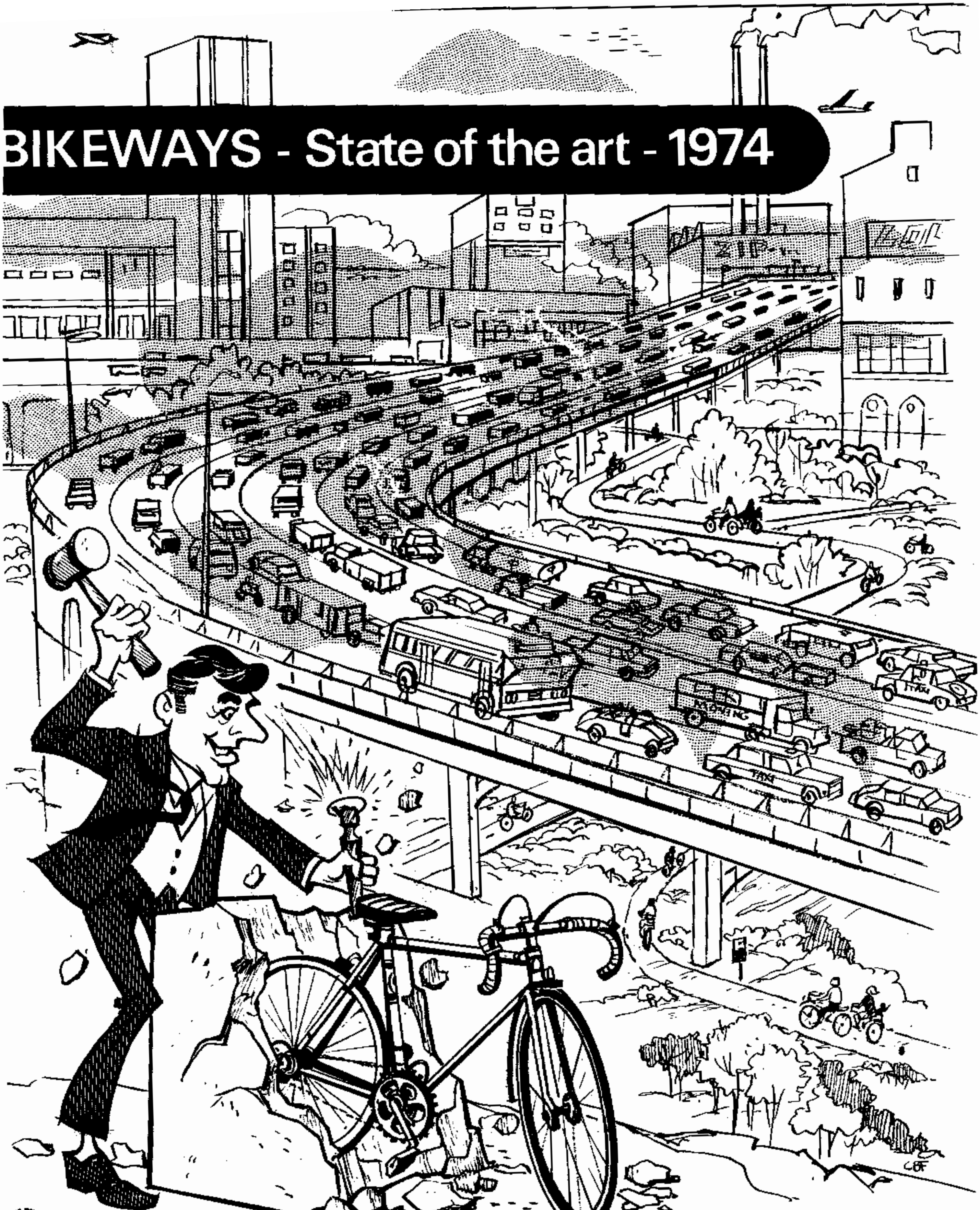
BIKEWAYS - State of the art - 1974



DEPARTMENT OF TRANSPORTATION
Federal Highway Administration

FHWA-RD-74-56

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TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA-RD-74-56	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle BIKEWAYS. State of the Art, 1974.	5. Report Date July 1974 6. Performing Organization Code
7. Author(s) Dan Smith, Jr.	8. Performing Organization Report No.
9. Performing Organization Name and Address DeLeuw Cather and Company 120 Howard Street San Francisco, California 94120	10. Work Unit No. FCP 31E3022 11. Contract or Grant No. DOT-FH-11-8134 13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address Federal Highway Administration U. S. Department of Transportation Washington, D.C. 20590	Final Report 14. Sponsoring Agency Code

15. Supplementary Notes
FHWA Contract Manager - John C. Fegan

16. Abstract

The recent phenomenal growth of bicycling activity has been paralleled by accelerating concerns for increases in bike-involved accidents and demands for good recreational and utility-oriented facilities on which to ride. All jurisdictional levels have responded with enforcement, development of bikeway locational and design criteria, and provision of physical facilities. Unfortunately, U.S. planners and designers were generally unprepared to deal with the bicycle and programs were based largely on intuitive judgements, European experience and trial and error. Results of initial experiences in various localities are now becoming available. This "State of the Art" report focuses on planning and design practices employed to date, reviews their successes and failures, outlines practices which appear to contribute to bicycle facility utility and safety, and identifies design pitfalls.

This report is one of four documents to be published in connection with this study. A final technical report and user manuals on design and location criteria will be available in late 1975.

17. Key Words Bicycle Bikeway Bike Lane Bike Route	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22151

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 97	22. Price

Form DOT F 1700.7 (8-69)

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Chapter I

PURPOSE OF THIS REPORT

The Federal Highway Administration has undertaken a program involving comprehensive assessment of experience to date and research in parameters affecting bicycle facility performance. The end product of this program will be locational criteria, design specifications and safety practices documented in manual form for uniform application by design professionals. However, research and quantitative assessment of current experience takes time and although the "Safety and Locational Criteria" study is in its initial stages, jurisdictions across the country desire and need to take action now. With this in mind, this "state of the art report" was conceived as a vehicle to document the range of studies and programs which have been undertaken in this country to date and to present inferential, empirical or, where available, quantitative evaluations of actual performance. As such, this report is not intended as a design manual, but as a first reference source for communities undertaking bikeway programs.

