoulders suitable for bicycle use. Available from ODOT, Technical Services Division, Transportation Building, Salem, OR 97310.

(e) Wisconsin Department of Transportation, 1986. *Feasibility of Paving Shoulders on Low ADT Highways*. Oct. 29, 1993, policy memorandum.

This memorandum explains how Wisconsin DOT calculated the costs and benefits of paving shoulders of highways with more than 1,000 average daily traffic.

WIDE CURB LANES

Two of the more influential research documents released in the 1980's deal with wide curb lanes and their design, and have helped confirm the use of wide curb lanes as the favored method of accommodating bicyclists during this period.[111,125]

Wilkinson reviews these and other studies and design manuals that discuss the appropriate width of wide curb lanes. Maryland DOT and guidelines developed by the New Jersey DOT both use 15 ft (4.6 m) as a guide.[111, 125] Others, such as Florida DOT, have adopted 14 ft (4.3 m) as a minimum width.[113,120,125]

According to the 1992 FHWA report, *Selecting Highway Design Treatments to Accommodate Bicyclists*, wide curb lanes accommodate only the group A cyclist and have a limited benefit in encouraging increased use of bicycles. However, they are successful in improving the capacity of highways, especially at intersections.[126]

While the 1981 AASHTO Guide covered the design of separate bicycle paths in some detail, there was — for many agencies — insufficient information on the provision of on-street facilities and the design of bicycle-compatible highways.

The New Jersey Department of Transportation developed its own set of recommendations in the 1982 *Bicycle-Compatible Highways — Planning and Design Guidelines*.[125] The manual concentrated on designing highways that provided the confident bicyclist with space in which to operate on any road. The principle behind the manual was that:

> Novice or inexperienced bicyclists tend to believe that a paved shoulder separated from the travel lane by an edge strip 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.

The manual recommended a 15-ft (4.6-m) travel lane on roads with an average daily traffic flow of more than 1,200 vehicles, where there is no shoulder present. The manual also provides detailed information on the placement and installation of drainage covers and other roadway features that affect bicyclists.

The New Jersey guide remains a useful resource for highway designers seeking to accommodate the confident rider through the provision of shared lanes and wide outside lanes. Many other State agencies followed suit, with recommended outside lane widths ranging from 14 to 17 ft (4.3 to 5.2 m).

The Maryland State Highway Administration, in cooperation with the U.S. DOT, undertook a study to determine the feasibility of providing a wider outside lane for bicyclists and motor vehicles to share.[111] The effect of a single bicyclist using lanes of different widths was studied, as was a bicyclist using a bike lane on a similar type of roadway. The study determined that "outside lanes wider than 12 ft [3.67 m] improved motor vehicle/bicycle lane sharing, but that lane widths can be excessive." The report recommended 15 to 15.5 ft (4.6 to 4.7 m) as an appropriate width for such a shared lane. The report also noted that bicycle lanes had a positive effect on bicycle and motor vehicle flow patterns at mid-block, offering the least amount of vehicle displacement and greatest uniformity of tracking by both user groups.

The Florida Department of Transportation is currently evaluating the effects of different shoulder and bike lane widths.[30] Burden reports that initial observations suggest that motorists drive farther away from the curb when a 4-ft (1.2-m) bike lane and 11-ft (3.4-m) travel lane configuration is used over a 15-ft (4.6-m) wide outside lane.

Studies such as these should be repeated in different locations throughout the United States to determine the impact of different lane widths and facility types on different bicyclists. The Maryland study has never been followed up.

Useful Resources

(a) Federal Highway Administration, 1992. *The Effects of Bicycle Accommodations on Bicycle/Motor Vehicle Safety and Traffic Operations*. Washington, DC.

Technical report that complements *Selecting Highway Design Treatments to Accommodate Bicycles*, and that has a chapter on wide curb lane design and policies. Available from FHWA, HEP-50, 400 Seventh St., SW, Washington, DC 20590.

(b) New Jersey Department of Transportation, 1982. *Bicycle Compatible Highways — Planning and Design Guidelines*. Trenton, NJ.

Available from NJ DOT, Bicycle/Pedestrian Program, 1035 Parkway Ave., Trenton, NJ 08625.

BICYCLE ROUTES

Bicycle routes are defined by AASHTO as being "a segment of a system of bikeways designated by the jurisdiction having authority with appropriate directional and informational markers, with or without specific bicycle route number."[(94)] Most often, they consist of series of roads where nothing has been done to change the physical characteristics, and signs have been installed along them indicating that it is a "preferred" or "suggested" route for bicyclists to take.

The City of Dallas and State of North Carolina have both utilized this method of accommodating bicyclists quite extensively. Dallas has almost 500 mi (805 km) of signed routes throughout the city, and North Carolina has over 2,000 mi (3220 km) of signed "Bicycling Highways" criss-crossing the State.[(100)]

There have been no studies or evaluations of the effectiveness of this approach to encouraging bicycling or improving bicyclist safety. Those using bike routes extensively point to the promotional benefits of signing routes and the potential for directing bicyclists away from busier or more dangerous routes.

Critics of this approach to bicycle planning and programs have a number of concerns. Ronkin, for example, points out that:

- The routes do not go where cyclists want or need to go, especially if they are used to direct riders away from busy roads.

- They fail to cater to either the group A or group B/C rider very effectively. The confident group A riders already know the routes they prefer to use, and will often choose a more direct route than those offered by the signed routes. The group B/C riders are not given the sense of protection they desire.

- Implementation of bike routes has been poor in many instances, consisting of a sign that says "BIKE ROUTE" but with no directional or distance information to help a rider navigate a whole route successfully.

- Motorists may get the impression bicyclists should only be using streets designated as bike routes.[127]

There are two areas of potential common ground. First, it is widely acknowledged that signed bike routes — with the correct destination information, etc. — do have considerable value for recreational riders, especially outside urban areas and for long-distance, cross-State routes. Second, bicycle route signs can be used effectively to sign gaps in an otherwise extensive or complete network of facilities and to sign cyclists through difficult areas, such as getting on and off bridges.

The city of Denver is experimenting with a new symbol to be used on streets with wider curb lanes and on their proposed bike route network.[128] (See figure 11.) The symbol will take the place of a bike lane marking, offering the encouragement and promotional value of the bike lane without restricting the operation of the bicyclist to the narrow bike lane (which is a concern of opponents of bike lanes). The results of this experiment should be reviewed and disseminated by the Federal Government. Indeed, it is the kind of work that should be supported or encouraged in other cities to determine its general applicability.

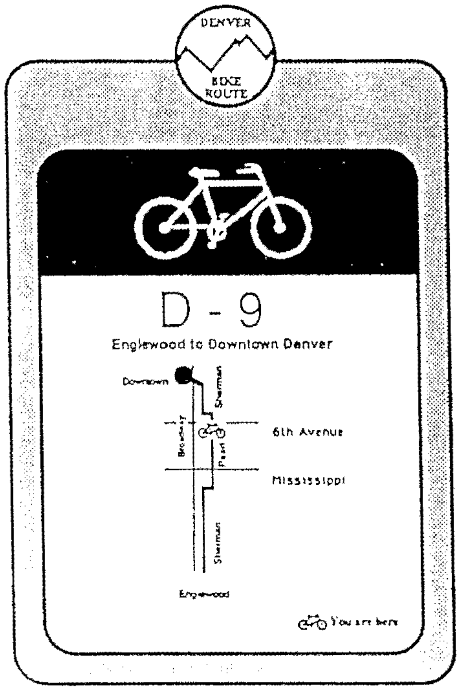
Useful Resources

(a) City of Denver, 1993. *Bicycle Master Plan.* Denver, CO.

The most recent example of a city-wide bike plan utilizing extensive bike route signing. Available from the City of Denver, Bicycle Program, 200 West 14th Ave., Room 302, Denver, CO 80204.

(b) Federal Highway Administration, 1986. *Selecting and Designating Bicycle Routes.* Washington, DC.

Detailed review of literature relating to the designation of roads as bikeways. Available for $15 from the Bicycle Federation of America, 1506 21st Street, NW, Suite 200, Washington, DC 20036.

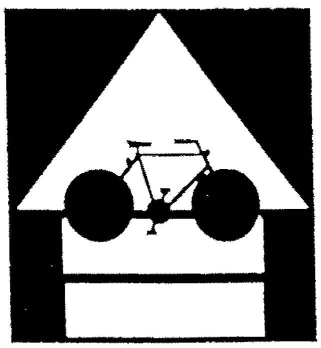


Finding the Right Route

Bicyclists using the new bike route network should always know where they are on any given route. Route markers like the one shown here will be posted along all the routes to indicate a cyclist's actual position in the system.

New Symbol Proposed

This pavement arrow graphic will be used on a trial basis as an alternative to a bicycle lane. Using this arrow will indicate a corridor for bicyclists. Significantly less pavement marking materials will be needed — with the sand and gravel use during plowing season, pavement markings need frequent replacement.



Source: City of Denver

Figure 11. Experimental bicycle route sign, Denver, CO.

BICYCLE LANES

Bicycle lane design has changed very little since the 1970's, when extensive research was carried out to determine appropriate widths and uses for this type of facility. The section of the AASHTO Guide dealing with bike lanes was not changed between 1981 and 1991.[(129)]

According to Kroll and Ramey (1977) and McHenry (1985), both motorists and bicyclists operate more predictably — and with less side-to-side movements — on streets with bicycle lanes.[(111,130)]

The 1992 FHWA report also identified the positive impact of bike lanes on channelization as compared to sites with shared roadways, leading the authors to conclude that "a marked bike lane tends to direct vehicular traffic in a manner that produces less perturbance when a car passes a bike."[(112)]

Since publication of this report, the use of bike lanes has been debated vigorously, particularly by proponents of the vehicular style of bicycling (group A riders).[(131)] They identify two major concerns — or disadvantages — caused by bike lanes:

- Bike lanes discourage the sweeping effect of cars, thus causing a buildup of debris in the bike lane that either causes a hazard to bicyclists or forces them to use the regular traffic lane.

- Bike lanes prevent bicyclists from making correct left turns (from the left lane) and motorists from making correct right turns (from the right edge of the roadway) (Lott and Lott, 1976).[132]

Ronkin (1993) addresses these concerns. He points out that:

- The difficulties associated with making a left turn in traffic has nothing to do with the presence of a bike lane. A bicyclist has to be prudent and look over their shoulder repeatedly before merging to the left regardless of the conditions.

- Conflicts with right-turning movements are dealt with by dashing the bike lane strip before intersections and dropping the markings altogether across intersections.

- Do bicyclists really want to be dependent on automobile traffic to blow the street clean — or is it more appropriate to schedule more frequent sweeping?[133]

He also highlights the importance of having an interconnected system of bike lanes — rather then the provision of isolated facilities — on all major streets. Wahl (1982) and Tardiff and Lott (1978) point out that "if a bicycle lane route is markedly less convenient than a route without one, convenience generally determines choice."[134,135] This is especially true of the group A (experienced) rider type who is confident riding in most traffic situations, according to Kroll and Sommer (1976).[136]

Burden adds that motorists and pedestrians can also benefit from the presence of bike lanes. Bike lanes allow motorists to turn into the roadway without encroaching on another lane, and negates the need for wide-turning radii at corners, thus maintaining shorter crossing distances for pedestrians at intersections.[30] In addition, bike lanes give a greater separation between cars and pedestrians for a greater level of comfort.

In Cupertino, Davis, and other California cities, bike lanes on low-volume collectors and minor arterials are often widened to 6 to 8 ft (1.83 to 2.44 m) at intersections to allow bicyclists and motorists to merge for turns.[89]

Wilkinson notes the importance of design and facility selection when on-street parking is present, particularly if it is angle parking.[112]

The current debate about the value and desirability of bike lanes is the most recent manifestation of the "separation vs. integration" debate referred to earlier. Opponents of bike lanes complain about the operational and maintenance difficulties mentioned above, and question the "safety" of bike lanes.

Studies that have reviewed the impact of bike lanes do not support this concern. For example, Lefler (1975) reported that bicycle lanes would have prevented approximately 14 percent of crashes in Santa Barbara, CA.[137]

The introduction of bicycle lanes on 18th Avenue in Eugene, OR in 1979 resulted in an increase in bicycle use and a substantial reduction in the bicycle accident rate. In the 18 months following installation, the crash rate per 100,000 bike miles (161,000 bike kilometers) fell from between 4.5 (1977) and 9 (1978) to 3.9 in the first 6 months and 2.6 in the following 12-month period. The motor vehicle crash rate also fell significantly.[138]

One year later, the city of Corvallis, OR installed 13 mi (21 km) of bike lanes. A newspaper story in 1982 reported that bicycle crashes fell from 40 in the year prior to the bike lane program to just 16 in the 12 months afterwards, and of the 5 crashes that occurred on streets with bike lanes, all involved bicyclists riding at night with no lights.[127]

Smith and Walsh (1988) undertook an evaluation of the impact of installing bicycle lanes on a 1.3-mi (2.1-km) section of a one-way arterial pair in Madison WI. The authors found that:

> Overall, the bicycle lanes on Johnson and Gorham Streets did not have a negative impact on bicycle safety. Except for the first year of bicycle lane implementation on Johnson Street, the bicycle lane corridor accidents did not increase significantly compared with significant increases in bicycle accidents city-wide.[139]

The Johnson Street bike lane was unusual in that it was placed on the left side of a one-way street. The increase in crashes during the first year was traced to two specific types of crash that occurred on Johnson (table 19).

More dramatic claims of the safety impact of bike lanes are made in Denmark. Laursen reports that "for some reason, the safety effect of painted cycle lanes seems to be just as good [as cycle tracks], although cyclists feel less safe. Even cycle lanes of half a meter width (19.7 in) — hardly able to accommodate a cyclist — reduce the risk by up to a third, whereas lanes of 0.6 meters (2 ft) reach risk reductions of 70 to 80 percent."[43]

In the context of the current Federal policy goal of increasing bicycle use, the issue of perceived safety and the comfort of bicyclists assumes much greater significance. Study after study reports that potential bicyclists and the existing group B/C riders want a designated space in which to operate — and that without the feeling of safety this confers on them, they simply will not ride in current traffic conditions. (See references 13, 14, 25, and 140.) This expression of desire is not new. In 1976, a majority of riders crossing the country on the "Bikecentennial Ride" indicated in a survey that marked bike lanes were their preferred roadway improvement for bicyclists. Only 12 percent indicated a preference for widened pavement.[141]

The difference in the 1990's is that potential bicyclists are being asked what would encourage them to ride more often, and people are listening to their answers. In addition, there is growing evidence that the presence of bike lanes is a significant determinant of the level of bicycle use in a given community. Goldsmith writes that:

Table 19. Bicycle accidents and types in Madison, WI, 1974-1981.

Year	Total Bike Accidents in Madison	Johnson & Gorham Bike Accidents		Estimated Daily Bike Trips In Madison	Total Acc. Rate per 1,000 Daily Bike Trips in Madison
		Number	Percentage of Madison-Total		
Before Bike Lane					
1974	135	7	5.2	86,000	1.6
1975	163	8	4.9	68,100	2.4
1976	146	12	8.2	79,000	1.8
1977	175	9	5.1	75,100	2.3
After Bike Lane Installed					
1978	173	20	11.6	59,100	2.9
1979	172	8	4.7	77,400	2.2
1980	247	14	5.7	97,600	2.5
1981	200	9	4.5	97,900	2.0
Summary					
Before					
- Total	619	36	5.8	308,200	2.0
- (Average)	(155)	(9)		(77,050)	
After					
- Total	792	51	6.4	332,000	2.4
- (Average)	(198)	(12.8)		(83,000)	
% Increase	+27.7%	+41.7%	+11.1%	+7.7%	20%
Expanded Before Acc.[a]					
-Total	-	38.8			
-(Average)	(167)	-			
% Increase	+15.7%[b]	+23.9%[b]			

[a] Before accidents expanded by 1.077.
[b] Significant at the 0.05 level based on the "After" Average or [Total].

Source: Smith and Walsh[(139)]

Even when university towns are excluded from consideration, cities with higher levels of bicycle commuting have on average 70 percent more bikeways per roadway mile and six times more bike lanes per arterial mile.[26]

In March 1993, the Florida Department of Transportation issued a new design bulletin that identifies 14 typical sections for new construction projects.[142] Each section has a 4-ft (1.22-m) minimum dedicated bike lane or 3 to 3.5 ft (0.92 to 1.07 m) of unmarked space in which bicyclists can operate. A series of studies are being undertaken to evaluate the effect of these new designs on bicycle use and safety.

In August 1993, the Oregon Department of Transportation issued supplemental guidance to its highway designers indicating how to retrofit existing State highways to incorporate designated bicycle lanes.[143]

Observation studies, such as the limited example in the 1992 FHWA report, are needed to determine the impact of bike lanes on bicyclist safety, speed, and behavior.

Useful Resources

(a) AASHTO, 1991. *Guide to the Development of Bicycle Facilities*. Washington, DC.

Basic design information for bike lanes. Available for $8 plus $3 postage & handling from AASHTO, 444 North Capitol Street, NW, Suite 225, Washington, DC 20001.

(b) Ronkin, M., 1993. "Bike Lane or Shared Roadway?" Article in *Pro Bike News*, Bicycle Federation of America (BFA), Vol. 13, No. 3, 1993. Washington, DC.

Discussion of the merits of bike lanes, with examples from Corvallis, OR. Available from the BFA, 1506 21st Street, NW, Suite 200, Washington, DC 20036.

(c) Federal Highway Administration, 1992. *The Effects of Bicycle Accommodations on Bicycle/Motor Vehicle Safety and Traffic Operations*. Washington, DC.