INTRODUCTION

The bicycle as we know it today is a product of the 19th century. By the 1890's cycling had become extremely popular both as a participant and spectator sport, as well as to some extent, a utility form of transportation. Cycle technology contributed significantly to the development of the motor vehicle and the cyclist inspired "good roads movement" led to the development of paved streets and highways which made travel by motor vehicle possible. However, with the increasing dependence of society on the motor vehicle over the first seven decades of this century, the bicycle was relegated to the role of a child's plaything, with the exception of use for recreation and exercise by limited bands of dedicated adult cyclists. But the late 1960s and the early 1970s have seen a sharp resurgence of bicycle activities. Noteworthy features of this resurgence have been the increases in the numbers of adult cyclists as well as youth and use of the cycle for utility trip making as well as for recreational activity. Bicycle sales give some measure of the activity. In 1973 some 14 million bicycles were sold in the United States, exceeding the sales of the automobile, and in 1974, bicycle sales are projected to reach 16 million. This is in stark contrast with estimates of annual sales of 8 to 8.5 million bicycles in as recent a year as 1971; and "adult bicycles" accounted for 55 percent of sales. Estimates of current active cyclists range to 100 million. This again contrasts sharply with 1958 estimates of some 50 million.

With this growth in cycling popularity and utilization have come both a demand for good recreational and utility oriented facilities on which to ride and a concern for the increase in bike involved accidents. The concern for accidents appears well founded despite the fact that only the gross numbers of accidents occurring are known with a reasonable level of accuracy. Very little is known about accident rates associated with the gross numbers. Despite this lack of accident rate information, the following national statistics are significant. In 1962, some 570 cyclists were killed and 30,000 injured in bicycle - motor vehicle accidents. By 1968, the corresponding figures had grown to 800 killed and 38,000 injured. The National Safety Council's statistics for 1972 show 100,000 bicycle - motor vehicle accidents and 1,100 fatalities.

As a result of the growing concern on the part of both the public and public officials at all levels, the past several years have been marked by a veritable blizzard of bicycle safety studies, studies for development of bikeway design and locational criteria, cyclist safety education programs, and provision of physical facilities for bicycles. But the sudden rise in activity and the demand for programs and facilities found planners and designers unprepared and uncertain as to means of responding to these demands. As a result, programs have been planned on the basis of intuitive judgment, what knowledge could be gleaned from European literature on the subject, and trial and error. The result of the past four or five years' independent activities undertaken in state jurisdictions across the country has been a broad range of studies, plans, programs, design manuals and in-use facilities with substantial variance and even conflict in recommended practices. The results of initial use and experiences in various localities are now becoming available and it appears that differences in design practices have significant implication for utility and safety.

Chapter II

USER CHARACTERISTICS

Basic to good design of cycle facilities is an understanding of the types of cyclists who would use a specific facility and how the purpose of riding affects cyclist behavior and corresponding facility needs.

Cycling activity falls into two categories: recreational and utility-oriented riding. Persons engaged in these two types of activities have very differing goals and objectives and, as a result, while many elements of bikeway design respond to both, there are differences in certain elements of physical facility provision which best respond to the needs of each category. For recreational cyclists (racers, tourers, exercisers and general pleasure riders), the trip itself is the objective. Scenic routes with meanders, overlooks, points of interest and even hills to add challenge are desirable features of the cycle facility. For the utility-oriented cyclist, the objective is not the trip, but reaching a specific destination -- place of employment, school, home, a store or community activity center. The bicycle is merely a vehicle for making the trip (although secondary objectives such as exercise, pleasure may have influenced the choice of vehicle). Because of this destination consciousness, the utility-oriented cyclist, while appreciating scenic routes where they coincide with specific travel desire lines, places highest priorities on directness of routes, acceptable grade profiles and minimized delay and inconvenience.

Two points are fundamental to the planning of good cycle facilities.

- Where cycle trip surveys have been conducted, recreational usage has been the predominant single trip purpose. However, in urban areas the number of trips and the composite of trip purposes, which can be characterized as utility riding, normally equal or outnumber recreational trips. In rural areas, touring (recreational) cycling is more prevalent. Thus, an urban bikeway system should be planned to serve a balance of these two trip categories, whereas a rural system might be primarily designed with recreational riders in mind.

- The second realization is that an urban setting implies that a considerable portion, possibly all of the system mileage will be on or along city streets. Bike trails and exclusive rights-of-way -- parklands, green belts, utilities rights-of-way and other open space -- have a number of desirable characteristics. However, opportunities to utilize these spaces in already developed areas are limited, as are the opportunities to incorporate these open space corridors in new development areas and structure them along cycle travel desire lines. But even where exclusive rights-of-way can be utilized, these must inevitably cross these streets at some location. The point is that in most corridors in which cycle facilities will be planned, the motor vehicle is a fact of life and is not going to disappear overnight, next week or next year. To a lesser extent, the same holds true for rural areas where most bikeway facilities will continue to be along motor vehicle roadways. Thus, a major element of cycle facility design practices is to arrange shared space so as to minimize conflicts between autos and bicycles, two not necessarily compatible types of vehicles.

BICYCLE FACILITY TERMINOLOGY

Current terminology used in describing bicycle facilities is a source of some confusion. Much of the terminology is English language nomenclature, some of it generic, but much of it descriptive of the physical characteristics of the facilities. Another set of terminology is defined in the "Bikeway Planning Criteria and Guidelines" prepared by the University of California Institute of Transportation and Traffic Engineering for the State of California Business and Transportation Agency.[3] This terminology classifies bicycle facilities according to the degree of exclusiveness with which the facilities are preserved for bicycle use. This classification system has been widely adopted in recent U. S. bicycle facility literature. The ITTE classification system and some of the appellative nomenclature are defined below.

BIKEWAY CLASSIFICATION

Class I: A completely separated right-of-way designated for the exclusive use of bicycles. Crossflows by pedestrians and motorists are minimized.

Class II: A restricted right-of-way designated for the exclusive or semi-exclusive use of bicycles. Through travel by motor vehicles or pedestrians is not allowed. However, vehicle parking may be allowed. Cross-flows by motorists, for example, to gain access to driveways or parking facilities, is allowed; pedestrian cross-flows, for example, to gain access to parked vehicles or bus stops or associated land use, is allowed.

Class III: A shared right-of-way designated as such by signs placed on vertical posts or stenciled on the pavement. Any bikeway which shares it's through-traffic right-of-way with either or both moving (not parking) motor vehicles and pedestrians is considered a Class III bikeway.

DEFINITIONS

- Mixed Use: Bicycles and motor vehicles or bicycles and pedestrians sharing space with no provisions for segregation of traffic.

- Bike Route: A street or system of streets and ways with signs denoting them as a "Bike Route." The signs warn motorists to anticipate bicycles on these streets and indicate to cyclists a desirable routing because of low traffic volumes or good grade profiles, a possibility of scenic views or continuity to activity centers. Most commonly, "Bike Routes" imply streets in mixed usage but they may include segments of the various types of exclusive bicycle facilities described below. In non-capitalized form, "bike route" indicates the bicycles' line of travel to reach a specific destination. (A Class III facility.)