Technical report that complements *Selecting Highway Design Treatments to Accommodate Bicycles*, and that has a chapter on bike lane design and policies. Available from FHWA, HEP-50, 400 Seventh St., SW, Washington, DC 20590.

(d) Florida Department of Transportation, 1993. *Interim and New Construction Typical Sections*. March 3, 1993, memorandum. Tallahassee, FL.

Drawings and explanatory notes of the 14 typical sections adopted by the Florida DOT for all new highway construction, which include bike lanes. Available from Florida DOT, 605 Suwannee St., MS-82, Tallahassee, FL 32399.

(e) Oregon Department of Transportation (ODOT), 1993. *Retrofitting Bike Lanes onto Existing Urban Roadways: Guidelines*. Salem, OR.

A four-page design brief showing how to restripe and re-allocate space on existing roadways to incorporate bike lanes. Available from ODOT, Bicycle Program Manager, Transportation Building, Salem, OR 97310.

BICYCLE PATHS

Bicycle paths have come to mean many different things, such as sidewalks, greenway trails, or other facilities separated from the roadway. As has already been mentioned, the debate between the proponents of separation vs. integration intensified during the 1970's as many State and local transportation and recreation agencies began to provide separate paths for bicyclists to use. The 1981 edition of the AASHTO Guide devoted a considerable amount of space to the design of these facilities, in recognition of the prevalence of ad hoc designs and "bike path" designations and the problems and dissatisfaction they caused.[105]

The Oregon Bicycle Master Plan (1992) summarizes many of the concerns:

> Early bike path efforts were aimed at multiple use of sidewalks as bike paths. While in some instances this type of path may be necessary, in most cases it should be avoided. Sidewalks are generally unsafe because they put bicyclists in conflict with pedestrians, utility posts, sign posts and motorists using driveways. A cyclist on a sidewalk is generally not visible or noticed by a motorist, so that the cyclist suddenly emerges at intersections or driveways, creating a hazardous condition. Cyclists are safer when they are allowed to function as roadway vehicle operators, rather than as pedestrians.[114]

In many locations, these problems were compounded by the fact that sidepaths were compulsory, regardless of their utility, safety, or state of repair. Insufficient width was often provided, intersection treatments put bicyclists in unexpected locations with little or no guidance, and maintenance was often non-existent. This has enabled at least one commentator to declare that "the bike path program of the last 20 years has been a failure."[110]

This issue has not been confined to the United States. Clarke and Bracher note a number of studies in European countries that identify an increased bicycle-motor vehicle crash record on streets with sidewalk bike paths.[42,144]

Laursen reports that in Sweden, Finland, and Norway, where sidewalk bike paths are quite common, attitudes are changing:

> The possibility that two-way operation may lead to extra traffic conflicts has long been recognized, but the reasoning has been that in the balance with costs, the solution provided reasonable safety. This conclusion may be undergoing revision at the moment, since new investigations show clear increases in intersection accidents

with this type of operation. Special markings on the roadway and warning signs at side roads alleviate the problems, but not enough.[43]

In the early 1980's, organized bicyclists and many government officials concerned with bicycling in the United States were not supportive of separate bicycle facilities. The experience had not been good. State agencies (for example, New Jersey), researchers, and bicycle advocates (for example, Wilkinson and Forester) favoring integration and education were highly influential.[107,108,125]

In the mid-1980's, this started to change quite dramatically. The Rails to Trails Conservancy was founded to preserve abandoned railroad corridors and turn them into linear parks, greenways, or trails for bicyclists, pedestrians, and other users. Between 2,000 to 3,000 mi (3220 to 4830 km) of railroad corridor were being abandoned every year, and the Conservancy set a goal of creating 500 trails covering 5,000 mi (8050 km) in their first 5 years. This goal was achieved.

In addition, the Conservancy attracted tens of thousands of members, eclipsing existing national bicycle membership groups in just 2 years. The interest in trails was spurred by the phenomenal popularity of mountain bikes — a new style of bike that was easy to ride and brought millions of adults back into bicycling for the first time since their childhood. These novice, infrequent, and recreational riders consistently state a preference for riding on trails and separate facilities.

Wilkinson notes that "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."[112]

In one of the few such studies, Flink (1993) found only 12 trails with any reliable use data, and only three were identified as having detailed trip-generation rates and usage data studies available.[145] Those listed in the survey suggest trails are popular facilities, especially with bicyclists, who make up an average of between 70 to 80 percent of the users.

A 1982 survey of bicycle use and crashes in Seattle monitored the impact of the construction of the Burke Gilman trail, a 12-mi (19.3-km) facility. The study found that:

> 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.[134]

A 1986 study by Eubanks reported that in the Chicago metropolitan area, "in census zones where trails exist, an average of 15.6 percent of the commuter trips are by bicycle, but when compared to the region as a whole, only one percent of the population commutes by bicycle."[145]

Flink and the National Park Service document a range of other environmental, economic, health, recreation, and transportation benefits of trails.[35,145]

Initial reaction from the group A bicycling community to this sudden interest and groundswell of support for separate trails, not surprisingly, ranged from cautious to openly hostile.[146] By the start of the 1990's, a kind of truce has developed between the protagonists. Even Forester, if grudgingly, has accepted that trails have a place in the system:

> Multi-use paths serve a useful purpose and will continue to be built. However, there is no point in designing these to be used as roadways. Cyclists must use them slowly, watching out for hazards at every point.[147]

The ground rules for accepting the legitimacy and value of separate facilities such as these seem to be:

- Rename the facilities "multi-use trails." Bike paths have an unfortunate connotation and inaccurately suggest that only bicyclists are going to use them. Any separate facility will be used by joggers, in-line skaters, and many others. Where volumes of pedestrians and bicyclists are quite high, providing separate walkways and bike paths may also be appropriate in some situations.

- Trails are not appropriate where there is frequent conflict with cross traffic on driveways, side streets, and intersections with major roads, i.e., sidewalks and sidepaths. They are appropriate in locations with continuous rights-of-way and grade-separated intersections, i.e., along canals, abandoned railroad corridors, and so forth.

- Use of trails should not be compulsory. Trail advocates should work with bicycle groups to repeal mandatory sidepath-use laws in States where these still exist.

- Trails are particularly appropriate for novice riders and children, and are good places to learn the skills and techniques that are necessary when riding in traffic. They may have limited utility for "fast" cycling.

- Trails are an addition to the highway system, not a substitute for it. Bicycles can still be expected to ride on all roads where they are legally allowed to operate and trails will exist in corridors with on-street facilities as well. Indeed, bicycle use on roads adjacent to trails will frequently increase.

- Appropriate design standards must be applied, especially in relation to width, sight distances, and intersections.

The 1991 AASHTO Guide provides more detailed advice than the 1981 edition on the appropriate design of these facilities and, in particular, stresses the problems associated with sidewalk bike paths.[94]

Despite the controversy and the huge interest in trails and separate facilities, very little is really known about the impact of these facilities. We do not know how many people use trails and how many of them will ONLY use trails. We do not know how many of the people who use trails are encouraged to use the street system and if certain levels of congestion or danger on trails speed up this process. Most importantly, we do not have an accurate picture of just how safe these facilities are compared to other types. The Kaplan study is dated, and a similar type of study urgently needs to be done.[78]

Useful Resources

(a) *Bicycle Forum*. Issue 30. Missoula, MT.

This issue discusses techniques for keeping motor vehicles off trails, the safety of trails, and sidewalk bike paths. Issue 31 deals with construction issues.[133] Available from Adventure Cycling Association, P.O. Box 8318, Missoula, MT 59807.

(b) Federal Highway Administration, 1992. *The Effects of Bicycle Accommodations on Bicycle/Motor Vehicle Safety and Traffic Operations*. Washington, DC.

Technical report that complements *Selecting Highway Design Treatments to Accommodate Bicycles*, and that has a chapter on trail design and policies. Available from FHWA, HEP-50, 400 Seventh St., SW, Washington, DC 20590.

(c) King County Roadshare Program, 1992. *The King County Non-Motorized Plan* (1993). Seattle, WA.

The plan describes situations in which separated facilities alongside road rights-of-way can provide a benefit.[103] Available for $10.17 from Phil Miller, 976 King County Administration Building, 500 4th Ave., Seattle, WA 98104.

(d) Lagerwey, P. 1992. *Designing Rail Trails*. Paper to the Velo Mondiale Conference, September 1992.

The paper discusses crossings and safety — both in relation to other trail users and personal security from crime — in some depth.[134] Available in the Velo Mondiale Proceedings, CAN$75 from Velo Quebec, 3575 Blvd. St. Laurent, Suite 310, Montreal, Quebec H2X 2T7.

(e) Rails to Trails Conservancy (RTC), 1993. *Trails for the 21st Century*. Washington, DC.

The Rails to Trails Conservancy has published a detailed trail design, construction, and operations manual.[132] Available for $24.95 plus $4 postage & handling from RTC, 1400 16th Street, NW, Suite 300, Washington, DC 20036.

SHARED LANES

On low-volume residential and rural roads with low-vehicle speeds, all adult and child bicyclists can operate safely and without being intimidated by traffic. Little or nothing — beyond adequate maintenance and removal of dangerous drainage grates and other surface irregularities — needs to be done for bicyclists.

Van Valkenberg developed a method for evaluating the suitability of Wisconsin rural roads for bicycling based, in part, on the likelihood of meeting a motor vehicle coming towards you at the same time as a motor vehicle behind you wants to pass. The more frequently this conflict was likely to happen, the lower the suitability of the road for bicyclists.[146]

Similar thresholds are now being developed for residential and urban roads. Davis has developed a methodology for assessing the suitability of roadway conditions for bicycling based on objective data, and has used the process to rate streets in a number of cities in the United States.[148] The formula used by Davis comprises several factors, including:

Average daily traffic (ADT)
Number of travel lanes (L)
Speed limit (S)
Outside lane width (W) ($W > 14$ ft $=0$)

He also has devised a method for determining pavement (PF) and location values (LF) that bring parking, surface conditions, grades, and other factors into account. These are then combined to create a Suitability Rating Index (SRI) for each segment of street.

The overall formula is:

$$ADT/(L \times 2500) + S/35 + (14-W)/2 + PF + LF = SRI$$

Davis has had his evaluations confirmed by local bicyclists riding the streets for which values have been assessed. Roadways with an SRI of 0 to 4 are rated excellent. An SRI of 4 to 5 is good, 5 to 6 is fair, and over 6 is poor.

Clark has also developed a Road Suitability Formula with a few less factors to consider:[149]

$$\frac{(ADT/50) \times (S-15)^2}{(\text{Total pavement width - parking lanes}) + 4\ (\text{usable bike space})^2}$$

Under this model, a score of less than 100 is excellent. From 100 to 500 is good; 500 to 1,000 is fair; 1,000 to 5,000 is poor; and anything above 5,000 is dangerous.

Useful Resources

(a) Wisconsin Department of Transportation, 1982. *Methodology for Evaluating the Suitability of Roadways for Bicycle Use*. Madison, WI.

In addition to this report, Wisconsin State bicycle maps show the results of the application of the methodology. Available from Wisconsin DOT, Division of Planning, P.O. Box 7913, Madison, WI 53707.

(b) Chicagoland Bicycle Federation (CBF), 1992. *Strategic Regional Arterial Phase One Survey of Bicycle Compatibility*. Chicago, IL.

Detailed analysis of the current state of the arterial network for bicycling and potential improvements to make it more bicycle-accessible. Available from the CBF, P.O. Box 64396, Chicago, IL 60664.

BICYCLE AND BUS LANES

There has been very little experience with shared bus and bicycle lanes in the United States, perhaps limited to just Madison, WI. The AASHTO Guide and 1992 FHWA report do not mention this facility type. However, literature from Canada, Germany, France, and the United Kingdom suggests dedicated bike and bus lanes might be a practical option. Egan reports that the creation of a bus and bike "Urban Clearway" in Toronto resulted in significant increases in bicycle use.[136,150] An existing four-lane downtown street was restriped to provide for bus, taxi, and bicycle use only in the curbside lanes between 7 a.m. and 7 p.m. on weekdays. Bicycle traffic increased 173 percent, transit ridership grew by 25 percent, and travel times for all users decreased.

Bicyclists were overwhelmingly supportive of the changes — and Egan notes how the level of satisfaction grows in sections where the curb lane is widest. For most of the Clearway, the curb lane is between 4 to 4.5 m (13 to 15 ft) wide. Over 75 percent of bicyclists surveyed felt these sections had been made safer than before the Clearway was installed. In the sections where the lane width is only 3 to 3.3 m (10 to 11 ft) wide, only 42 percent of respondents felt the Clearway made conditions safer.

Metzger reports similar findings in Grenoble and Annecy, France; and Mathew notes that "cycle use of bus-only streets [in the United Kingdom] is widespread and virtually trouble-free."[44,151]

Facilities such as these should be tried in the United States.

BICYCLE BOULEVARDS

A small number of communities are starting to experiment with the development of Bicycle Boulevards. These facilities are developed along residential — or low-volume, low-speed — roads that parallel major highways. A continuous, direct route is created for bicyclists through signing and changes in priority to favor bicyclists on the through bike route, and through motor vehicle traffic being prevented by barriers placed along the route. It is important to note that these facilities do not deny or reduce access to residents and their cars — they simply prevent the route from being used as a cut-through by commuters or other users.

Palo Alto, CA was the first community to experiment with this type of facility in 1981 (figure 12). During the demonstration period, bicycle use along the boulevard increased dramatically, and the rate of growth exceeded that of other routes in the city. The boulevard concentrated bicycle traffic along the corridor, and motor vehicle use of the street declined by 50 percent.[80]

Figure 12. Bicycle boulevard, Palo Alto, CA.

CONCLUSIONS

The most important development in the last decade is that the separation vs. integration debate has become redundant and futile. Enough is known about the design and appropriate use of different bicycle facilities and shared roadways to counter any fears that one type of facility is inherently more or less dangerous than another. The 1992 FHWA report is a major breakthrough in this regard, highlighting the realization that different facility types can achieve markedly different outcomes in terms of level of bicycle use — all within acceptable margins of user safety.

There are still issues that need further work and study, however. Forecasting the potential impact of different facilities on levels of use and, in particular, rates of diversion away from car trips remains inexact.

SECTION 5. SURFACE QUALITY

INTRODUCTION

Very few of the crash studies reviewed as part of this study refer specifically to surface defects as being an important cause of crashes for bicyclists. This may be because they rarely involve another vehicle — and thus do not get reported to the police — or because the coding and reporting forms do not ask for information about surface quality or pertinent information is not reported or computerized.

One exception to this is a 1986 survey of bicycling crashes in Boulder, CO, which found that almost 30 percent of crashes were caused by loose gravel in the street.[152] Joshi and Smith, in the United Kingdom, report that poor road maintenance accounts for 5 percent of incidents considered threatening by bicyclists.[153]

Williams identifies two sets of standards and policies from California that address pavement patching. Caltrans has a set of tolerances for grooves and steps, and the City of Palo Alto has developed Compaction and Smoothness Standards for bicyclists on Palo Alto streets.[154]

Denver is one of many cities that have adopted construction detour standards for bicyclists, so that riders are given a safe and continuous alternative to trails and bikeways when these facilities are under repair.[155]

In addition, it is interesting to note that up to 20 percent of bicycle crashes involving no other vehicle in the United Kingdom and Denmark are due to surface conditions — either loss of control on wet or broken surfaces, or hitting debris or an obstacle in the road.[42,43] As so many bicycle crashes in the United States are categorized as being due to bicyclist error or loss of control, it would be useful to determine just how many of these incidents are due to surface irregularities.

There are some surface conditions that have been singled out for attention: railroad crossings, drainage grates, and surface materials.

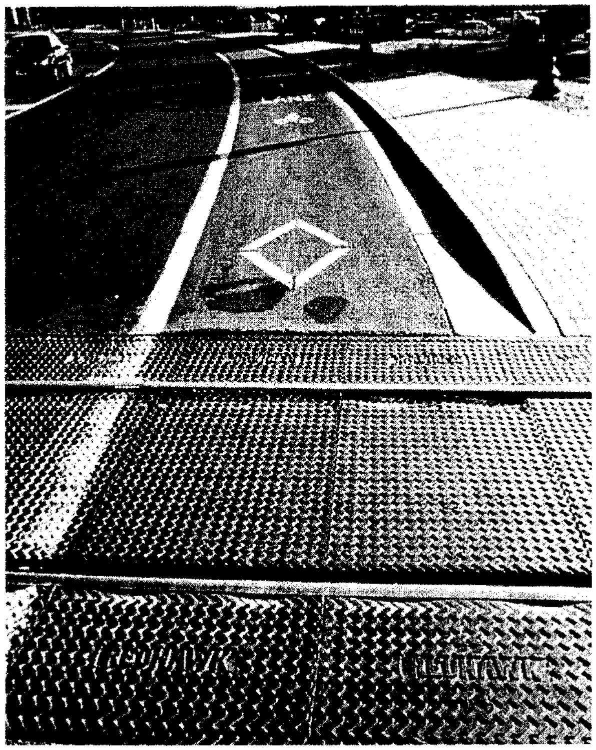
RAILROAD CROSSINGS

Railroad tracks can catch the wheel of a bicycle and cause the rider to fall. The farther the angle of the tracks from 90 degrees to the road, the greater the chances of this happening.

There are three recognized solutions. First, Mathew reports that in the United Kingdom, "all roads cross rail tracks at 90-degree angles, thereby reducing problems of trapped wheels to a minimum. Maintenance standards tend to be high so that road and rail surfaces are at a similar level."[44] Even with this solution, steel tracks and poorly maintained flanges and flangeway fillers can cause spills on a 90-degree crossing.

Second, where train speeds are less than 10 mi/h (16 km/h), fill the tracks with flangeway filler and install a rubberized crossing (figure 13).[20] The MUTCD and other traffic control device manuals have further information on the designs for these installations.[156] The city of Seattle will occasionally install the expensive rubberized crossings just in the portion of the roadway where cyclists will be operating.

Third, provide additional asphalt to the sides of the crossing to allow a bicyclist to approach and cross the tracks at a 90-degree angle (figure 14).

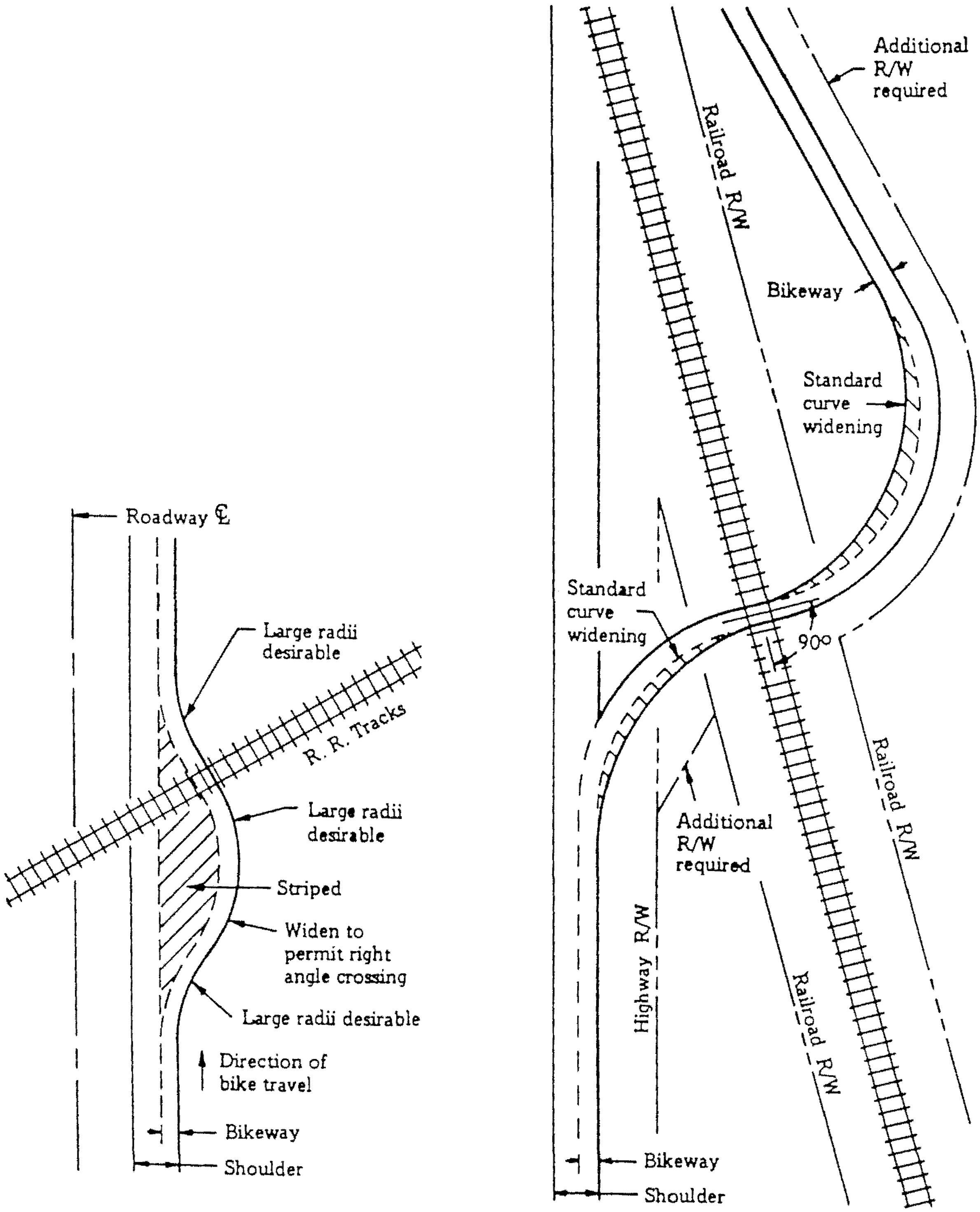


Source: Florida Department of Transportation

Figure 13. Rubberized crossing strategy for safe bicycle crossing of railroad track.

DRAINAGE GRATES

There was extensive research work in the 1970's to develop and approve bicycle-friendly drainage grates that are effective in performing their drainage function as well. This was summarized in a 1977 FHWA report.[157]



Source: Minnesota Department of Transportation.

Figure 14. Crossing at 90 degrees.

During the 1980's, further studies have confirmed this work, and newer designs for grates and modifications to old grates are widely available (figures 15 and 16).[158] These newer designs are also the best from a hydraulics standpoint. There is little excuse for the continued installation of drainage grates that can catch the wheel of a bicycle — and yet the practice continues.

Drainage grates and utility covers are always slippery when wet and can accumulate debris in and around them. Thus, the ideal solution would be to eliminate grates from the path of a bicyclist altogether, or reduce their frequency. Grates can be offset, out of the travel lane. Or, agencies can use inlet-style drainage systems that avoid the need for covers entirely.

Williams (1993) has also provided information on dealing with sunken utility covers, using Montana's Public Works Standards as an example of how to ensure a smooth ride for bicyclists (Montana, 1988).[154]

SURFACE MATERIALS

There is no mention of the impact of different surface materials on bicyclist safety in the United States in current literature. However, with the advent of traffic-calming techniques, traditional neighborhood design, downtown revitalization projects, and other trends encouraging the use of roadway surfaces other than asphalt and concrete, research into this area might be appropriate.

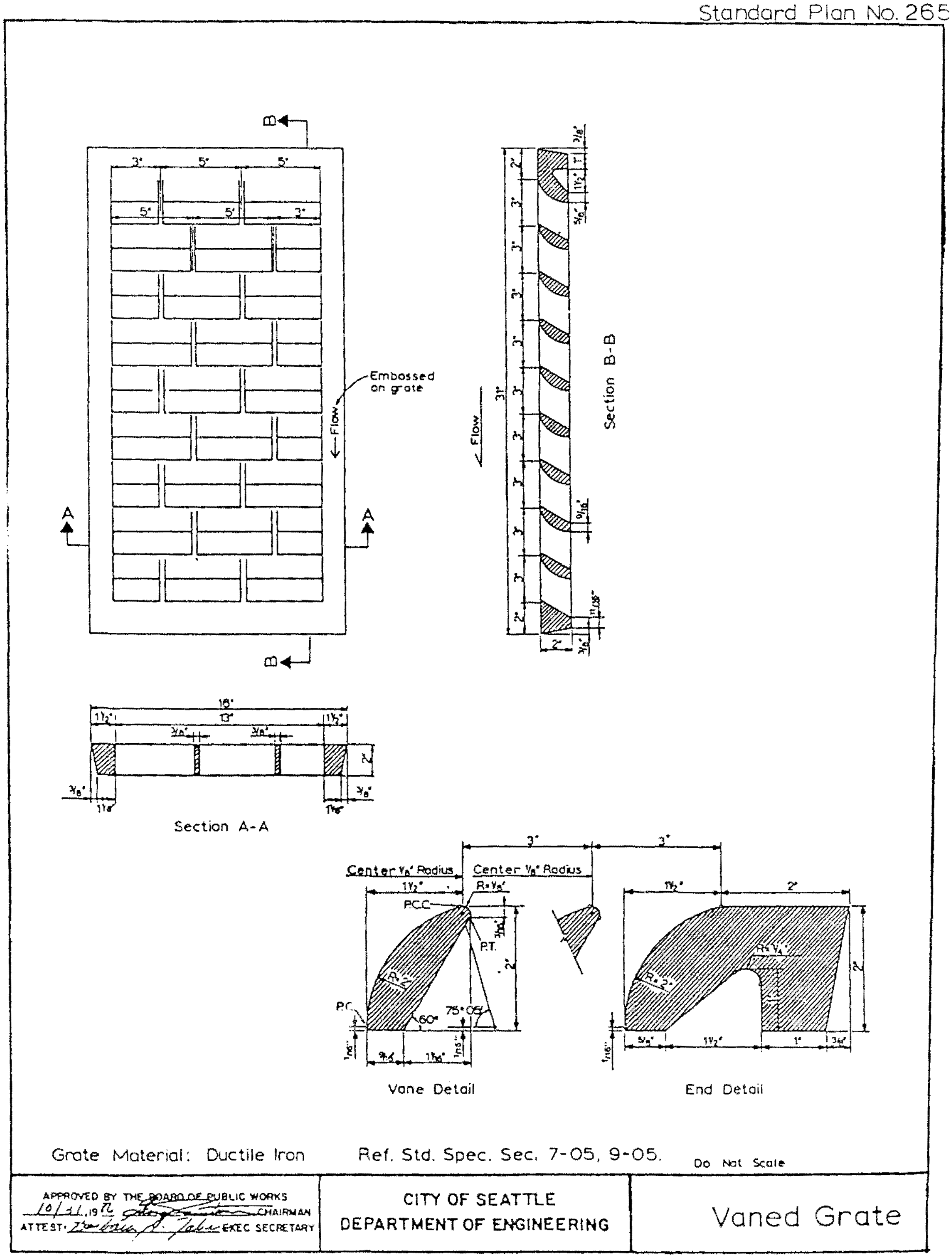
The Cyclists Touring Club urges caution in the use of textured surfaces, as bicyclists may be displaced onto busier roads or sidewalks.[159] Cobblestones and bricks with rounded edges are especially difficult to ride on, particularly with narrow tires and no suspension.

The University of Oldenberg in Brussels, Belgium, (Bracher, 1988) found that prolonged riding on brickwork paths can actually cause physical injury to riders and is uncomfortable for all but very short rides.[144]

MAINTENANCE AND OTHER ISSUES

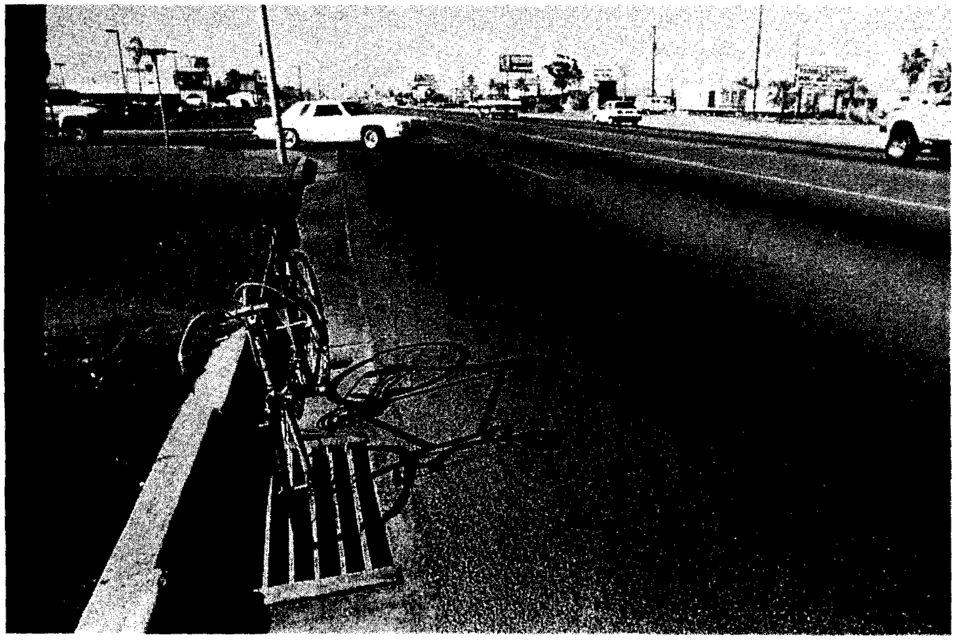
Road-edge conditions are crucial for bicyclists. Bicycles are quite finely balanced when being ridden on the roadway, and even the new breed of mountain bikes with wider tires are very susceptible to surface irregularities, debris, and features such as those described above.

A number of construction and maintenance practices have a very direct bearing on the safety and comfort of bicyclists using the roadway. For example, if concrete and longitudinal seams are located 2 to 3 ft (0.61 to 0.92 m) from the roadway edge, or surface overlays cause a drop-off at the gutter, bicyclists will ride further out into the travel lane to avoid catching their wheels. This can negate the benefit of a wider curb lane or bike lane.

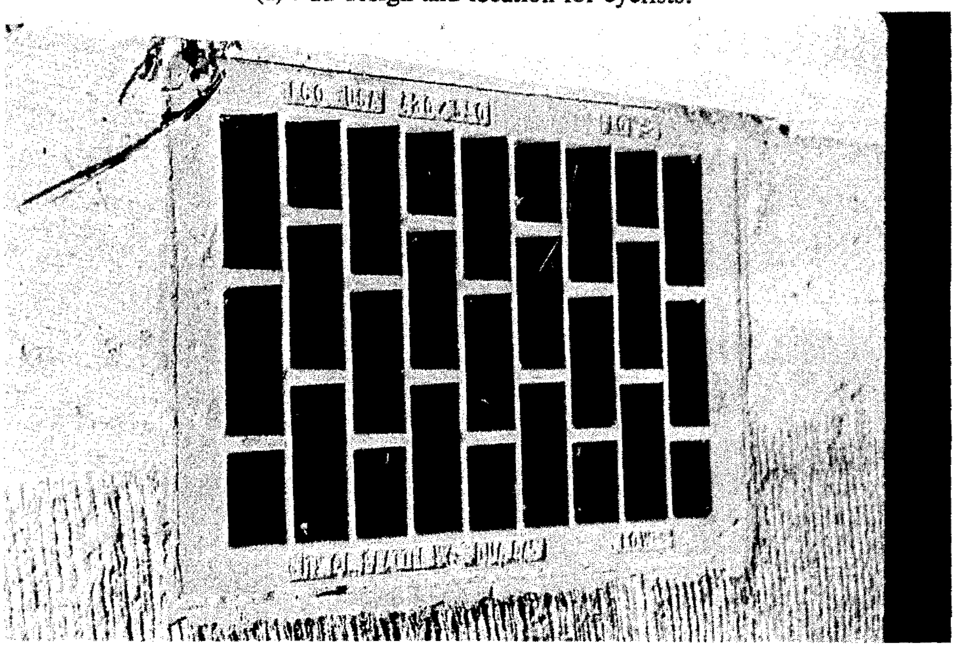


Source: City of Seattle.

Figure 15. Bicycle-safe drain grate.



(a) Bad design and location for cyclists.



(b) Good design for cyclists.

Figure 16. Good and bad drain grates.

Some agencies are now changing their maintenance guidelines to better accommodate for bicyclists as a result of expensive lawsuits that have arisen from crashes caused by surface defects.

CONCLUSIONS

Surface defects have long been identified as a threat to bicyclists and a source of considerable discomfort. Solutions to the problems caused by drainage grates and railroad tracks have been around for years, with continual fine-tuning and modifications.

This is not the case with surface materials. If traffic-calming, neighborhood, and downtown revitalization programs continue to grow in popularity and extent, research into the impact on bicyclist safety and comfort will be necessary.

Research into the impact of rumble-strip designs and shoulder surface materials would help ensure that rural roads, in particular, remain viable and safe places to ride.

Useful Resources

(a) Bicycle Forum, 1990. *Improving Local Conditions for Bicycling.* Missoula, MT.

Four-page guide to overcoming surface irregularities. Available from the Adventure Cycling Association (Bikecentennial), P.O. Box 8318, Missoula, MT 59807.

(b) City of Seattle. Bike Spot Improvement Card. Seattle, WA.

Mail-back card distributed by the city engineering department that solicits information on small-scale improvements that can be made, such as fixing potholes, replacing missing signs, and installing bicycle parking facilities. Available from the Bicycle and Pedestrian Program, Seattle Engineering Department, 600 4th Ave., Seattle, WA 98104.

SECTION 6. TRAFFIC CALMING

INTRODUCTION

A profound change in philosophy and practice has swept through urban and suburban areas in Europe — and to some extent in Japan and Australia — during the 1980's and 1990's: Traffic Calming. A number of traffic-calming techniques are also becoming common in the United States, often at the request of citizens groups.

Dornfeld and Clarke chart the development and definition of traffic calming, describing it as one of the tools being used in the "struggle to manage the motor vehicle."[160] A number of quotations are used to define traffic calming variously as:

> ...aiming to reduce the dominance and speed of motor vehicles.
>
> ...an attempt to mix the different transport modes and create a form of peaceful coexistence between them.
>
> ...far from being a witch hunt policy against the car. It simply means motor traffic has to lose its dominance in those cases where it has become a nuisance and danger. It will be the struggle for the emancipation of the pedestrian, the reclamation of public and cycle transport and the preservation of the historic built environment and the residential neighborhoods.