- Bikeway, Cycleway: Generic terms encompassing all of the exclusive bicycle facility treatments described below. Both most commonly denote bicycle facilities which are off the street or highway pavement but not necessarily separate from the roadway right-of-way.

- Bike Lane: An on-street treatment in which separate auto and bicycle travel lanes are designated visually by signs and street markings. (A Class II facility.)

- Protected Lane: An on-street bike lane in which a positive physical separation is placed between bicycles and moving motor vehicle traffic. Separation may be achieved through striped buffer areas, raised and possibly landscaped median strips or by placing the lane between parked cars and the curb. (A Class I facility.)

- Bike Path, Pathway: Generic terms denoting bicycle facilities off the roadway surface, though not necessarily out of the roadway right-of-way.

- Sidewalk Path of Wide Sidewalk Treatment: A bike path within the roadway right-of-way which may be used by pedestrians as well as cyclists. (May be Class I, II or III.)

- Independent Path: A cycle facility in its own right-of-way, entirely separate from streets and highways. Includes pathways specially provided for bicycles, park and green belt trails, service roadways along utility rights-of-way, drainage and irrigation canals, etc. (Class I or II).

- Mall Treatment: A block or blocks of city streets closed to motor vehicle traffic with the exception of emergency and possibly service and public transit vehicles. (May be Class II or III).

Neither the classification system nor the appellative definitions themselves provide adequate description of the functional aspects of a bicycle facility. For instance, a sidewalk bikeway would be considered a Class III treatment in the most typical cases in which the facility is used as a shared facility with pedestrians. However, in cases where a stripe delineation on the sidewalk is used to designate separate bicycle and pedestrian areas, the same travelled way would be considered a Class II facility. Similarly, an independent pathway might be considered a Class I or Class II facility depending upon the actual level of pedestrian utilization. And the Class II designation might be used with equal applicability to describe an on-street bike lane, the sidewalk area with separate delineation for bicyclists and pedestrians, or an independent pathway which has high utilization by pedestrians as well as cyclists. Because of the lack of specificity in both terminologies, both class and appellative terminology are used concurrently in this report to avoid ambiguity.

BIKE ROUTES:

The signed bike route (illustrated on Figure 1) or route system has typically been the first step in many jurisdictions' attempts to deal with the bicycle activity boom. These Class III facilities may be the product of significant effort on the part of the planner to indicate to cyclists utility routes with continuity to activity centers having low traffic volume or desirable grade profile characteristics or recreational routes having the possibility of scenic views, continuity to points of interest and recreational facilities. However, beyond the measure of safety which may accrue as a result of the route signs being seen by alerting drivers to anticipate cyclists, signed route facilities typically do little to insure bicycle safety. Moreover, establishment of signed routes has unfortunately been used as a temporizing device or to create the illusion of providing facilities by public officials who are unconvinced of bicycle facility needs or uncertain how to implement more advanced types of treatment.

Signed bike routes do have some utility in providing guidance to touring cyclists. However, their limited overall usefulness in urban and suburban system context is illustrated by the experience of Palo Alto, California in the late 1960's. In 1967 Palo Alto implemented a 27 mile signed bike route system (a full 15% of the city's street miles) as a one year test demonstration. Results of this demonstration program were indicative of the inadequacies of the signed-route system. In a survey of Palo Alto cyclists, more than 65% of respondents reported that they seldom or never used the signed routes and where usage was reported, it was most frequently incidental and coincidental rather than intentional. Part of the explanation for lack of route utilization was the fact that in many cases the routes did not serve desired activity center destination points. But more importantly cyclists simply were unwilling to ride any distance out of their way in order to use a signed bike route that appeared to offer no obvious travel or safety advantages.

Figure 1: TYPICAL SIGNED ROUTE

The 24% increase in city-wide bicycle-motor vehicle incidents in the year after implementation of the bicycle route system offers further evidence of the ineffectiveness of the facilities.

The City of Seattle has developed an innovative variation of the signed bike route. On one portion of the City's demonstration bicycle facility, insufficient right of way was available to designate space for exclusive use of bicycles. In this area the City has reclassified the street as a bikeway, that is, a facility primarily intended to serve bicycles. Motor vehicles are allowed to travel on the street segments but must yield to bicycles in any conflict situation. This facility, illustrated on Figure 2, has only recently been placed in use and it remains to be seen whether motorists will actually grant cyclists priority on the roadway or whether the treatment is merely a matter of semantics.

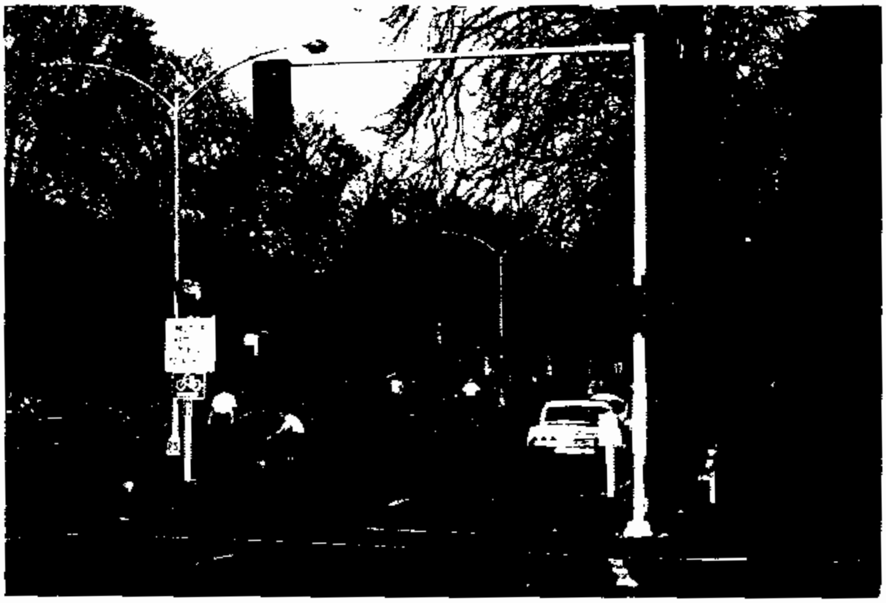


Figure 2: SEATTLE SIGNED ROUTE INNOVATION

BIKE LANES:

This Class II treatment which has come into widespread use across the U.S. in the last several years has proven quite effective in separating flows of motor vehicle and bicycle traffic. Bike lanes add legitimacy and credence to the cyclists' presence on the road and delimit a physical area for cycle riding. Provision of designated space for cyclists, when properly dimensioned, eliminates the tendency for cyclists to distribute themselves over the roadway cross-section and gives the cyclist a sense of security. Establishment of predictable cyclist position on the roadway also gives motorists a sense of security and given that the cyclist would be on the roadway in any case, appears to have positive traffic flow and capacity implications as well. This is not simply because of removal of the slower moving bicycle from the motor vehicle's path. Some evidence exists, although as yet unquantified in flow/capacity relationships, that motorists are willing to pass cyclists at higher speeds and with lesser separation distances when designated lanes are present than in mixed use conditions. Figure 3 illustrates displacement of vehicles across all three lanes of an arterial street as a result of cyclist presence without a designated lane. Figure 4 illustrates motor vehicle displacement across the centerline of a two-lane roadway due to cyclist presence when no designated bike lane is provided. Figure 5 illustrates a motor vehicle passing a cyclist where a designated lane is provided. Note the positioning of the vehicle squarely in its proper travel lane.

Figure 3: NOTE VEHICLE DISPLACEMENT ACROSS ALL 3 TRAVEL LANES DUE TO CYCLIST PRESENCE

Figure 4: NOTE DISPLACEMENT OF MOTOR VEHICLE ACROSS ROADWAY CENTERLINE DUE TO CYCLIST PRESENCE

Figure 5: NOTE MOTOR VEHICLE AND BICYCLIST POSITIONED SQUARELY IN PROPER LANES WHEN BIKE LANE IS PROVIDED

While lane delineation lines are by no means a physical barrier and may breed some overconfidence, they have, as illustrated above, demonstrable positive impact on bicycle-motor vehicle positioning.

Recently, a number of sources have reported findings to the effect that on-street bike lanes have little impact on safety performance. A study of bicycle-motor vehicle accidents in the City of Santa Barbara, California,[26] for example, concluded that "perhaps only 13% of the accidents would have been prevented had bike lanes or bikeways been provided." The primary basis for conclusions of this type has been the relatively small percentage of bicycle-motor vehicle accidents comprised by mid-block side-swipe and rear-end collisions, the type which prima facie would be most susceptible to resolution by bike lanes. However, two significant factors are not considered:

- Mid-block treatments may have a significant effect on movement patterns and predictability of cyclists' behavior at intersections which could contribute to reduced accident experience at these locations.
- Bike lanes constitute a physical reminder to both cyclist and motorist which can reinforce cyclist obedience to the rules of the road and predictable behavior (the same Santa Barbara studies indicated 70% of the cyclists involved in accidents were clearly in violation of the law) and raise motorist consciousness relative to the presence of cyclists.

Accident experience before and after provision of bicycle facilities appears more valid evidence than hypotheses based on circumstances of accidents which took place when no lanes were present. The experience of Davis, California, is instructive. In the period of 1967-68 before the city's comprehensive bikeway program was implemented, an average of 23 bicycle-motor vehicle accidents (mid-block and intersection) were experienced annually. In 1971, after implementation of the bikeway system, some 31 bicycle-motor vehicle accidents were reported, an increase of some 35%. Yet over the intervening period, both motor vehicle and bicycle traffic had increased by more than 100%. The conclusion of this and supportive data from European studies is that bike lanes can be substantially more safety-effective than gross collision causal analyses would appear to indicate.

Within the category of on-street bike lanes, a broad range of design treatment has been evolved. Typically, directional lanes are provided on each side of the street operating with traffic. In the most common form of this treatment the bike lanes placed between the parking apron and the motor vehicle travel lane. A typical illustration of this design variation, labeled Type A, is shown on Figure 6. Along streets where no parking is allowed, or where parking must be removed to provide space for the bike lane, a curbside positioning is used. This treatment, labeled Type B, is illustrated in Figure 7.

At times when available street space is limited, directional lanes

Figure 6: TYPICAL TYPE A LANE (Davis, California)

Figure 7: TYPICAL TYPE B LANE
(Eugene, Oregon)

can be provided by eliminating parking on one side of the street, offsetting the traveled way centerline, and providing directional lanes of Type A on one side and Type B on the other. This offset the centerline treatment, labeled Type C, is illustrated on Figure 8.

Figure 8: TYPICAL TYPE C, OFFSET CENTERLINE TREATMENT (Denver, Colorado)

Another means of incorporating on-street lanes where limited street width is available is by providing directional lanes on one side only of each of a pair of parallel streets. In effect, this creates a one-way bike lane couplet along streets which operate bidirectionally for motor vehicle traffic. Type A or Type B lane positioning can be used with this treatment. Similar treatments are used on one-way street couplets. Unfortunately, because cyclists are reluctant to go even a block out of their way and because they are, in general, less scrupulous about obeying traffic controls, ordinances, than motor vehicles, this type of design often leads to wrong way riding in the lanes or wrong way riding out of the lane area.

Some variations have been employed with varying success. On one-way streets in Denver, the bike lanes have been placed in a left side rather than the common right side position, as illustrated on Figure 9. The rationale for this was that under one-way street operations, the left side placement would improve visibility relationships between the cyclist and motor vehicle drivers travelling in the same direction because of the availability of the outside rear view mirror on the left side of the motor vehicle and the driver positioning on the left side.

Figure 9: LEFT SIDE LANE POSITIONING ON ONE-WAY STREET (Denver, Colorado)

Seattle, Washington has employed left side positioning of bike lanes along a two-way divided boulevard. In this case, a broad median separates cyclists from opposed direction traffic. In addition to the improved visibility relationship benefits noted above, in the Seattle case, the left side positioning has the added benefit of eliminating the interference of the right side curb parking with bike lane operations. This unique treatment is illustrated on Figure 10.

Another variation of the on-street lane treatment involves bi-directional operation. In this treatment, bike lanes may be placed on one or both sides of the street and used in either direction by cyclists, as illustrated on Figure 11.

In many states bi-directional bicycle operations on one side of the street are at least implicitly prohibited by law as the bicyclist is usually required to obey the vehicle code when operating on the street. Even if bi-directional operation in a lane is legal, motorists are apt to perceive contra-flow cyclists as riding in violation of the law.