POTENTIAL BENEFITS OF TRAFFIC CALMING

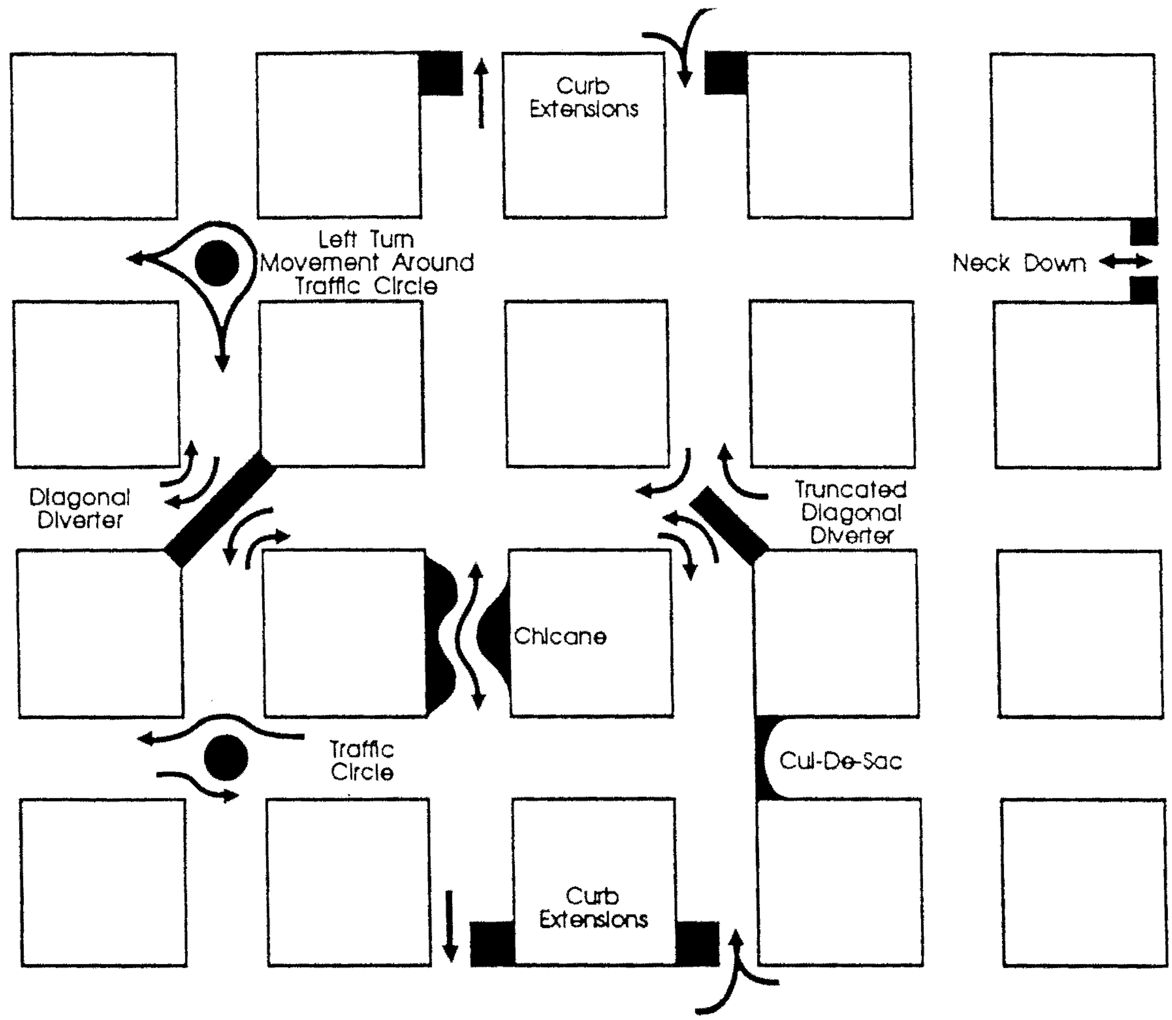
Traffic calming has improved bicyclists' safety. Both the incidence and severity of crashes involving bicyclists has been reduced, primarily through the reduction in speed of motor vehicles. Eighty percent of pedestrians struck by a motor vehicle traveling between 35 to 45 mi/h (56 to 72 km/h) are killed. This figure falls to just 5 percent at speeds of 18 mi/h (29 km/h).[161]

Bicycle use has also been increased through traffic-calming measures. Many authors have stressed the importance of realizing that traffic calming is not just a safety program designed to reduce risk.[162,163] The United Kingdom Department of Transport has acknowledged that the comprehensive redesign of streets cannot be justified solely on the grounds of improved safety. The goals of traffic calming go beyond crash and vehicle speed reduction. They also include reducing air pollution, noise, and fuel use; enhancing the local environment; and encouraging interaction, walking, bicycling, playing in the streets, and improving the quality of life in residential areas and city centers.

Traffic calming, according to Mathew, "offers an acceptable compromise in the ideological argument about cycle paths that still rumbles on in the cycling community. Make cyclists co-equal road users, as one side has always said, but offer them the protection the average cyclist wants, as the other side has always argued."[164]

U.S. EXPERIENCE

Dornfeld provides a good summary of experience in U.S. cities with isolated traffic management techniques, such as speed humps, traffic circles, curb extensions, neck downs, and chicanes (figure 17).[160]



Source: Dornfeld[160]

Figure 17. Traffic-calming techniques.

The Institute of Transportation Engineers produced a detailed manual in 1989, and papers have been presented on traffic calming at the International Pedestrian Conferences and, occasionally, at the Transportation Research Board.[165]

The city of Seattle has pioneered the use of small traffic circles in residential streets as a means of neighborhood traffic control. More than 200 circles have been installed in recent years — all at the request of residents, who have to go through a thorough application process and trial period before the circles are installed permanently.[166]

Many cities have experimented with speed hump designs and installation in order to gain maximum impact from the features (figures 18 and 19). The city of Bellevue, WA, studied the introduction of 14 humps in 5 residential streets and found them to be effective in reducing speed. They also enjoyed a high degree of public support.[160]

The most comprehensive program of traffic calming in the United States is now under way in Portland, OR, following a lengthy public outreach effort.[167]

INTERNATIONAL EXPERIENCE

Traffic calming in Europe began in the 1960's with the pedestrianization of city centers (Monheim, 1990) and the strict management of car traffic in cities such as Gothenburg, Sweden, and Groningen, the Netherlands, through the use of traffic cells (U.S. DOT, 1980).[168,169]

In the mid-1970's, the Dutch developed a new concept for traffic management in residential streets called the "woonerf" (living street or living yard), in which all traffic is required to travel at walking speeds and the most vulnerable users take precedence over the least vulnerable (motor vehicles). This new legal creation was, most importantly, backed up with a new type of street design in which the layout was developed specifically to deter through traffic and slow down the remaining cars. These new "woonerven" were enormously popular with both residents and traffic planners — more than 70 percent of the population thought that woonerven were highly attractive or attractive. Almost 3,000 woonerven were installed in just 7 years after passage of a special 1976 law allowing their use.[170] The results were impressive. Injury crashes in these streets fell by 50 percent and vehicle speeds were cut to an average of between 13 to 25 km/h (8.1 to 15.5 mi/h).[160] In 1984, a review panel made a number of changes to the rules and regulations affecting the design and implementation of these measures — mostly making their use easier and cheaper.[160]

Meanwhile, their German neighbors were already building on this work and were using similar traffic-calming techniques over entire residential areas — not just individual streets and pairs of streets, as was common with the woonerven. Tolley reports the early success of these schemes in reducing through traffic in residential areas by 33 percent, and lowering mean speeds from 27 to 22 km/h (16.8 to 13.7 mi/h).[162]

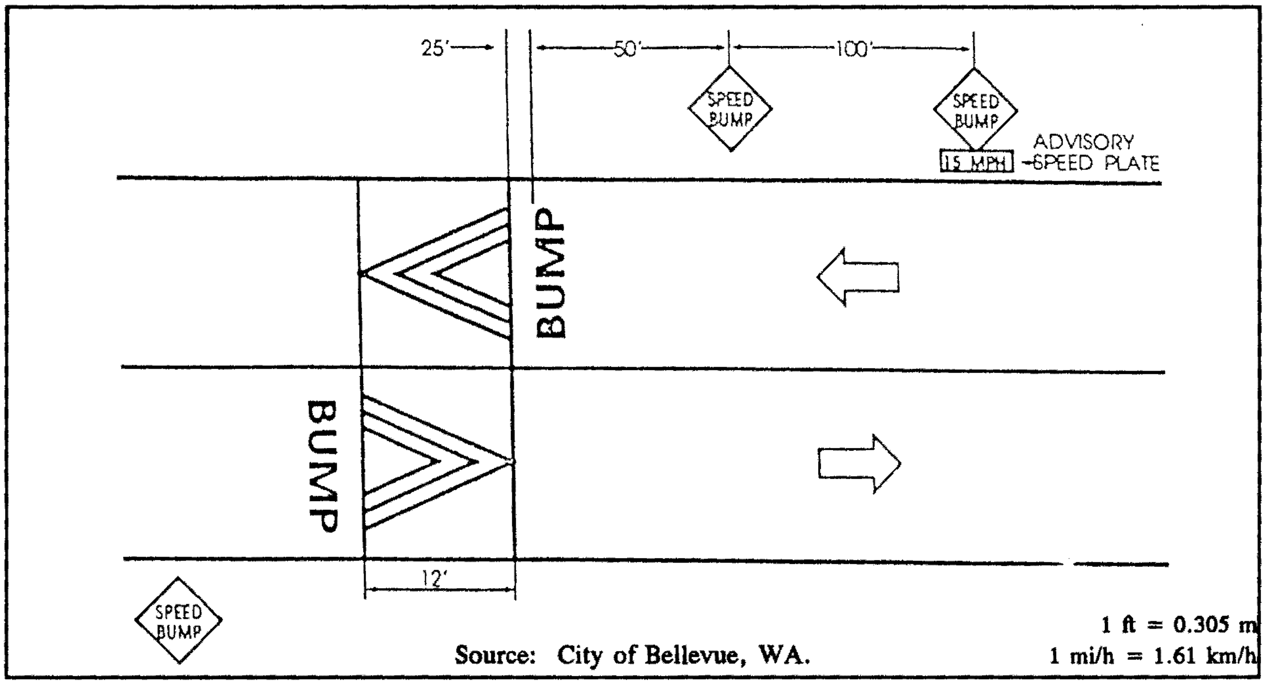


Figure 18. Speed bump design, Bellevue, WA.

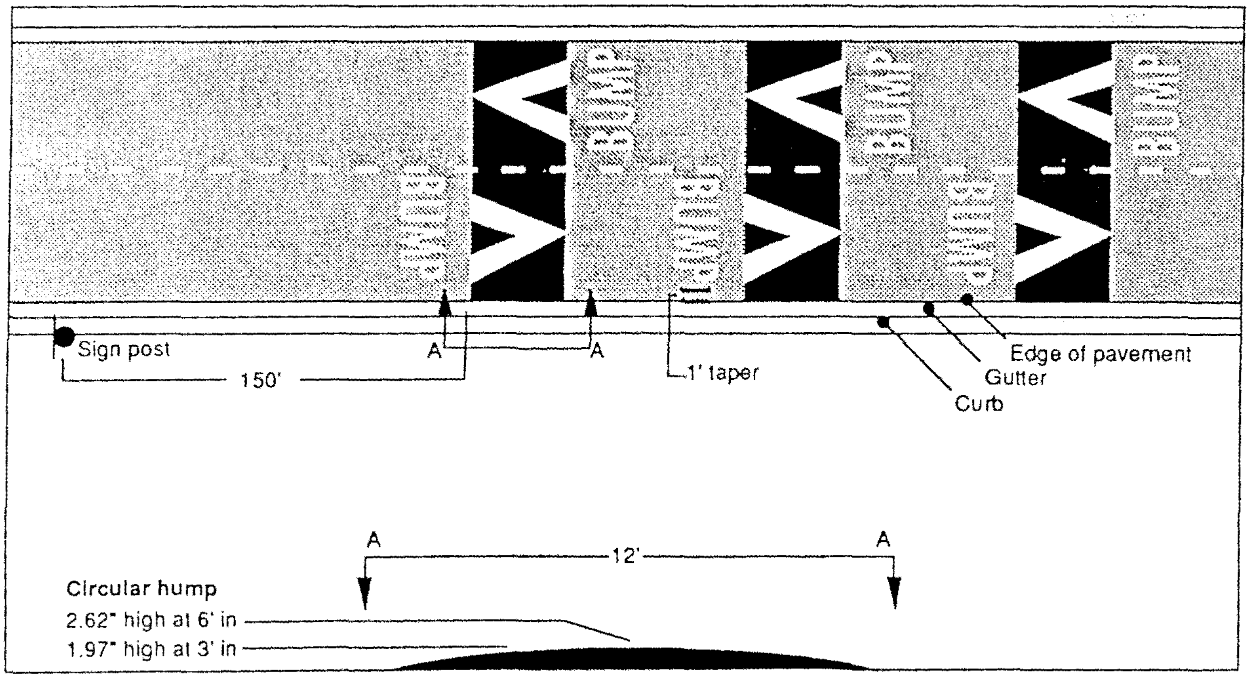
German town and city planners were incorporating these new traffic-calming techniques into a major reshaping of transportation priorities and safety in their cities. A new hierarchy of urban streets was developed:

- Arterials with a maximum speed of 50 km/h (33 mi/h) with synchronized traffic signals, bike lanes, marked crosswalks, wide sidewalks, and medians.

- Collectors with a maximum speed of 30 km/h (18 mi/h) with narrow lanes, bike lanes, speed tables, and wider sidewalks designed to make the speed limits self-enforcing.

- Residential streets designed to encourage walking speeds with managed parking, chicanes, reclaimed play areas, speed humps, and road closures.

There has been extensive evaluation of a number of experimental and demonstration projects in Germany and other countries, with encouraging results. Crashes, both fatal and injury, involving all road-user types have decreased — in some cases by as much as 60 percent — and bicycling, walking, and other street activities have increased.[162] While there has been little overall change in traffic volumes, average vehicle speeds have been cut, and yet average journey times for motorists have risen by only a minimal amount — just 33 seconds, on average, in one major study of six demonstration projects.[162] Citizen approval ratings are high, and other environmental benefits have also been noted, such as reducing vehicle emissions, noise, and fuel use.



Source: City of Los Angeles.

1 ft = 0.305 m

Figure 19. Speed bump design, Los Angeles, CA.

Tolley points out that "if the cost-effectiveness is seen as a relevant criterion, the potential savings in accident costs alone promise to more than recoup the outlay on the environmental traffic schemes [in Germany]."(162)

The Cyclists Touring Club has taken a close look at how the various traffic-calming techniques affect bicyclists. They provide general and specific guidance on how to implement these techniques so as not to discourage bicycling, or encourage the use of busier streets so as to avoid speed humps and other traffic controls.(159)

The most comprehensive coverage of the design and implementation of different types of facilities is provided by Hass Klau.(163) Many German provinces, counties in the United Kingdom, and national authorities in the Netherlands and Denmark have developed standards and guidelines for the design and location of these techniques.

TRAFFIC-CALMING ISSUES FOR THE UNITED STATES

There are at least three primary obstacles to the widespread development of traffic-calming techniques in the United States.

1. Determining applicability. Hass Klau warns in her 1992 guide to traffic calming aimed at a primarily British audience that:

   Copying continental schemes may not work as well as expected because British circumstances, such as road width, motor vehicle density or the amount of road space available, are in many respects very different to their continental partners.[163]

Exactly the same is true for the United States. Our experience with pedestrianization — which has not worked as well in the United States as in Europe — could not be lifted wholesale from Dutch towns and cities and applied freely in U.S. cities. We must not make the same mistake with a tool as important as traffic calming.

2. Legality. In every country where traffic calming is widespread or growing, special national laws have been passed to facilitate the process. A review of State and Federal design manuals and codes would be necessary in the United States to determine whether similar changes are required here.

   In a related area, the issue of liability will have to be fully explored in the United States before State and local transportation agencies will commonly install facilities that are, in some cases, specifically designed to place obstacles in the path of motorists to force them to slow down.

3. Public acceptance. Indications from Portland, OR; Seattle, WA; and other communities already implementing traffic-calming techniques are that the public is ready to accept this new traffic management philosophy — just as is the case in Europe.[166,167] Some commentators have noted that while traffic calming as a concept may appeal to urban dwellers in compact and crowded European cities, the same might not apply to the car-loving American family.

If this is true, perhaps a new name is needed. Perhaps a serious campaign of public education on the dangers of speed, the desirability of bicycling and walking, and the potential benefits of traffic calming would have to be undertaken. Certainly, comprehensive public participation in the development and design of area-wide traffic calming in U.S. cities and suburbs is going to be a crucial component to the successful adoption of traffic calming in this country.

CONCLUSION

Traffic-calming techniques and the philosophy behind it appear to offer a great potential benefit to bicyclists in the United States, and to other user groups and communities. The choice, design, and implementation of individual design features must be approached carefully. Existing and new designs adapted from a European setting should be tested in U.S. communities.

Useful Resources

(a) Cyclists Touring Club (CTC), 1991. *Cyclists and Traffic Calming.* Godalming, United Kingdom.

Illustrated guide to designing speed reduction and environmental enhancement that can encourage bicycling. Available for £10 from the CTC, 69 Meadrow, Godalming, Surrey GU7 3HS, U.K.

(b) Danish Ministry of Transport, 1993. *Improved Traffic Environment — A Catalogue of Ideas.* Road Data Laboratory, Herlev, Denmark.

English-language summary of traffic-calming experiments throughout Denmark. Available for DKK 400 plus DKK 100 postage and handling, from the Road Data Laboratory, Stationsalleen 42, DK-2730 Herlev, Denmark.

(c) Dornfeld, M. and Clarke, A. 1993. *Traffic Calming, Auto-Restricted Zones, and Other Traffic Management Techniques — Their Effects on Bicycling and Pedestrians.* FHWA, Washington, DC.

Case Study 19, prepared as part of the National Bicycling and Walking Study, details the development of traffic calming in Europe and the United States. Available from FHWA, HEP-50, 400 Seventh St., SW, Washington, DC 20590.

(d) Environmental and Transport Planning, 1992. *Civilized Streets: A Guide to Traffic Calming.* Hass Klau et al., Brighton, United Kingdom.

Detailed description of design elements tried and tested by local governments in the United Kingdom. Available for £37.95 from Environmental and Transport Planning, 10 Clermont Terrace, Brighton, BN1 6SH, United Kingdom.

(e) Institute of Transportation Engineers (ITE), 1989. *Residential Street Design and Traffic Control.* Washington, DC.

Design manual based on U.S. experience. Available for $60 plus $6 postage and handling from ITE, 525 School St., SW, Suite 410, Washington, DC 20024.

(f) City of Portland, OR, 1993. *Reclaiming Our Streets.* Portland, OR.

A 50-page community action plan to calm neighborhood traffic throughout the city. Available from the Bureau of Traffic Management, 1120 SW 5th Ave., Suite 730, Portland, OR 97204.

(g) Seattle Engineering Department (SED), 1993. *Neighborhood Traffic Circles.* Seattle, WA.

Video describing the traffic-circle program in Seattle. Available for $20 from Jim Mundell, SED, 6th Floor, Municipal Building, 600 4th Ave., Seattle, WA 98104.

SECTION 7. SAFETY EQUIPMENT

INTRODUCTION

Most of the foregoing discussion has been about the physical environment in which bicycling takes place, and the impact on the safety of bicyclists that derives from modification of that environment. Simultaneously, work has been going on to determine the safety of the bicycle itself, and the safety value of various pieces of equipment that attach either to the rider or to the bicycle.

Petty reports that between 8 and 17 percent of all bicycle crashes are product-related.[171] Kaplan puts the figure at 3 percent, and Mills puts the United Kingdom figure at 5 percent.[78,172]

Most of the countries studied have consumer product standards for the manufacture of bicycles, especially children's bicycles. Petty says there is "little evidence to support the argument that [Consumer Product Safety Commission's (CPSC's)] Bicycle Safety Standard has had significant effects," although other elements of the agency's work may have had more of an impact.

LIGHTS AND REFLECTORS

Many of these government safety standards require the sale of bicycles with reflectors, and all bicyclists in all countries are required to use at the very least a white front light, red rear light and/or reflector, and additional reflectors in the wheel or pedals. In all cases, this shows considerable concern over the vulnerability of bicyclists while riding at night.

The Cross study, in 1975, found that 30 percent of fatal and 10 percent of injury crashes involving bicyclists occurred in darkness.[46] The National Highway Traffic Safety Administration (NHTSA) reports that the proportion of fatal bicycle crashes occurring in dusk or darkness grew from 33 percent in 1977 to 42 percent in 1987.[173] In Florida, as many as 60 percent of fatal bicycle crashes occur at night.[30]

Although there are no statistics on bicycle use at different times of the day and night, even casual observations suggest significantly lower levels of bicycle use at night. Thus, bicycling at night does appear to be more dangerous. The crash rate for all traffic fatalities climbs from 1.66 to 4.15 deaths per million vehicle miles traveled (per 1.61 million vehicle kilometers traveled) when comparing daylight to nighttime, so the problem is by no means unique to bicycling.[173]

The issue of conspicuity revolves around four factors: detection, selection, recognition, and location. To avoid striking a bicyclist when passing, a motorist must take all four steps in this process. In the United Kingdom, researchers have noted that even when a bicyclist has been observed and recognized as a bicyclist, this may not help them much, as drivers consider them to be of "low value."[161]

Detection is, according to Blomberg et al., (1984) best achieved with active light sources, such as strobe lights or the new LED lights. Retroreflective clothing and standard bicycle reflectors are also effective.[174]

Recognition as a bicyclist is best achieved by devices that provide motion, i.e., pedal reflectors. These help identify the light source as being attached to a moving body — which is an important "signature" for a bicyclist to show.

Locating the position of the bicyclist on the roadway is significantly enhanced by the use of more than one light source, according to Burden. Having two or more sources of light allows the brain to assess distance from the object and closure rate. In addition, the lower the light sources, the closer they appear to the driver.[30]

A mini-debate over the efficacy of red vs. amber rear lights revealed the important distinction between detection and recognition. It was argued that amber lights, both flashing and constant, are easier to detect than red lights — however, amber lights are associated in the driver's mind with construction warning markers and breakdown vehicles rather than bicyclists. Thus, while they may detect the light source, they may react and respond to it in the wrong way.[175]

It is worth noting that in the United Kingdom, research has determined that up to 20 percent of motorists have some kind of defective vision, excluding night myopia.[45] FHWA lists many other factors, particularly those associated with aging, that reduce the visual acuity of drivers and bicyclists, both during the day and at night.[176]

Extensive research has been undertaken by the United Kingdom's Transport Research Laboratory into the effectiveness of different conspicuity aids, including spacer arms and clothing.

Spacer arms — extending out from the side of the bicycle to encourage motorists to pass with more space between them and the bicyclist — do work, but are easily damaged and do not remain functioning for long periods.

Daytime conspicuity is aided by bright fluorescent and luminous jackets and shirts. Nighttime visibility is aided by wearing retroreflective strips on clothing or the bicycle.[177] Fluorescent clothing works well at twilight and in low light, but not in darkness, when the colors appear as black.

HELMETS

The bicycle helmet is the single most effective bicycle safety device for preventing serious injury. Its effectiveness has not only served to decrease bicycle-related fatalities and serious head injuries among those who wear them, but has also inspired a high level of activity among the medical community. Increasingly, since the late 1980's, injury control, public health, and medical organizations have brought new resources and funding to helmet promotion that had previously been championed primarily by bicycling interests. These groups, often in collaboration with the more traditional groups, have initiated promotions, developed materials, and more consistently evaluated the progress of their efforts.

HELMET EFFECTIVENESS

In 1989, the *New England Journal of Medicine* published the first study to quantify the benefits of helmet use. "A Case-Control Study of the Effectiveness of Bicycle Safety Helmets" found that bicyclists who wore helmets reduced their risk of head injury by 85 percent and their risk of more serious brain injury by 88 percent.[178]

This year-long study, involving five Seattle, WA, hospitals and an HMO, compared bicyclists with head injuries to two control groups: bicyclists with other types of injuries and bicyclists who had had some type of crash in the previous year — whether or not they had been injured or had sought medical attention. Bicyclists from this second control group were selected to match the same gender, age range, and zip code as the head-injured bicyclists. Study participants provided information about themselves, their bicycling experience, their bicycle crash, and their use of helmets. Medical records established the severity and type of injury.

It should be noted that in the vast array of medical research regarding bicycle-related head injury, there appears to be little standard definition of head injury (often also called brain injury), its severity, and means of measuring it.

HELMET PROMOTION EFFECTIVENESS

An unprecedented level of bicycle helmet promotion was stimulated in the mid- to late-1980's by a number of factors, including:

- Clear and compelling evidence of their effectiveness in preventing head injury or reducing its severity.
- Widespread recognition of the long-term societal costs of serious head injury.
- The publication of helmet protective performance standards by the Snell Memorial Foundation and the American National Standards Institute.
- The increased availability of helmets where bicycles were sold, the introduction of children's helmets, and the growth in the number of helmet models available from fewer than 10 to more than 100.
- Helmet use required by bicycle racers by the United States Cycling Federation, the governing body for amateur and Olympic racing.
- Increased Federal funding for injury prevention research.

During this time, the Centers for Disease Control (CDC) within the Federal system established a network of regional injury control centers, such as those at the University of North Carolina, Harborview (Washington) Medical Center, and Dartmouth College. CDC provided capacity building grants through this infrastructure that were used to fund various helmet promotions. In a NHTSA-funded study of bicycle helmet promotions in the United States, a majority of the promotions targeted child bicyclists and/or their parents.[179]

The Washington (State) Children's Bicycle Helmet Campaign, begun in 1986, provided an early bicycle helmet promotion model for subsequent national, as well as local, efforts. This coalition of Harborview Medical Center, the Cascade Bicycle Club, the Seattle-King County Health Department, and others developed and tested a multi-faceted community-based helmet campaign that increased children's helmet use from 1 to 2 percent to well over 50 percent by the early 1990's. The influence of this model grew not only from its success, but also from its continued thorough documentation and wide dissemination of campaign materials, methodology, and technical assistance.[179]

As increased funding became available, especially through the medical and public health fields, assessments of the success of helmet promotion activity became more common and more comprehensive. These have included process evaluations of the number of printed materials distributed, the number of articles published, and the number of participants at a presentation or event. Outcome evaluations have included the number of bicyclists who report owning a helmet and how often they wear it, the level of bicycle-related head injuries treated, and changes in awareness or attitude. Specific examples cited in the NHTSA helmet promotion study include:

- Over 17,000 "Buckle Up Your Baby" helmet brochures were distributed by the District of Columbia in 1 year.

- The White Clay Bicycle Club made presentations to 6,300 third and fourth grade students at 26 Delaware schools.

- A National Safe Kids Campaign public service announcement was broadcast on ABC, CBS, and CNN to an estimated 51.5 million households.

- Following several years of an intensive community-based campaign, Harborview Medical Center in Seattle, WA, noted a 50-percent decrease in bicycle-related head injuries.[179]

- In a New York Department of Health survey, 15 percent of 28,000 kindergarten through twelfth graders reported owning a helmet in 1989. That number increased to 17 percent the following year.[179]

- In a 4-year period, a national Seattle, WA, based helmet manufacturer increased their sales in the Seattle area from 1,500 to over 30,000 helmets per year.[179]

- A resource guide, developed by the New York Department of Health, encourages local helmet promotion evaluation by providing detailed instructions for conducting and analyzing self-reported classroom surveys and helmet-use observations.[180]

LEVELS OF HELMET USE

Clearly, encouraging helmet purchase is only a step in promoting consistent helmet use. In a 1984 roadside study in Vermont, 19 percent of bicyclists stopped said that they owned a helmet, but only 8 percent of them were actually wearing it at the time.[181] Most reasoned that they were only on a short trip or that their helmet was uncomfortable.

Other factors influencing actual helmet use include the bicyclist's age and whether or not he or she is riding alone or with others. Helmet use has tended to be higher among those adults who belong to bicycle clubs. Use among the less-experienced or less-informed general adult population has been considerably lower, especially among college students.

Children were five times more likely to wear a helmet when riding alone than when riding with their unhelmeted peers.[182] However, when riding with their peers or adults who were wearing helmets, children were 22 times and 28 times more likely to be wearing a helmet themselves, respectively. A similar study of bicyclists of all ages found that they were more likely to adopt the habits of their companions of either gender or of any age.[183] Bicyclists were observed to be more likely to wear a helmet if riding with others who were also wearing one and less likely to wear one if their companions were not.

Nationally, no estimate of bicycle helmet use was found. However, 1 percent of bicyclists of high school age reported that they wore a bicycle helmet in the 1991 Youth Risk Behavior Survey conducted by the Centers for Disease Control (CDC).[184]

MANDATORY LEGISLATION

Several States and local jurisdictions now have some form of legislation requiring bicycle helmet use, and numerous others are proposing or awaiting action. California, Connecticut, Georgia, Oregon, New Jersey, New York, Pennsylvania, Tennessee, and Virginia each mandate use for young bicyclists ranging from under 12 to under 18 years of age. Prior laws in California, New York, and Massachusetts existed for children under 5 years of age who were carried as passengers. However, only three local jurisdictions (two local parks and King County, WA, excluding the city of Seattle) have required helmet use for all riders. Each quarter, the National Safe Kids Campaign compiles and sells an updated list of mandatory legislation.[185]

Observed bicycle helmet use among children increased from 4 percent to 47 percent in Howard County, MD, following an education campaign and the enactment of mandatory bicycle helmet use legislation for bicyclists under 16 years of age.[186] Self-reported helmet-use among fourth, seventh, and ninth grade students in the county increased from 11 percent before the law was enacted to 37 percent afterward.[183] The same helmet use survey was sent to similar populations in two neighboring counties in the State. After a similar education campaign was conducted in a county without such a law, helmet use increased from 8 percent to 13 percent. Children in the third county were not exposed to any campaign or law. Helmet use among them increased from 7 percent to 11 percent.

HELMET STANDARDS

Helmet performance testing using one of three standards remains voluntary, and compliance appears to be complete. There have been no reports of helmets on the market that do not meet the Snell Memorial Foundation B-90 Standard or do not claim to meet one of two self-certification standards, the American National Standards Institute (ANSI) Z-90.4 and the American Society for Testing and Materials (ASTM) F1446, F1447.

Each standard seeks to assess the helmet's ability to absorb and attenuate the impact of a blow to the head. The testing technique involves mounting a helmet to an instrumented head form, dropping it from various heights onto various surfaces, and measuring the resulting impact. Additional tests assess strap and buckle strength.

CONCLUSION

The addition of the medical, public health, and injury control community involvement in promoting helmet use has lead to a marked increase in the quantity and quality of evaluation of the effectiveness of bicycle helmets, their means of promotion, and the reduction of related head injury.

Additional data is needed to determine the level of bicycle use, crash causes, the severity of the resulting injuries, and the demographics of head-injured bicyclists. As discussed earlier in the section on bicycle crashes, injury rates by age based on total population may be misleading, especially when comparing children (a high proportion of whom ride bicycles) with adults (a much lower proportion of whom ride bicycles).

Useful Resources

(a) North Carolina Department of Transportation, 1992. *North Carolina Bicycle Helmet Campaign Guide*. Raleigh, NC.

A step-by-step guide to implementing bicycle helmet promotion programs. Contact the NC Department of Transportation, P.O. Box 25201, Raleigh, NC 27611.

(b) Tracy, L., 1992. *Procedures and Resource Guide for Bicycle Helmet Promotions: A Review of Bicycle Helmet Promotions in the United States.* NHTSA, Washington, DC.

A review of more than 250 bicycle helmet promotion programs. Available from NHTSA, 400 Seventh St., SW, Washington, DC 20590.

SECTION 8: EDUCATION

INTRODUCTION

Bicyclist education is one key to changing behavior, and research at several critical stages in the development of materials plays a vital role in determining the effectiveness of the product and its ultimate outcome. Beginning in the 1970's, researchers have identified the most common bicycle-motor vehicle crash types and the age groups most affected. Studies such as the Cross study, for example, have been instrumental in defining objectives for educational materials.[46]

Outside the typical comment and review process, little formal research has been conducted during the development of such materials. For example, little has been done to determine the effectiveness of messages as they are presented to target audiences. Even less research has been conducted and published to evaluate educational materials once they have been distributed.

PROGRAM AND MATERIALS DEVELOPMENT

Over the past 15 years, numerous agencies and groups have created and distributed or implemented bicycle safety materials and bicyclist education programs. Much of the foundation for the development of these materials and programs can be traced to the Cross Study.[46]

This National Highway Traffic Safety Administration (NHTSA)-sponsored research, discussed in detail in section 2 of this report, identified for the first time bicycle crash types, their frequency, and the age groups most often affected. With this powerful tool, program developers could determine the specific needs of their target audiences. For instance, materials developed for children could address bicyclists who ride out into the roadway from a residential driveway without yielding to cross traffic (type 1), while those developed for adults could deal with unexpected motorist left turns from a parallel, but facing, direction (type 23).

Application of the Cross crash types to more recent and local crash data has helped customize programs to meet local needs. This type of analysis, conducted in Missoula, MT, home to the University of Montana, determined the types and frequency of crashes involving college students. Public service announcements, among other materials, targeted bicyclists who rode at night without lights, those who failed to stop at stop signs, as well as motorists who failed to yield when required.[56]

A second phase of Federal research was intended to further carry out the work of the Cross study. "Identification and Development of Countermeasures for Bicyclist/Motor Vehicle Problem Types" developed preliminary messages and program ideas.[187] This research recognized the role of bicyclist error in those crashes involving very young bicyclists and the role of immature perceptual and motor development. The study concluded that children 8 years of age or younger seemed to be incapable of riding in traffic. With training, children 9 years of age or older seemed to be capable of this type of riding. Unfortunately, the development of this project coincided with a general deemphasis on bicycle safety within the Federal Government. As a result, much of this research has not been widely distributed or considered.[187]

TYPES OF PROGRAMS AND MATERIALS

A vast array of bicycle education materials and programs has been created, distributed, and used in the past decade — mostly geared toward child bicyclists or their parents. Some examples include:

- Videos such as *Be Safe on Your Bike,* created by the Los Angeles Police Department to illustrate key bicycle traffic skills to elementary school-aged children.[188]

- Brochures such as Bicycle Forum's *Bicycle Safety: What Every Parent Should Know*, which debunks commonly held myths, introduces common child crash types, and offers suggestions to prevent them.[189]

- Presentations, usually to a classroom or a school assembly, that tend to focus on a few key messages and often include some form of send-home material. Once the domain of police officers, these *Officer Friendly* programs are just as likely to be conducted by bicycle enthusiasts, injury control specialists, and others. Captain Cycle and Sprocketman, costumed superheroes, have especially captured the attention of young bicyclists.

- School-based programs, such as the *Basics of Bicycling* and *Traffic Ed*, include on-bike and in-class instruction for children of elementary school age. The *Basics of Bicycling* was created to reduce the number of bicycle-related crashes and injuries by teaching the basic skills and knowledge needed to ride a bike safely. *Traffic Ed*, originally called *BikeEd*, includes pedestrian lessons for younger students and has evolved from over a decade of earlier work in Montana and Florida.[190]

- The community-based *Effective Cycling* program and its video are often taught through community colleges and bicycle clubs primarily to adults. This program teaches assertive, vehicle-style bicycling skills in a traffic setting. Approximately 200 *Effective Cycling* instructors have been trained and certified to teach this thorough program.[107,191] Informally, individual instructors have considerably shortened this program for their own use in a high school or junior high school context.