Figure 10: LEFT SIDE LANE POSITIONING ALONG WIDE MEDIAN (Seattle, Washington) NOTE SIGNING PAVEMENT STUDS TO FEND TURNING CARS OUT OF BIKE LANE

Figure 11: BI-DIRECTIONAL LANE (Santa Barbara, California) NOTE NON-STANDARD SIGNING, INDICATING LANE AND PART-TIME (During School Commute Hours Hours) PARKING BAN

Riding against traffic has, of itself, been identified as a major causal factor in bicycle-motor vehicle accidents, yet provision of bi-directional facilities, particularly bi-directional on-street lanes, legitimizes and formalizes this unfortunate practice. Some of the more obvious deficiencies of bi-directional operations are:

- Higher rates of closure resulting in decreased effective sight distances and reaction time. This is particularly critical in areas of impaired sight clearance such as on horizontal or vertical curves or in the vicinity of sight obstructions.
- Increased potential for the more serious head-on collision.
- Impaired or total lack of visibility of traffic control devices, particularly STOP and YIELD signs, for bicycles travelling in the against traffic direction.
- "Against traffic" bicycle flows conflicting with motorist ingrained anticipation of flow according to the "keep right" rule.
- Unpredictable and hazardous operations at transition areas where bi-directional facilities terminate and one-way (keep right) operations begin.

In addition to the negative physical factors noted above, the legitimate status which bi-directional facilities confer on travel against traffic may induce cyclists to travel against traffic even where no special facility provisions exist. In one extreme case of this type of habit formation, a bi-directional lane placed to serve an elementary school is involved. The bike lane operates only in school commute hours; at other times it is occupied by parked vehicles. Yet school children return to the area for play in hours when the lane is not in operation and, by force of habit, ride against traffic as if the bi-directional lane were in effect. There are numerous situations where the specific circumstances of access to an activity center, the configuration of linking bikeway facilities, right of way considerations and the like make bi-directional facilities in roadway corridors necessary and possibly even desirable. But as a general rule, bi-directional operations should be limited to independent pathways and sidewalk facilities where lengthy segments uninterrupted by cross streets and driveways exist. At roadway crossings of bi-directional facilities, clear signs and markings alerting motorists to bi-directional operation should be provided.

PROTECTED LANES:

Protected lanes are a major variant of the on-street lane concept which differ in operational characteristics to the extent that they should be considered as a separate design category. These Class II on-street treatments are distinguished from the common on-street lanes in that they provide a positive physical separation between bicycles and motor vehicles rather than a simple marking delineation. Lanes protected by visually delineated buffer areas or plastic pylons fall somewhere between the common bike lane and the protected lane concept, but are most similar in operation to the common stripe delineated on-street lane. In the case of visually delineated buffer areas, the buffer area does provide an additional shy distance which can serve as a recovery area in case of incidents and may reduce the occurrence of encroachment. Lane delineation by pylons provides an audio-tactile barrier as well as increased visual delineation, which tends to discourage auto encroachment into the bike lanes.

Lanes conforming to the strict definition of a protected lane are separated from moving vehicle traffic by a more or less positive physical barrier. Figure 12 illustrates a typical form of this treatment with the lane placed between the curb and the parking apron. In this instance, the parking vehicles are prevented from encroaching on the bike lane by use of bumper blocks normally employed in parking lots. Raised berms, traffic bars, or possibly even right side parking lane stripe delineation would be equally effective.

In Sausalito, California, planter boxes have been deployed as the lane delineation barrier. Where parking is prohibited, protected bikelanes may be placed adjacent to a motor vehicle travel lane. When the

Figure 12: TYPICAL PROTECTED LANE (Davis, California)
NOTE USE OF CONCRETE "PARKING LOT BUMPER BLOCKS" AS BARRIER

lane is placed between the curb line and parked vehicles, particular care must be taken to insure adequate dimensioning since the cyclist is relatively confined and has limited ability to swerve to avoid an incident such as opening of a car door. This type of treatment where parked motor vehicles comprise part of the physical barrier protecting the lane has proved less than satisfactory in cases where it has been employed in Davis, California. It was conceived in an effort to remove the interference of high turnover parking in the more common Type A on-street lanes, but in application, it has been used to protect the lanes in cases where higher speed, higher volume motor vehicle traffic has made such protection seem desirable; but the parked cars which comprise the protective barrier create sight distance problems at driveways and intersections. In Davis, this has forced removals of parking where such treatment has been employed for distances of 100 feet on the intersection approach, but sight distance problems continued to be experienced at driveways. Treatments which employ positive barriers to protect the lanes make it difficult for cyclists to cross the street at mid-block when necessary to get into the proper directional lane. As a result, they tend to produce bi-directional use with the attendant problems of both bike-bike conflicts in the lane and bicycle-motor vehicle traffic stream conflicts at intersections and driveway crossings. Another problem with this type of lane is maintenance, particularly sweeping. Unless the protected lane is wide enough for operation of mechanical street sweepers, debris tends to accumulate, discouraging use. Because of these kinds of problems, employment of the protected lane concept is becoming less frequent. Proposals for such lanes located between curb and parking area have drawn strong public criticism in Washington, D.C. In Eugene, Oregon, use of plastic pylons as a lane protection was abandoned due to public criticism of the aesthetics and the fact that the pylons became a target for pranksters. And in Davis, California, lanes similar to those illustrated on Figure 12 have been replaced by conventional on-street lanes due to problems of induced bi-directional travel.

SIDEWALK TREATMENTS:

Sidewalk treatments have been employed with varying degrees of success across the U.S. A sidewalk facility might be considered a Class III, Class II or even in some cases, Class I facility dependent on the level of pedestrian activity in the area and the physical circumstances of the facility. Considerable unsatisfactory experience with sidewalk bikeways in the Class III category is being reported. Among the factors contributory to this experience are the following:

- Poor sight distances and visibility relationships often prevail at driveways. Landscaping, shrubbery and fences tend to impair sight distances at driveways. Compounding the problem are the poor visual relationships which result because motor vehicles are typically backing to exit and completing a turn upon entry.

- Poor visual relationships between cyclists and motorists also occur at intersections. The emergence of a high speed bicycle (as opposed) to pedestrian speed) into the crosswalk area is often unanticipated by motorists, particularly those completing turns.

- Sidewalk bikeways tend to be used bi-directionally despite signs and marking to the contrary, and hence suffer the drawback associated with bi-directional operations. Bi-directional operations compound the sight distance/visual relationship problems at highways and intersections noted above.

- Sharing space with pedestrians creates a number of problems. Pedestrians are extremely mobile directionally and often do change direction unpredictably. This factor, coupled with the difference in travel speed (average travel speed for a bicycle is 3 to 4 times the average walking speed) leads to a high conflict potential. Small children often use sidewalks as play areas and they, together with their toys, can comprise an obstacle course. Older pedestrians and blind persons are particularly uneasy at meetings with cyclists along sidewalks.

An uninviting sidewalk bikeway. Note shrubbery obscuring driveway view and reducing effective width of already narrow sidewalk

- Sidewalk surfaces often offer a poorer quality ride than the pavement of the streets they parallel.

- In many cases, existing sidewalks which have been pressed into service as Class III bikeways are too narrow to function effectively under conditions of shared use with pedestrians and are uninviting routes, even when no pedestrians are present.

- Due to the above factors singly or in combination, in the absence of extreme traffic pressure on-street or sometimes in spite of it, cyclists frequently elect to use the street rather than the Class III sidewalk bikeway.

A Class II sidewalk bikeway can be created by striping or otherwise visually delineating separate areas of the surface for cyclists and pedestrians. Class II sidewalk facilities may suffer from many of the same deficiencies as the Class III facilities discussed above. Sight distances and visual relationships can continue to be a problem at intersections and driveways. The facilities remain prone to bi-directional use and surface quality and dimensional characteristics continue to be concerns. In the extent to which pedestrians respect the spatial delineation is a matter of some question. Sidewalk bikeways are most effective when provided on long stretches uninterrupted by cross-streets or driveways. Under such conditions, and where there is very little or no pedestrian activity, these facilities have performance properties similar to independent pathways and might be considered Class I facilities.

In Irvine, California, where arterial and collector streets have been developed within broad environment corridors, the parallel path facilities have many of the characteristics of Class I bikeways. Along freeways and expressways, particularly in low-density suburban and rural areas where broad rights-of-way are observed, substantial opportunities are available for construction of parallel pathways without bringing the cyclist in close proximity to high speed roadways. The greatest problem with such usage occurs at grade separations and interchanges. Also, the fencing provided along such high speed corridors to keep wild or domestic animals as well as persons, off the roadway presents a problem. Two sidewalk bikeways with Class I characteristics are illustrated on Figure 13.

In proper circumstances and settings, sidewalk bikeways can be extremely attractive and effective facilities. Gainsville, Florida has had excellent success with a system comprised of sidewalk facilities, but all too often, sidewalk treatments are employed as a last resort because space for more desirable treatments is not available.

INDEPENDENT PATHWAYS:

Bikeway corridors in their own rights-of-way are in many ways the most desirable and attractive facilities. Such facilities might function as

Figure 13: SIDEWALK BIKEWAYS WITH CLASS 1
CHARACTERISTICS
(Above - Ithaca, New York
Below - San Francisco, California)

Class I or Class II facilities, depending on the level of pedestrian activity along them. Most frequently, such facilities are recreational in character, but often the locational circumstances of right-of-way make them useful as recreational routes as well. In Fort Worth, Texas for instance, the Trinity River Bikeway System was planned primarily as a recreational facility, but since it leads directly into the downtown area, it is also highly useful as a commuter route. In Denver, the commuter route system incorporates independent pathways and park land whenever such opportunities are available. In other cases, independent pathways have been designed specifically for utility use as has been done in "new town" communities or subdivisions where green belt bikeways extensively penetrate the neighborhood areas and provide bikeway accessibility to residences completely independent of the motor vehicle roadway structure. Figure 14 illustrates a typical Class I bikeway.

One of the frequent problems with independent pathways in unattractiveness due to failure to construct the facilities to adequate specifications and standards for bicycle use. Inattention to grade profiles, curvature, sight distance and proper pavement surfacing are frequently problems on some of the older bicycle facilities which have been designed by park

Figure 14: A TYPICAL CLASS 1 INDEPENDENT PATH (Eugene, Oregon)

trails planners or landscape architects. In the past, park trails planners have been more oriented to the needs of pedestrians, particularly hikers and strollers rather than cyclists and designed with the pedestrian rather that the cyclist in mind. But in recent years, trails planners have become much more sensitive to cyclists' particular needs. Landscape architects in many cases have been more concerned with the visual aspects of a facility than its functional service qualities. This problem is also likely to be resolved as better literature on functional bikeway planning becomes commonly available.

Another common problem concerns the use of what might be described as "corridors of opportunity" as rights-of-way for independent pathways. In many cases, such corridors -- levees, utility line maintenance paths, abandoned railroad rights-of-way, and the like afford unique opportunities for the creation of independent pathways and many jurisdictions have pressed forward to utilize them. Unfortunately, a number of bikeway facilities have been constructed in such corridors, simply because the right-of-way was available and with little regard for the potential usefulness of the ultimate facility. In urban areas, such facilities may not be useful as utility routes unless they provide as effective a linkage between residence areas and activity centers as do the city streets. In many cases, such corridors may provide unattractive surroundings for recreational riding. Perhaps the most glaring errors have been made where bikeways have been constructed for several miles from nowhere to nowhere simply because the right-of-way was available. A classic case of this is the California Aqueduct Bikeway, a facility conceived to provide Class I bikeway linkage between northern and southern California. However, very few users are likely to travel the several hundred mile length of the facility when completed and most of it is out of the range of day use trips from population centers. Moreover, the facility is located in the San Joaquin Valley where daytime temperatures in summer range well over 100°F. In this case, the facility was constructed from aqueduct project funds to enhance the recreational use potential of the corridor -- not from scarce bikeway construction funds. But it is illustrative of the penchant to react to physical opportunities without considering the utility and attractiveness to bicyclists.

Another inherent problem of independent pathways is that inevitably, they must cross motor vehicle roadways. Typically, such crossings occur at isolated -- that is, away from roadway intersections -- locations and appear to have a high accident potential. The grade separations at these locations as well as signs and markings are discussed in subsequent chapters.

Chapter III

BICYCLE FACILITY DESIGN STANDARDS

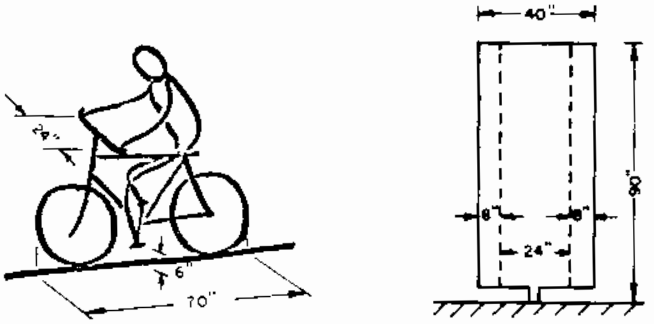
There is considerable variance in the bikeway design standards now being used in the U.S., particularly in the areas of bikeway widths, design speed and curvature, and grade profiles. Standards which are reported here should be taken as preliminary guidelines, until such time as further basic research confirms or modifies them.