- Bicycle rodeos are popular with community organizations, police departments, and injury control specialists looking for a single-day event to promote bicycle safety among children. Most follow the Adventure Cycling Association's *A Guide to*

Bicycle Rodeos, which includes lesson plans, skill station layouts, and explanations of why each skill is important. Participants are encouraged to practice each skill until they have mastered it.[192]

EVALUATION: PROGRAM AND MATERIALS SELECTION

With a wide array of bicycle safety and education materials available, it can be difficult, especially for those new to the field, to select the most appropriate and effective materials for their needs. In the early 1980's, NHTSA created the "Program Assessment Kit" to give administrators, program developers, and instructors criteria to judge these materials. The kit was based on an analysis of crash types and bicyclists' errors. Questionnaires helped decision makers evaluate a candidate program's relevance to the crash data, the appropriateness of instruction, its suitability for the target audience, and the level and type of resources required to conduct the program.[193]

No research was found as to the level of distribution or use of this kit. Given the high levels of interest in bicycling, in general, and activity by those in fields not traditionally involved in bicycle safety, the need for this type of resource is especially critical today. It can be very difficult for those beginning their bicyclist education or safety programs to find resources, and to determine the appropriateness and potential effectiveness of such programs.

IMPLEMENTATION

Evaluating program implementation is another stage in influencing the effectiveness of the final outcome. Program materials, presentation, and content can be fine-tuned in response to the data gathered. For instance, the draft *Basics of Bicycling* curriculum was pilot-tested in Mebane, NC schools as part of a University of North Carolina Highway Safety Research Center evaluation of the program. The curriculum was taught by physical eduction teachers during their regularly scheduled classes. This research determined that the *Basics of Bicycling* could be successfully taught in its intended setting and was appropriate for the target fourth to fifth grade student age group. This evaluation also recommended some revisions prior to publication. For example, the draft program recommended a bicycle for each child in the class. Fieldtesting determined that bicycles for one-half of the children in the class, plus a few spare bikes in case of mechanical failure, actually worked much better. Teamed with a partner, children actually became part of the informal evaluation and remediation of each other's performance in the class.[194]

In another example, a market study helped the Florida Department of Transportation establish a baseline for their work to promote comprehensive bicyclist education in schools throughout the State.[195] Surveys were mailed to school district superintendents asking, among other things, what, if any, type of bicycle safety programs were being conducted in their schools; whether their teachers had received any training; and what problems they had in implementing this type of program. Surveys returned by 60 of the 67 superintendents indicated:

- 72 percent of schools teach some form of bicycle education to their students. The scope, content, and methodology of these education programs, however, vary widely.

- The bicycle education program in two-thirds of the school districts use some form of the classic *Officer Friendly* presentation.

- 11 percent of the districts use the Florida DOT-developed bicycle education program. At the time of the study, teachers from 22 percent of the school districts had been trained in bicycle safety through this State program. Outreach to train teachers and support their implementation of bicycle education programs continues.

- Finding time to conduct a bicycle education program in an already overloaded curriculum and funding are the most common problems in implementing this type of program. Reworking classroom schedules, team teaching, and State funding were strategies recommended to overcome these barriers.

Through this simple survey and its high response rate, Florida DOT can continue to fine-tune and more effectively market their bicycle education program and teacher training to schools.

PROGRAM EFFECTIVENESS: PROGRAM OBJECTIVES

Bicycle education programs typically include several measures of their participants' progress and often involve pre- and post-program implementation tests. Bicycling myths, traffic laws, and the meaning of traffic signs, for example, may be assessed through a true/false quiz or other test of knowledge. How to fit a helmet, scan behind while continuing to ride straight, and making vehicle-style left turns can be assessed by asking participants to demonstrate behaviors or skills.

A Madison, WI, study used a paper-and-pencil test to assess the knowledge and intended behavior of 118 third through fifth grade students before and after a school-based bicycle safety education program.[196] This program was designed to address the types of crashes this age group was likely to have: wrong-way riding, driveway ride-out, and bicyclist sudden swerve to the left. True-false questions assessed students' knowledge of which side of the road to ride on. Fill-in-the-blank questions asked students to report their intended behavior as they entered a road. Finally, students were asked in their own words to tell how they would know if it were safe to move or turn left. Students showed significant improvement in the test after the program's on-bike training and classroom instruction.

EXTERNAL EFFECTIVENESS

Little research was found to assess the external impact of educational programs or materials. These external impacts may include changes in the number and/or types of crashes, the number and/or severity of injuries, the level of helmet use, and the number of bicyclists and/or the amount of riding they do.

A survey of fourth and fifth grade students in Alamance County, NC, established the level of self-reported bicycle and helmet ownership and use, and bicycle crash and injury experience.[194] Children were asked if they had been to a doctor or received treatment at a hospital for a bicycle-related injury and, if so, what was the cause of that crash. Of the 400 students, one in eight had been injured seriously enough to require medical attention and one in four had hit their head in a bicycle crash.

One-half of the students in this county were then taught the *Basics of Bicycling* curriculum that included on-bike and in-class instruction. All students were surveyed again after the following summer. Children who had received this instruction rode more often and were less likely to be injured than their peers in the control group from the other half of the county.

An attempt was also made to obtain information from area physicians and hospitals about child bicycle-related injuries that they treated during the spring and summer that followed the *Basics of Bicycling* program implementation. Even with five out of six area physicians and both local hospitals participating, only two cases were identified during this limited time period.

What appears to be missing from the body of research conducted on education programs and materials are direct observations of bicyclist behavior in the field. In a test requiring them to demonstrate their skills and knowledge, children exposed to the *Basics of Bicycling* curriculum out-performed those from the control group. However, little can be said about the transference of these skills and behavior, or their application to real-world bicycling challenges.

In addition, we know little about these children's behavior over a longer period of time — with the exception of a study conducted by Bike Ed Hawaii. Parents of the previous year's students reported a 15-percent increase in the number of children riding on the right side of the road, a 30-percent increase in the number of children with no accidents in the year following the course, and a 100-percent increase in helmet use.[197] No studies of observed behavior were found.

CONCLUSION

To truly assess the effectiveness of educational programs and materials, we must not only learn of the immediate changes, but also the extent to which these new skills are retained correctly and become habits.

We also know little about the effectiveness and outcomes of various types of education programs and materials relative to other program and material types. With this information, practioners could better assess the most appropriate avenue to meet their needs. It seems evident that a 1-day bicycle rodeo cannot be expected to have the same level of impact as a seven-lesson comprehensive program, but to what degree? What outcomes can be expected from an *Officer Friendly* classroom presentation or school assembly? How do the potential outcomes relate to the level of effort or costs required to implement a given program or use a particular material?

Useful Resources

(a) Bicycle Federation of America (BFA), 1990. *Basics of Bicycling*. Washington, DC.

Seven-lesson training program for elementary school students. Video, classroom, and on-bike instruction components. Available for $99 from the BFA, 1506 21st Street, NW, Suite 200, Washington, DC 20036.

(b) Forester, J., 1993. *Effective Cycling*. MIT Press, Cambridge, MA.

Together with a video of the same name, this publication comprises a comprehensive adult education program. Courses are available through the League of American Wheelmen (L.A.W.). Contact L.A.W. for program details and materials. L.A.W., 190 West Ostend St., Suite 120, Baltimore, MD 21203.

(c) Williams, J. and McLaughlin, K., Feb. 1993. *Balancing Engineering, Education, Law Enforcement and Encouragement in Local Bicycle Programs*. FHWA, Washington, DC.

Case Study 11 of the National Bicycling and Walking Study describes the four E's of bicycling and the balance that must be struck between them. Available from FHWA, HEP-50, 400 Seventh St., SW, Washington, DC 20590.

SECTION 9. ENFORCEMENT AND REGULATIONS

INTRODUCTION

The overwhelming cause of traffic crashes — whether bicyclist, motorist, or pedestrian — is human error. Education is one way of affecting human performance and decision making. Enforcement is another.

LACK OF RESEARCH

Enforcement, however, is probably the least evaluated and documented element of bicycle safety and program activity. This gap was identified in all the other countries studied. An Australian study of police attitudes toward traffic law enforcement identified the low importance given to bicycle safety-related laws and behavior. Some of the reasons for this are:[198]

- Low perceived public support for enforcement.
- Difficulty of enforcing penalties on children.
- No training or knowledge of issues and laws.

Another major reason is the competing demand for police time. The criminal justice system is currently overwhelmed in most parts of the United States — murder, rape, thefts, and other crimes demand attention. The relative lack of frequency of bicycle crashes, especially fatal crashes, makes it difficult for the police to show any real progress as a result of their work.

Even when illegal behavior has resulted in crashes causing death and injury, law enforcement officials are noticeably reluctant to issue citations. In King County, WA, for example, 37.9 percent of drivers who struck bicyclists were in violation of traffic laws, and yet only 12.8 percent received a citation. Only 40 percent of drivers who were driving under the influence were issued citations.[68]

In general, where traffic law enforcement of bicyclists has been undertaken, the results are positive and short-lived. For example, the university cities of Boulder, CO and Madison, WI have all employed bicycle enforcement patrols and have noted a reduction in violations for the duration of the enforcement activity.[199,200]

Burden reports that an enforcement campaign in Key Largo, FL, in 1985, focused on the requirement for cyclists to wear lights at night. Use of lights rose from just 10 percent to over 95 percent over a 3-month period.[30]

Failure to adhere to traffic laws is becoming endemic. Thom and Clayton (1992) reported, from their observations of 900 bicyclists in Winnipeg, Manitoba, that "one-half of cyclists were doing something wrong during a maneuver."[54]

Watanabe reports that "the decline of cyclists' morals has come to the surface" in Japan, with increased friction between bicyclists and pedestrians being an issue. Other authors of case studies written as part of this research report the same problems in Australia, the United Kingdom, the Netherlands, and the Nordic countries. (See references 43, 44, 201, and 202.)

Pauen-Hoppner describes three categories of bicyclist observed in Germany in terms of their behavior and regard for laws. She concludes that cyclists "try to optimally influence their situation according to their individual perceptions of safety and performance." Under these conditions, riding on the sidewalk, riding against traffic, and failing to signal become part of the necessary repertoire of skills and actions necessary to survive and make the trip practical.[203] This suggests that until road conditions and the riding environment become more conducive to bicycling, bicyclists will continue to ride as they see fit, rather than as the law requires of them. Thus, efforts to enforce laws that require cyclists to behave otherwise will have limited and short-lived success.

The issue of conflicts between bicyclists and pedestrians is a good example of this point. Bicyclists ride on sidewalks and ignore stop signs, signals, and crosswalks, even though it may be illegal, because they perceive this behavior to be safer or to give them better performance over riding on the roadway. This behavior usually conflicts with pedestrians, threatening their safety and comfort. However, riding illegally on the sidewalk (where it is illegal) is rarely punished and is often considered "sensible" or the "right thing to do" by the police and public because it is thought to be "safer" than riding in the road. Enforcement of a law against riding on the sidewalk — without any effort to make the roadway better for bicycling — may result in the rider not riding at all. (Conflicts between pedestrians and bicyclists on specially designated trails is a separate issue. Trail design manuals identify numerous ways to enable bicyclists and walkers to successfully share facilities through the use of pavement markings, signage, surface texture, and other features.)

The Australian researcher, Keay, advocates appropriate enforcement of road rules that will make the greatest difference. He notes that rules against riding with no lights at night or in a reckless fashion should be strictly enforced. However, adopting the same approach to rules that forbid riding on footpaths may actually force some bicyclists into more dangerous situations.[204]

The U.K. Department of Transport reports the failure of motorists to abide by speed limits and notes the close correlation between increased speeds and a higher incidence and severity of crashes. Over 60 percent of drivers exceed motorway speed limits [113 km/h (70 mi/h)], almost 40 percent exceed this speed on four-lane divided highways, and 10 percent of drivers exceed the 97-km/h (60-mi/h) limit on two-lane highways.[161]

CONCLUSIONS

We know there is a problem with lawlessness on our streets and highways, and that this contributes to crashes. We also know, however, that implementation of effective enforcement programs is a low priority in almost every community and that the evaluation of programs that have been implemented is an even lower priority.

There are a number of strategies that have been tried in communities across the United States to reverse this trend. To be successful, it appears enforcement programs should concentrate on:

- Selective enforcement. There are a small number of types of behavior that are associated with a large percentage of bicycle crashes. Selective enforcement of riding without lights at night, wrong-way riding, and failure to stop and to yield at road entry points can tackle the most common contributory factors to bicycle crashes. In addition, enforcement can be directed towards specific high accident locations, times of the day, and age groups.

- Alternatives to fines. The police may be reluctant to fine offenders, especially children. Programs may be devised to issue warnings, reward good behavior, or send offenders to riding school for training.

- Identifying appropriate levels for fines. Sometimes the police are reluctant to pass down fines that they consider to be too high for bicycle infractions. The California legislature has recently passed a law allowing local jurisdictions to lower the amount of fines for bicycle offenses to encourage stricter enforcement. Conversely, some police have reported that fines are too low to bother with and, therefore, increasing fines has helped.

- Police training. There are courses available to teach the police about bicycle-law enforcement and the impact of traffic-law enforcement, as a whole, on bicycling.

- Police on Bikes. Many communities in the United States now have police patrolling by bicycle. The patrols are part of the regular operation of the police department and are not specifically for traffic-law enforcement purposes. However, these patrols do raise awareness of the presence of bicyclists on the road and introduce police officers to the importance of traffic-law enforcement from the perspective of a bicyclist.

These and other strategies that appear to be successful in overcoming the resistance to enforcing bicycle laws need to be properly evaluated in the coming years. In addition, it is vital that research be undertaken to identify the impact of motor vehicle violations on the safety and perceived safety of bicyclists, especially in relation to speed limits and excessive speed.

Useful Resources

(a) Hunter, W. and Stutts, J. *Bicycle Law Enforcement Manual*. Raleigh, NC.

Available from the NC DOT Bicycle Program, P.O. Box 25201, Raleigh, NC 27611.

(b) Grady, P., 1992. *Policing by Mountain Bike*. Seattle, WA.

Guide to implementing a police on bikes program. Available for $55 from Paul Grady, Box 14255, Seattle, WA 98114.

SECTION 10. CONCLUSIONS

INTRODUCTION

This report was originally conceived as an update of a synthesis of bicycle safety-related research written in 1981, and as a complement to similar documents that exist in the field of pedestrian safety. However, little pure research has been done in this field since the 1970's, particularly when compared to the pedestrian field. Thus, the scope of this report necessarily broadened the definition of research to include applied research and documented evaluations of program activities — of which there have been much more in the 1980's and 1990's.

The one area for which considerable research has been conducted is bicycle helmets. In 1981, bicycle helmets were used almost exclusively by a small number of experienced cyclists, and rarely by the everyday or casual cyclist. Since then, almost an entire body of research and knowledge has been developed on the effectiveness of helmets in crashes, helmet standards, and helmet-wearing promotions.

DATA NEEDS

One consequence of this small amount of research is that we still know surprisingly little about the amount of bicycling in the United States, and the purposes for which bicycling is currently used. This is despite the fact that more bicycles are sold every year than new cars and the bicycle industry is worth $4 billion in the United States.

We do not know how many miles are traveled by bicycle each year. Thus, it is impossible to develop reliable figures for a number of important statistics, such as:

- Bicyclists' exposure to danger.
- Forecasting growth and modal shifts.
- Health benefits of bicycling.
- Environmental benefits of bicycling, especially in relation to air quality and the reduction of motor vehicle emissions.
- Riding habits, e.g., daytime vs. nighttime levels, and riding habits by age, gender, and trip purpose.

These numbers are necessary for transportation planners, safety practitioners, and politicians as future transportation plans and programs are developed and funds are allocated. At present, figures such as these are usually developed in an ad hoc manner.

CRASH DATA

Information about bicycle crashes has improved in the past decade. For example, there is now a much clearer recognition of the degree to which bicycle crashes go unreported to the police, and this is taken into account more often. However, the section on crashes in this report highlights the many other problems with data currently available in this area. In particular, the reporting of bicycle crashes, as with all crashes, remains arbitrary and subject to the personal prejudices of the reporting police personnel. Bicycling advocates may feel that there are still a great many crashes that are "blamed" on the cyclist because the reporting officer didn't believe the cyclist should have been riding on a particular street — or on the street at all.

There is also no understanding of the reasons for fluctuations in the annual count of bicyclist fatalities and injuries. The number of fatalities is currently very low compared to a decade ago, but whether this is due to improved safety, decreased exposure, changes in reporting, or some other reason is not clearly understood.

There is relatively little data on crashes that do not involve another motor vehicle. Conflicts between bicyclists and walkers are a major problem in many communities, and yet this is not addressed in the statistics used by transportation and safety organizations.

BICYCLE FACILITIES

Much of the research covered by the 1981 synthesis report was on the safety and design aspects of different bicycle facility types. This has continued to receive a significant amount of attention during the period covered by this report. The result appears to be that, at the present time, the information and experience exists to ensure that bicycle facilities are both appropriately selected — based on location, use, etc. — and designed for safe operation by bicyclists and other users. This applies to separate facilities, such as trails, and to on-road facilities, such as bike lanes and wider outside lanes. There are numerous design manuals and guidelines available for the practitioner, and a range of training courses are available through the Federal Government and private sources.