BICYCLE FACILITY DIMENSIONAL REQUIREMENTS

Perhaps the area of greatest variance is that of minimal dimensional space provided for cycle facilities. In many jurisdictions, minimum width dimensions have been defined simply by space available and a more commodious dimensions defined in an effort to provide a margin of safety on the facility or the ability for multiple vehicle passage. The most rationally based standards which have been adopted by numerous jurisdictions are German specifications shown in Figure 15. These specifications define the space occupied by the bicycle, an additional lateral space requirement because the bicycle does not travel in a true straight line but tends to weave along its projectory, and an additional shy clearance from lateral obstructions. Also defined is an overhead clearance as shown in the figure. Also illustrated is the method of combining lane modules to create multi-lane facilities. Applying these standards, the minimum desirable width for a single on-street bike lane would be slightly over 4 feet, including right hand shy distance between the bicycles and curb or parked auto, with a left hand shy distance assumed to be included in the width of the motor vehicle travel lane. Our observations indicate that when less than 4 feet of bike lane space is provided, the cyclists tend to align their wheel track as closely as possible to the lane definition stripe, increasing the amount of shy distance and physically occupied space, in effect, "stolen" from the motor vehicle lane.

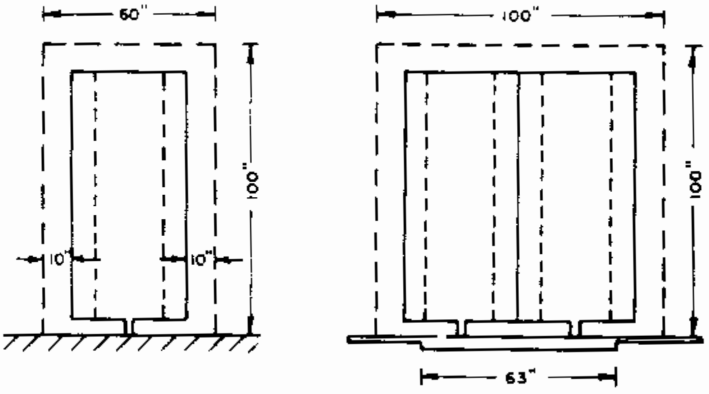
While 4 feet appears to be minimum acceptable dimension for cycle facilities, greater width is desirable to allow passing within the designated cycle facility space and to provide a margin of safety -- a recovery space for avoidance of incidents. Also, since cycling is, in some senses, a social activity, wherever possible, provisions should allow for riders to travel side by side. The specifications presented in Figure 16 indicate a width requirement including shy distance slightly in excess of 8 feet (2.5 meters) to allow comfortable passing or side by side operation with about 5.25 feet of the width actually paved. Many U.S. jurisdictions have adopted standards calling for 8 foot pavement width on independent pathways.

This pavement width, according to the German standards as presented on Figure 15, would allow proper operating space for simultaneous passage of three bicycles and appears to be an appropriate normal width standard for independent paths. (Such a width is also the approximate minimum width for passage of a maintenance vehicle such as a pickup truck -- an important consideration on facilities out of roadway rights-of-way.) However, where high levels of utilization are anticipated such as on college campuses, frequented recreation areas and the like, additional width is desirable. In the case of on-street lanes, satisfactory 2-lane functional operations have been achieved with 6 foot bike lane reservations despite the fact that this provision only partially meets full width requirements including shy distances as per Figure 15. In these situations, the shy distance is being in effect taken from the motor vehicle travelled way and/or the parking shoulder. It should be noted that where 8 foot parking shoulders are