In the 1990's, a significant new demand has been placed on those implementing bicycle programs at the State and local level — encouraging new and infrequent riders to ride more often. This has required engineers and planners to consider which types of facilities help to achieve this goal, and which simply accommodate riders who are already using the system with some confidence. In some instances, those confident riders who are already using the existing system have failed to recognize this new paradigm and they have opposed the provision of any special facilities for cyclists. However, as noted in sections 4 and 5, the debate over the safety and effectiveness of different facility types, and the on-road vs. off-road argument, is quite redundant.

In the past 3 years, a significant amount of research and practical experience has been devoted to the area of facility selection — as opposed to facility design — and that is where more work is still required in the near future. Facility design issues remain in certain areas, particularly at intersections.

TRAFFIC CALMING

One of the areas with the greatest potential in the United States is the application of traffic-calming techniques in a wide variety of situations, particularly in urban and suburban locations.

Traffic calming has swept Western Europe over the past 20 years and there is a significant body of knowledge showing the benefits of slowing down motor vehicle traffic and actively discouraging car use through modification of the roadway environment. Particularly in relation to bicycling, this new way of thinking has a great deal to offer — and presents many challenges to the practitioner. While a number of the techniques of traffic calming have already been employed in U.S. cities, such as Seattle, WA and Portland, OR, many more remain to be tested. In particular, the application of traffic-calming measures over wider areas needs to be evaluated.

EDUCATION AND ENFORCEMENT

The greatest need in the important areas of education and enforcement is for consistent implementation of programs. There are numerous educational programs available for all age groups, and there is a significant amount of knowledge regarding the most important rules and regulations to enforce. However, in almost no community in the United States is there any comprehensive implementation of these programs — and there is almost no ongoing evaluation of programs that do occur. Thus, research is needed in determining how to more successfully implement existing programs, or how to get messages across to bicyclists and motorists in a way that can be realistically implemented.

HELMETS

As previously mentioned, helmet effectiveness and use has been the focus of much research and program activity in the past decade. Currently, the quest for mandatory helmet laws for bicyclists is a high priority for the medical community and some safety practitioners. However, little existing research, with the exception of research from Australian provinces where helmet laws have been passed, has determined the probable impact of helmet laws on wearing rates and bicycle use after laws are passed. This is an essential part of the equation and will ultimately determine whether mandatory helmet laws are effective in saving lives.

THE 1990's

The 1990's have begun with a tremendous amount of interest in bicycling. Public agencies and employers are facing new mandates to promote alternatives to the single-occupant automobile and the Federal Government has set ambitious new target levels of bicycle use and bicycle safety.

The research and experience of the past 20 years provides practitioners with a good starting point for their work — but it is still far from adequate. There are significant gaps in knowledge that must be filled in the next 3 to 5 years, through research, experimentation, and practical application.

REFERENCES

1. Bicycle Manufacturers Association.

2. Federal Highway Administration, 1993. *National Bicycling and Walking Study.* Washington, DC.

3. FHWA, 1982. *Synthesis of Safety Research Related to Traffic Control and Roadway Elements, Vol. 2.* Office of Research, Development, and Technology. Washington, DC.

4. U.S. Department of Transportation, 1990. *Moving America: New Directions, New Opportunities.* Washington, DC.

5. U.S. Congress, 1991. Transportation and Related Agencies Appropriations Act. Washington, DC.

6. Federal Highway Administration, 1990. *Bicycle and Pedestrian Facilities in the Federal-Aid Highway Program.* Washington, DC.

7. Federal Highway Administration, 1990. *Policy on Bicycle and Pedestrian Projects.* Memorandum from the Administrator. Washington, DC.

8. The Intermodal Surface Transportation Efficiency Act of 1991. PL 102-290.

9. The Clean Air Act Amendments of 1990.

10. Bicycle Institute of America, 1993. *Bicycling Reference Book: Transportation Issue.* Washington, DC.

11. Primedia, Inc. 1993. *1993 Interbike Directory.* Newport Beach, CA.

12. National Park Service, 1986. *1982-83 Nationwide Recreation Survey.* Washington, DC.

13. *Bicycling Magazine,* 1991. "A Trend on the Move: Commuting by Bicycle." Rodale Press, Emmaus, PA.

14. Rodale Press, 1992. *Pathways for People.* Emmaus, PA.

15. Texas Parks and Wildlife Department, 1989. *Texans Outdoors: An Analysis of 1985 Participation in Outdoor Recreation Activities.* Austin, TX.

16. Wallack, Roy, 1989. "Texas: A Big Wheel in the Bicycling World." *Texas Bicyclist,* Vol. 1, No. 3. (April 1989).

17. Federal Highway Administration, 1991. *Interim Report: National Bicycling and Walking Study.* Washington, DC.

18. U.S. Census, 1990.

19. National Personal Transportation Survey, 1983.

20. Lagerwey, P. Personal correspondence, November 30, 1993.

21. Hu, P., 1991. *Preliminary Results of the 1990 Nationwide Personal Transportation Survey.* Oak Ridge, Tennessee.

22. Delaware Valley Regional Planning Commission, 1993. *Transportation Control Measure Evaluation Assistance, Interim Report.* Comsis, Philadelphia, November 3, 1993.

23. MacKenzie, J. et al., 1992. *The Going Rate: What it Really Costs to Drive.* World Resources Institute, Washington, DC.

24. Federal Highway Administration, 1981. *Feasibility of Demand Incentives for Non-Motorized Travel. Washington, DC.*

25. Noland, Robert B. 1992. *The Role of Risk in Policies to Promote Bicycle Transportation.* University of Pennsylvania. Philadelphia, PA.

26. Federal Highway Administration, 1993. *Reasons Why Bicycling and Walking Are and Are Not Being Used More Extensively As Travel Modes.* Case Study 3, National Bicycling and Walking Study. Washington, DC.

27. Willey, et al., 1991. "A Longitudinal Comparison of Bicycle and Moped Use By University Students." *Transportation Quarterly*, July 1991. Westport, CT.

28. Wright, Charles, 1991. *A Characteristics Analysis of Non-Motorized Transport.* UMTRI Research Review. University of Michigan, Ann Arbor, MI.

29. Rodale Press, 1991. *The Bicycling Consumer of the 1990's.* Survey by NFO, Emmaus, PA.

30. Burden, D. Personal correspondence, November 22, 1993.

31. National Highway Traffic Safety Administration, 1992. *The Economic Cost of Motor Vehicle Crashes: 1990.* Washington, DC.

32. Hillsborough County, FL, 1986. *Economic Benefits of "Bicycle Friendly" Roads.*

33. University of Wisconsin Cooperative Extension Service, 1989. *A Look at Visitors on Wisconsin's Elroy-Sparta Bike Trail.* Madison, WI.

34. Lawton, K. 1986. *The Economic Impact of Bike Trails: A Case Study of the Sugar River Trail.* Madison, WI.

35. National Park Service, 1992. *The Impacts of Rail-Trails: A Study of Users and Nearby Property Owners From Three Trails.* Washington, DC.

36. Waring, Frederick Allen, 1991. *A Bicycle Master Plan for Texas.* University of Texas, Austin, TX.

37. Federal Highway Administration, 1993. *The Environmental Benefits of Bicycling and Walking.* Case Study 15, National Bicycling and Walking Study. Washington, DC.

38. Personal conversation with Peter Lagerwey, Bicycle Coordinator for the City of Seattle, WA.

39. Transportation Alternatives, 1993. *Bicycle Blueprint. A Plan to Bring Bicycling Into the Mainstream in New York City.* New York, NY.

40. Burke, E., 1993. *Benefits of Bicycling and Walking to Health.* FHWA, Case Study 14, Washington, DC. See also, Hillman, M., 1992, *Cycling for Health and Safety.* British Medical Association, London, England.

41. Paffenbarger, R.S. et al., 1986. "Physical Activity, All-Cause Mortality and Longevity of College Alumni." *New England Journal of Medicine,* 314:605-613.

42. Clarke, Andy. 1993. *Bicycle Safety Research: Germany.* For the Bicycle Federation of America, Washington, DC.

43. Laursen, Jan Grubb. 1993. *Nordic Experience with the Safety of Bicycling.* For the Bicycle Federation of America. Denmark.

44. Mathew, Don. 1993. *Bicycle Safety Research: Great Britain.* For the Bicycle Federation of America, Washington, DC.

45. Federal Highway Administration, 1991. *Nationwide Personal Transportation Study.* Washington, DC.

46. Cross, K. and Fisher, G., 1976. *A Study of Bicycle/Motor Vehicle Accidents: Identification of Problem Types and Countermeasure Approaches.* National Highway Traffic Safety Administration.

47. Kaplan, J., 1975. *Characteristics of the Regular Adult Bicycle User.* FHWA, Washington, DC.

48. Baker, S. et al. 1993. *Injuries to Bicyclists: A National Perspective.* Centers for Disease Control, Atlanta, GA.

49. Consumer Product Safety Commission, 1993. Bicycle-related data and personal conversations. NEISS data, Washington, DC.

50. Stutts, J. 1986. *An Analysis of Bicycle Accident Data From Ten North Carolina Hospital Emergency Rooms.* Highway Safety Research Center, University of North Carolina. Chapel Hill, NC.

51. Thom, R. and Clayton, A., 1992. *Low-Cost Opportunities for Making Cities Bicycle-Friendly.* TRB, TR Record 1372, Washington, DC.

52. Consumer Product Safety Commission, personal correspondence with G. Rodgers, 1993.

53. National Highway Traffic Safety Administration, 1993. *1992 Traffic Safety Facts.* Washington, DC.

54. Thom, R. and Clayton, A., 1992. *Accident Data Required for Improving Cycling Safety.* Paper to Velo Mondiale Conference, September 1992. Montreal, Canada.

55. Cross, K., 1978. *Bicycle Safety Education: Facts and Issues.* AAA Foundation for Traffic Safety, Falls Church, VA.

56. Williams, J., 1983. "Crossing Your Accident Stats." *Bicycle Forum 8.*

57. Ross, A., 1992. *Bicyclist Crash Analysis in a City of Adult Bicyclists.* Paper to Velo Mondiale Conference, September 1992, Montreal, Canada.

58. Plotkin and Komornick, 1984. *Bicycle-Motor Vehicle Accidents in the Boston Metro Region.* TRB. TR Record 959, Washington, DC.

59. City of Denver, 1992. *1989 - 1991 Denver Bicycle Accident Study, Summary of Findings.* Denver, CO.

60. National Highway Traffic Safety Administration, 1993. *Fatal Accident Reporting System (FARS) 1991.* Washington, DC.

61. Oregon Department of Transportation, 1991 and 1992. *Bicycle/Motor Vehicle Accident Summary.* Salem, OR.

62. Arizona Transportation Safety Office. *Arizona Bicycle Safety Stat-Pac: 1990 Statistics.* Phoenix, AZ.

63. Kiburz, et al., 1986. "Bicycle Accidents Among Adult Cyclists." University of Kansas Medical Center, *American Journal of Sports Medicine.*

64. Ontario Ministry of Transport, 1992. *Bicycle Policy: Review and Update.* Technical Report, May 1992. Ottawa, Canada.

65. Walker, et al., 1992. "In-Vehicle Navigational Devices: Effects on the Safety of Driver Performance." *Public Roads*, Washington, DC.

66. National Public Services Research Institute, 1991. "Study Finds Cellular Phone Use Leads to Significant Increases in Response Time, Non-Response to Highway Traffic Situations." *Urban Transportation Monitor*, Burke, VA, April 12, 1991.

67. Preusser et al., 1981. *The Effect of Right-Turn-On-Red on Pedestrian and Bicyclists Accidents.* NHTSA, Washington, DC.

68. Miller, P. and Rivara, F., 1991. *Pedestrian and Bicycle Collisions With Motor Vehicles in King County, 1985-90.* King County Department of Public Works, Seattle, WA.

69. Ratte, C., 1992. *The Wisconsin Project on Drinking Bicyclists.* Paper to the Velo Mondiale Conference, September 1992, Montreal, Canada.

70. Kraus, J. et al., 1989. "The Causes, Impact and Preventability of Childhood Injuries in the United States: Brain Injuries Among Infants, Children, Adolescents and Young Adults in the United States." Reported in *Childhood Injuries in the United States*, Centers for Disease Control, Atlanta, GA.

71. Insurance Institute for Highway Safety, 1989. *Fatality Facts, 1989.* Falls Church, VA.

72. Insurance Institute for Highway Safety, 1993. *Fatality Facts, 1993.* Falls Church, VA.

73. Selbst, S. et al., 1987. "Bicycle-Related Injuries." *American Journal of Diseases in Children*, Vol. 141.

74. Stutts, J. 1992. Statistics Presented at Bicycle Safety Workshop, Wrightsville Beach, NC.

75. Spokespeople, 1988. *Florida Pedestrian and Bicyclist Accident Cost Analysis.* Tallahassee, FL.

76. Verhaleif, R. and Tinsworth, D. Results of NEISS Suveillance Level Study on Bicycles, August 1986. March, 16, 1987. Memorandum from CPSC, Washington, DC.

77. Department of Orthopaedic Surgery, SUNY, 1992. *An Epidemiological Study of Head and Spine Injuries Occuring in School-Aged Children from Oct. 1989 to June 1991*. Syracuse, NY.

78. Federal Highway Administration, 1976. Characteristics of the Regular Adult Bicycle User. Washington, DC.

79. Minnesota Department of Transportation. 1983. *Bikeway Design Manual.* St. Paul, MN.

80. City of Palo Alto, 1982. *Bicycle Boulevard Demonstration Study —— Evaluation.* Dec. 9, 1982 Staff Report to City Council. Palo Alto, CA.

81. Shields, Gordy. 1986. *Light Tripping.* San Diego, CA.

82. Bicycle Transportation Alliance, 1993. "Traffic Signals: Why Bicyclists Don't See the Light." *Newsletter article*, Portland, OR.

83. City of San Diego, 1985. *Traffic Signal Bicycle Detection Study.* San Diego, CA.

84. Federal Highway Administration, 1993. *Current Planing Guidelines and Design Standards Being Used by State and Local Agencies for Bicycle and Pedestrian Facilities.* Case Study 24, National Bicycling and Walking Study. Washington, DC.

85. Grigg, Glenn. 1993. Personal Communication. Jan. 20 to Bill Wilkinson, Bicycle Federation of America.

86. Washington Department of Transportation. *Highway Design Manual.*

87. Chao, Peter Ju-Cheng; Anderson, Mary; and Matthias, Judson. 1977. *A Study of Cyclist Behavior at Signalized Intersections.* Arizona State University, Tempe, AZ.

88. Wachtel, Alan. 1993. *Proposed Signal Timing for Bicyclists.* Paper for California Bicycle Advisory Committee, 26 March 1993. Sacramento, CA.

89. Zador, Paul. 1983. *Right-Turn-on-Red Laws and Motor Vehicle Crashes: A Review of the Literature.* Insurance Institute for Highway Safety, Washington, DC.

90. Forester, J. 1992. *The On-Ramp Controversy and Cyclists' Strategy.* E-mail Correspondence, July 11. Sunnyvale, CA.

91. Harland, G. 1987. *U.K. Research into Cycling Since 1984.* Paper to the 1987 Velo City Conference, Groningen, Netherlands.

92. Cyclists' Touring Club, 1992. *Cyclists and Major Roads,* Godalming, United Kingdom.

93. Layfield and Maycock, 1986. "Pedal Cyclists at Roundabouts." *Traffic Engineering and Control.*

94. American Association of State Highway and Transportation Officials, 1991. *Guide for the Development of Bicycle Facilities.* Washington, DC.

95. Department of Transport, 1986. *Hills Road, Cambridge: Segregated Cycle Lane at Traffic Signals.* Traffic Advisory Leaflet. London, United Kingdom.

96. Leden, Lars. 1988. *The Traffic Safety of Cycling Children — The Influence of Street Lay-Out and Regulation.* Lund, Sweden.

97. Wheeler, A.H., Leicester, M.A.A. and Underwood, G. 1993. "Advanced Stop-Lines For Cyclists." *Traffic Engineering and Control*, Feb. 1993. London, United Kingdom.

98. Cyclists' Touring Club, 1984. *Pedal Cyclist Accidents*. Godalming, United Kingdom.

99. Department of Transport, 1986. *Cyclists at Road Crossings and Junctions*. Local Transport Note 1/86. HMSO, London, United Kingdom.

100. Federal Highway Administration, 1993. *Analyses of Successful Provincial, State and Local Bicycle and Pedestrian Programs in Canada and the United States*. Case Study 18, National Bicycling and Walking Study. Washington, DC.

101. Ryan, Karen Lee, 1993. *Trails for the 21st Century: A Planning, Design and Management Manual*. Rails to Trails Conservancy, Washington, DC.

102. Minnesota Department of Transportation. 1992. *Plan B: Comprehensive State Bicycle Plan*. St. Paul, MN.

103. Department of Transport. Traffic Advisory Unit leaflets 9/86, 11/86, 7/87.

104. McClintock, Hugh. 1992. *The Bicycle and City Traffic*. Belhaven Press, London, U.K.

105. American Association of State Highway and Transportation Officials, 1981. *A Guide to the Development of New Bicycle Facilities*. Washington, DC.

106. U.S. Department of Transportation, 1980. *Bicycle Transportation for Energy Conservation*, Washington, DC.

107. Forester, J. 1984. *Effective Cycling*. MIT Press, Cambridge, MA.

108. Federal Highway Administration, 1986. *Selecting and Designating Bicycle Routes*. Washington, DC.

109. Arizona Governor's Bicycle Task Force, 1988. *Bicycle Facilities Planning and Design Guidelines*. Phoenix, AZ.

110. *Bicycle Forum*, 1992. Issue 26. Missoula, MT.

111. Maryland Department of Transportation, 1985. *Evaluation of Wide Curb Lanes as Shared-Lane Bicycle Facilities*. McHenry and Wallace, Baltimore, MD.

112. Federal Highway Administration, 1992. *The Effects of Bicycle Accommodations on Bicycle/Motor Vehicle Safety and Traffic Operations*. Washington, DC.

113. Piaw, 1993. "The Case Against Bike Paths and Lanes." Published in *Spinning Crank*, Newsletter of the Silicon Valley Bicycle Coalition, May/June 1993. Cupertino, CA.

114. Oregon Department of Transportation, 1992. *Oregon Bicycle Plan.* Salem, OR.

115. King County, WA. 1993. *Nonmotorized Transportation Plan.* Seattle, WA.

116. Wisconsin Department of Transportation. 1986. *Feasibility of Paving Shoulder on Low ADT Highways.* Oct. 29 Memorandum. Madison, WI.

117. Texas Transportation Institute, 1989. *Guidelines for Wide Paved Shoulders on Low-Volume Two-Lane Rural Highways.* Woods, Rollins and Crane. College Station, TX.

118. Cottrell, Jr., B.H. 1992. *Cost Analysis of Paved Shoulders.* For the Virginia Transportation Research Council. Charlottesville, VA.

119. AASHTO, 1990. *A Policy on Geometric Design of Highways and Streets.* Washington, DC.

120. Florida Department of Transportation, 1984. *Policy for Incorporation of Bicycle Facilities in Design — Wide Curb Lanes, Bicycle Lanes and Paved Shoulders.* Tallahassee, FL.

121. Burden, Dan. 1989. *The Effect of Large Trucks and Buses on Bicyclists.* Preliminary Draft for the Florida Department of Transportation, Tallahassee, FL.

122. *Bicycle Forum*, 1987. "Rumble Strips." Issue 14. Missoula, MT.

123. *Urban Transportation Monitor*, 1993. Article about Utah Rumble Strip Policy.

124. Federal Highway Administration, 1990. *Paved Shoulders.* Technical Advisory Notice, Feb. 2, 1990. Washington, DC.

125. New Jersey Department of Transportation, 1982. *Bicycle Compatible Highways — Planning and Design Guidelines.* Trenton, NJ.

126. Transportation Research Board, 1985. *Highway Capacity Manual.* Washington, DC.

127. Ronkin. "Beyond Bike Routes: Building a System of Bikeways." *Pro Bike News*, Vol. 13, No. 8, August 1993. Bicycle Federation of America, Washington, DC.

128. Mackay. "Denver Bicycle Master Plan." *Pro Bike News*, Vol. 13, No. 6, June 1993. Bicycle Federation of America, Washington, DC.

129. *Bicycle Forum*, 1992. Issue 29. Missoula, MT.

130. Kroll and Ramey, 1977. "Effects of Bike Lanes on Driver and Bicyclist Behavior." *Transportation Engineering Journal*, American Society of Civil Engineers, March 1977.

131. Melton, Bud. 1993. "Misinformation Dogs Bike Planners." Published in *The Advocate*, Newsletter of the Texas Bicycle Coalition, July/August 1993. Austin, TX.

132. Lott and Lott. 1976. "Effect of Bike Lanes on Ten Classes of Bicycle-Automobile Accidents in Davis, CA." *Journal of Safety Research*. 8:4, 1976.

133. Ronkin. "Bike Lane of Shared Roadway?" *Pro Bike News*, Vol. 13, No. 3, March 1993. Bicycle Federation of America, Washington, DC.

134. City of Seattle, WA. 1982. *Bicycle Facility Evaluation Study*. Seattle, WA.

135. Tardiff and Lott. 1978. "Evaluation by Experienced Riders of New Bicycle Lane in an Established Bikeway System." *Transportation Research Record* 683. TRB, Washington, DC.

136. Kroll and Sommer, 1976. "Bicyclists' Response to Urban Bikeways." *Journal of the American Institute of Planners*, 43:1.

137. Lefler, C.L. 1975. *A Balanced Approach to Bicycle Safety*. Institute of Transportation and Traffic Engineering, University of California, Berkeley, CA.

138. City of Eugene, OR. 1980. *18th Ave. Bike Lanes — One Year Progress Report*. Dec. 2, 1980, Memorandum to City Council. Eugene, OR.

139. Smith and Walsh, 1988. "Safety Impacts of Bicycle Lanes." *Transportation Research Record* 1168, TRB, Washington, DC.

140. Sacramento Area Council of Governments, 1993. *SACOG Bicycle Questionnaire, Informational Summary*. Sacramento, CA.

141. National Highway Traffic Safety Administration, 1976. *Bicycle Safety Highway User Information Report*. Washington, DC.

142. Florida Department of Transportation, 1993. *Interim and New Construction Typical Sections*. March 3, 1993, Memorandum. Tallahassee, FL.

143. Oregon Department of Transportation, 1993. *Retro-Fitting Bike Lanes onto Existing Urban Roadways*. Salem, OR.

144. Bracher, T. 1988. *Policy and Provision for Cyclists in Europe*. European Cyclists Federation Report to the European Commission. Brussels, Belgium.

145. Federal Highway Administration, 1993. *Transportation Potential and Other Benefits of Off-Road Bicycle and Pedestrian Facilities.* Case Study 7, National Bicycling and Walking Study. Washington, DC.

146. Van Valkenberg, P. 1982. *Methodology for Evaluating the Suitability of Two-Lane, Two-Way Paved Rural Roads for Shared Bicycle/Motor Vehicle Use.* Wisconsin Department of Tourism. Madison, WI.

147. *Bicycle Forum*, 1992. Issue 28. Missoula, MT.

148. Davis, J., 1992. *Assessing Roadway Conditions for Bicycle Suitability.* Paper to the Velo Mondiale Conference, September 1992. Montreal, Canada.

149. Clark, S., 1993. *Road Suitability Formula.* Training materials, Cushing, WI.

150. Egan, D. 1992. *Toronto's Bay Street Urban Clearway: A Bicycle and Bus Success Story.* Paper to the Velo Mondiale Conference, September 1992. Montreal, Canada.

151. Metzger, E. 1992. *Les Couloirs Mixtes Bus/Deux-Roues a Grenoble et Annecy (France).* Paper to the Velo Mondiale Conference, September 1992. Montreal, Canada.

152. Watts, Cliff et al. 1986. "Survey of Bicycling Accidents in Boulder, Colorado." *Physician and Sports Medicine*, Vol. 14, No. 3.

153. Joshi and Smith. 1992. "Cyclists Under Threat: A Survey of Oxford Cyclists' Perceptions of Risk." *Health Education Journal*, 51:4.

154. *Bicycle Forum*, 1993. "10 of the Questions We Hear Most." Issue 33. Missoula, MT.

155. City of Denver, CO. 1992. *Construction Detour Standards for Bikeways and Multi-Use Trails.* Mackay.

156. *Bicycle Forum*, 1990. "Improving Local Conditions for Bicycling." Missoula, MT.

157. Federal Highway Administration, 1977. *Bicycle-Safe Grate Inlets Study, Vol. 1. Hydraulic and Safety Characteristics of Selected Grate Inlets on Continuous Grades.* Washington, DC.

158. Cincinnati Cycle Club, 1983. *Bicycle Safety Report: The Stormwater Grate.* For the City of Cincinnati, Cincinnati, OH.

159. Cyclists' Touring Club, 1991. *Cyclists and Traffic Calming.* Godalming, United Kingdom.

160. Federal Highway Administration, 1993. *Traffic Calming, Auto-Restricted Zones and Other Traffic Management Techniques — Their Effects on Bicycling and Pedestrians.* Case Study 20, National Bicycling and Walking Study. Washington, DC.

161. Department of Transport, 1992. *Killing Speed: Saving Lives.* London, United Kingdom.

162. Tolley, R. 1990. *Calming Traffic in Residential Areas.* Brefi Press, Dyfed, Wales, United Kingdom.

163. Hass Klau et al. 1992. *Civilized Streets: A Guide to Traffic Calming.* Environmental and Transport Planning, Brighton, United Kingdom.

164. Cyclists' Touring Club, 1989. "Calming the Traffic, Exciting Cyclists." *Cycle Touring and Campaigning*, Feb./March 1989. Godalming, United Kingdom.

165. Institute of Transportation Engineers. 1989. *Residential Street Design and Traffic Control.* Washington, DC.

166. Seattle Engineering Department, 1993. *Neighborhood Traffic Circles.* Seattle, WA.

167. City of Portland, 1993. *Reclaiming Our Streets.* Portland, OR.

168. Monheim, R. 1990. "The Evolution and Impact of Pedestrian Areas in the Federal Republic of Germany." Chapter in *The Greening of Urban Transport*, Belhaven Press, London.

169. U.S. Department of Transportation, 1980. *Center City Environment and Transportation Innovations in Five European Cities.* Washington, DC.

170. Royal Dutch Motoring Club, 1980. *Woonerf.* The Hague, Netherlands.

171. Petty, Ross. 1987. "The Consumer Product Safety Commission's Promulgation of a Bicycle Safety Standard." *Journal of Products Liability*, Vol. 10. 1987. Pergamon Journals, USA.

172. Mills, P. 1989. *Pedal Cycle Accidents — A Hospital-Based Study.* Transport Research Laboratory, Research Report 220. Crowthorne, United Kingdom.

173. League of American Wheelmen, 1990. *Lighting the Way Ahead: A Special Report on Bicycle Lighting and Night Riding.* Baltimore, MD.

174. Blomberg, R. et al. 1984. *Conspicuity for Pedestrians and Bicyclists: Definition of the Problem, Development and Test of Countermeasures.* For NHTSA, Washington, DC.

175. *Pro Bike News.* December 1989.

176. Federal Highway Administration, 1992. *Bicyclist and Pedestrian Safety and Accommodation.* Draft training materials. Washington, DC.

177. Watts, G.R. 1984. *Evaluation of Conspicuity Aids for Pedal Cyclists.* Transport and Road Research Laboratory, Crowthorne, Berks, United Kingdom.

178. Thomson et al. 1989. "A Case Control Study of the Effectiveness of Bicycle Safety Helmets." *New England Journal of Medicine*, Vol. 320, pp. 1361-1367, 1989.

179. Tracy, L. 1992. *Procedures and Resource Guide for Bicycle Helmet Promotions: A Review of Bicycle Helmet Promotions in the United States.* National Highway Traffic Safety Administration, Washington, DC.

180. New York State Department of Health, 1990. *Methods for Evaluation of Bicycle Helmet Projects: A Manual for Local Projects.* Albany, NY.

181. Wasserman, R.C. et al., 1988. "Bicyclists, Helmets and Head Injuries: A Rider-Based Study of Helmet Use and Effectiveness." *American Journal of Public Health*, Vol. 78, No. 9, September 1988.

182. DiGuiseppi, C.G. et al., 1989. "Bicycle Helmet Use by Children: Evaluation of a Community-Wide Helmet Campaign." *Journal of the American Medical Association,* 262:2256-2261, October 1989.

183. Dannenberg A.L. et al., 1993. "Bicycle Helmet Laws and Educational Campaigns: An Evaluation of Strategies to Increase Children's Helmet Use." *American Journal of Public Health*, Vol. 83, No. 5, pp. 667-674, May 1993.

184. *Behaviors Related to Unintentional and Intentional Injuries Among High School Students - United States, 1991.* Centers for Disease Control, Atlanta, GA, 1992.

185. Quarterly update of mandatory bicycle helmet use legislation. National Safe Kids Coalition, Washington, DC.

186. Cote, T.R. et al., 1992. "Bicycle Helmet Use Among Maryland Children: Effect of Legislation and Education." *Pediatrics*, Vol. 89, No. 6, June 1992.

187. Blomberg, R.D., 1992. *Identification and Development of Countermeasures for Bicyclist/Motor Vehicle Problem Types.* National Highway Traffic Safety Administration, Washington, DC.

188. *Be Safe on Your Bike.* Video. Los Angeles Police Department, Los Angeles, CA, 1989.

189. Williams, J.E., 1981. "Bicycle Safety: What Every Parent Should Know." *Bicycle Forum*, Missoula, MT.

190. Tracy, L. and Williams, J.E., 1990. *Basics of Bicycling.* Bicycle Federation of America, Washington, DC and North Carolina Department of Transportation, Raleigh, NC.

191. Forester, J., 1993. *Effective Cycling Video.* Seidler Productions. Tallahassee, FL.

192. Williams, J.E. and Burden, D., 1988. *A Guide to Bicycle Rodeos.* Bikecentennial, Missoula, MT.

193. Blatt, J. et al., 1984. *Program Assessment Kit.* National Highway Traffic Safety Administration, Washington, DC.

194. Stutts, J.C. and Hunter, W.W., 1990. *Evaluation of a Bicycle Safety Education Curriculum for Elementary School Age Children.* University of North Carolina, Raleigh, NC.

195. Starnes, E. et al., 1992. *Florida Traffic and Bicycle Safety Education Training Program: Final Report.* University of Florida, Gainesville, FL, December 1992.

196. Ross, A.D., 1990. *Comprehensive School-Based Bicyclist Education Program Pre- and Post-Test Results, 1989.* May 31, 1990 Letter to Mila Plotsky, City of Madison Department of Transportation, Madison, WI.

197. Vesenka, M., 1992. "Bike Ed Hawaii." *Pro Bike News,* Washington, DC, February 1992.

198. Vic Roads, 1990. *Survey Report on Police Attitudes to Traffic Law Enforcement.* Victoria, Australia.

199. Clark, S. Personal Correspondence, Aug. 19, 1993.

200. Markham, A. Article in *Bicycle USA: 1991 Almanac.*

201. Smith, Dr. N. and Katz, R., 1993. *A Review of Recent Bicycle-Related Safety Research in Australia.* Sydney, Australia.

202. Grontmij Consulting, Inc., 1993. *17 Summaries of Major Dutch Research Studies About Bicycle Traffic.* Zeist, Netherlands.

203. Pauen-Hoppner, U., 1991. *Cyclists Behavior and Experiences: Insider Stories on the Question of Safety.* Paper to the Velo City Conference, Milan, Italy.

204. Keay, C. 1990. *Bicycle Law Enforcement Priorities.* In NSW Roads and Traffic Authority — Bicycle Advisory Council Workshop. Penrith, NSW, Australia.

OTHER REFERENCES USED DURING RESEARCH FOR REPORT

Allen, John. 1989. *Seeing Red About Traffic Lights That Don't Turn Green?* Unpublished article. Waltham, MA.

ANCMA, 1991. *The Bicycle: Improving Mobility and the Environment in Our Cities.* Proceedings of the Velo City 1991 Conference. Milan, Italy.

Antonakos, Cathy. 1992. Survey of Riders, Michigan Bicycle Events. Ann Arbor, MI.

Brog, Werner, et al. 1984. "Promotion and Planning for Bicycle Transportation: An International Overview." *Transportation Research Record 959*, Transportation Research Board, Washington, DC.

California Department of Transportation, 1989. *Design Manual: 1020 — Facilities for Nonmotorized Transportation.* Sacramento, CA.

Chang-Chuan Chan et al. 1991. "Commuter Exposures to VOC's in Boston, MA." *Journal of the Air and Waste Management Association.* Vol. 41, No. 12.

City of Boulder, CO. 1993. *Modal Shift in the Boulder Valley 1990-1992.* Center for Program and Policy Analysis. Boulder, CO.

C.R.O.W. 1987. *Planning for the Urban Cyclist.* Procedings of the Velo City 1987 Conference. Ede, Netherlands.

Dansk Cyklist Forbund, 1990. *Proceedings of the 1989 Velo City Conference.* Copenhagen, Denmark.

Feldman, W.J. 1983. *Empirical Bicycle Safety Field Testing of Cast Iron Prototype Bicycle Grate Pattern 2617.* New Jersey DOT, Trenton, NJ.

JHK and Associates, Undated. *Bicycle Access Survey,* Montgomery County, MD.

Koch, T. 1988. *The Problem of Conspicuity in Bicycle Motorist Accidents: Notes on Conspicuity and Intersection Design.* Hawaii Bicycle League, Honolulu, HI.

Lagerwey, P. and Pendleton, T. 1981. *Designing and Implementing a Bicycle Patrol.* For the City of Ann Arbor, Ann Arbor, MI.

Minneapolis Environmental Commission, Bicycle Task Force, 1993. *Survey of Selected Bicycle Commuters in the Minneapolis/St. Paul Metropolitan Area.* Minneapolis, MN.

Oak Ridge National Laboratory, 1974. *Energy Use for Bicycling.* Hirst. Oak Ridge, TN.

Ochia, Krys. 1991. *Bicycle Programs and Provision of Bikeway Facilities: An Overview of U.S. Jurisdictions, 1985-90.* City of Portland, Alternative Transportation Program. Portland, OR.

Oregon Department of Transportation, 1990. *Touring Bicyclists Interviews, Oregon Coast Bike Route.* Salem, OR.

Paltell, Eric. 1984. *An Investigation of Safety Problems at Skewed Rail-Highway Grade Crossings.* For the Virginia Highway and Transportation Research Council.

Van Valkenberg, Phil and Shidell, Doug. 1993. "Columnists Lock Horns on Bike Transportation." Series of Articles and Letters in *Silent Sports*, Minneapolis, MN.

Velo Quebec, 1992. *The Bicycle: Global Perspectives. Proceedings of the Velo Mondiale Conference.* Montreal, Quebec.