TYPICAL BICYCLE DIMENSIONS

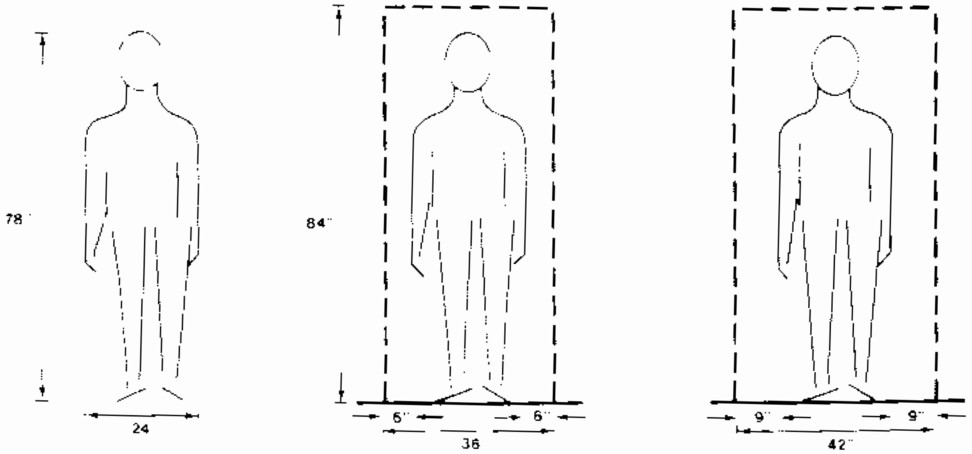
BICYCLE OPERATING SPACE



OPERATING SPACE PLUS MINIMUM CLEARANCES

TYPICAL BICYCLE PATH DIMENSIONS

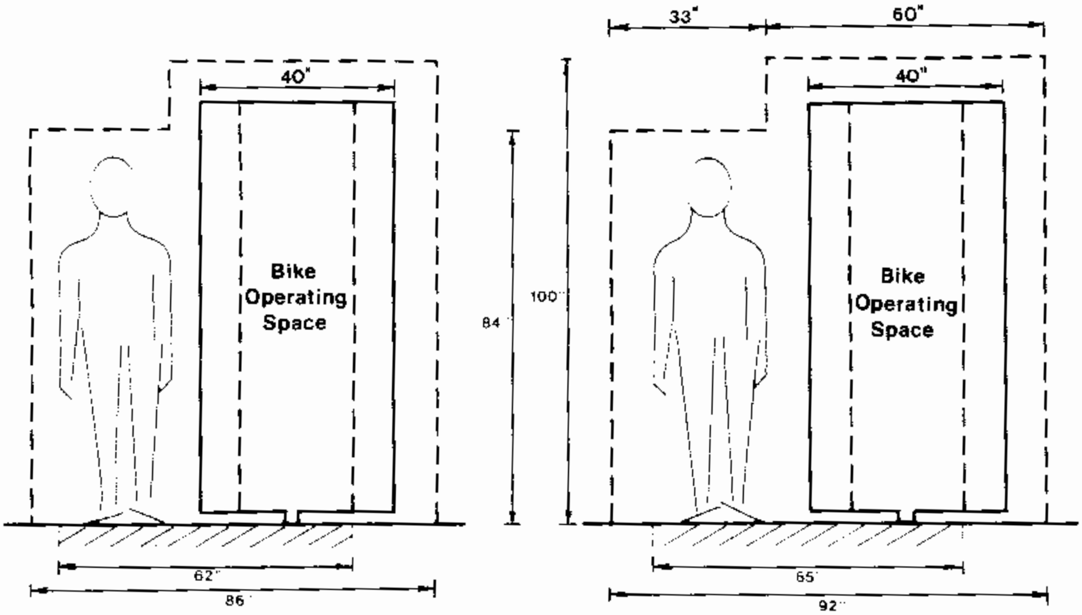
Figure 15: BASIC DIMENSIONS



Physically
Occupied
Space

Occupied Space
Plus "No Touch" Zone

Occupied Space Plus
"Personal Comfort" Zone



Bike Module Plus Pedestrian
"No Touch" Space

Bike Module Plus Pedestrian
"Personal Comfort" Space

Figure 16: BIKE-PEDESTRIAN SPACE REQUIREMENTS

provided, as is common in modern designs, parked cars usually do not occupy the full reservation and the additional space can function as bike lane shy distance. A 6 foot bike lane reservation also significantly reduces the hazard of opening doors of parked cars. Open car doors at full extension on the largest current production automobiles project about 4'4" from the car body. Fully extended door projection on more common models is typically about 2'9" to 3'. With a 6 foot bike lane reservation, full operating space (per Figure 15) is preserved within the lane with a car door open to the normal projection width (to the first stop) and even with opening to full projection on most models.

Cyclists will encroach on the roadway where bikeway fails to provide minimum adequate width.

Basic roadway widths required to deploy on-street lanes can be determined by adding minimum or desired bike lane dimensions to basic motor vehicle travel and parking lane width requirements. Basic minimum widths for travel lanes are indicated on Table 1. Where parking is permitted, a full 8 foot allowance should be made for the parking shoulder (except where rolled-pan curbs are employed -- 7 foot parking shoulder reservations are then acceptable).

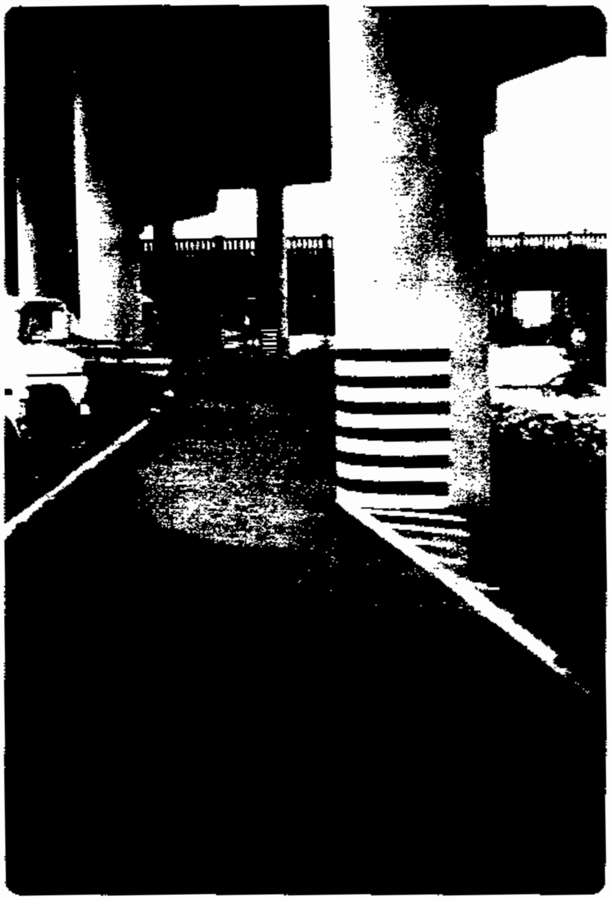
Table 1
MINIMUM MOTOR VEHICLE TRAVEL LANE WIDTHS

Type	Width in Feet
Expressway	12
Arterial	11
Collector	
Single Family	10
Other	11
Local	
Single Family Residential	10
Other	11

Source: Traffic Engineering Handbook[16]

Thus, minimum collector or local street widths for provision of minimal on-street bike lanes in each direction would be 44 feet with parking permitted both sides, 28 feet with parking prohibited both sides, and 36 feet with parking on one side only. For provision of more desirable bike lanes which will permit simultaneous passage of two cycles, widths of 48, 32 and 40 feet are respectively required for the three cases as above.

On sidewalk bikeways, either in mixed use with pedestrians (Class III) or where delineated bicycle and pedestrian areas are provided, dimensional requirements can be defined by combining the cyclist space module as presented in Figure 16 with a similar pedestrian space module. Typical human shoulder breadth is about 24 inches. In addition to space physically occupied by the pedestrian, Fruin[11] defined "no-touch" and "personal comfort" zones -- spacing which allows movement and personal comfort. An 18 inch radius "no-touch" zone would imply a minimum sidewalk reservation of 3 feet for pedestrians. Using the 21 inch "personal comfort" definition, a reservation of 3'6". Figure 16 presents these pedestrian modules in combination with the cyclist module. This would indicate a minimum width of paved sidewalk to be used jointly by cyclists and pedestrians of about 5'2" or 5'5" with additional lateral clearance to obstructions such as fences, posts, curbs, etc. In practice, a 6 foot sidewalk width appears to be a minimum acceptable for joint use by cyclists and pedestrians. However, in urban areas pedestrians often travel 2 and 3 abreast (at times by necessity, as in an adult with child situation). Cyclists also enjoy the opportunity to travel abreast. Hence, in areas where more than occasional encounters between groups of pedestrians and cyclists can be anticipated, provision of facilities wider than the above minimum is desirable. In design of off-street bikeways, whether for exclusive use of cyclists or in mixed use with pedestrians, particular attention should be paid to maintenance of proper lateral clearances. As can be seen from Figures 15 or 16, much of the required space can actually be off the pavement clear space. This allows some saving in pavement costs, but unfortunately clear space requirements, when assumed in off-pavement areas, are often ignored. One countermeasure to this is to provide paved surfacing to the full lateral clearance width. Although this increases costs, it may result in a more attractive facility overall, but at times obstructions are even placed within bikeway pavement areas. The most common lateral clearance obstructions are trees and bushes, utility poles, parking meters, sign standards, drain grates, street furniture, and fencing. Logs, rocks and other materials placed along a bikeway to landscape and delineate it should also be regarded as lateral clearance obstructions as should drainage ditches. Where restricted lateral clearances are unavoidable, it is helpful to mark the obstruction.



A marked obstruction.

The need to provide proper bikeway width and lateral clearance at all points along a facility cannot be overemphasized. National statistics indicate some 20 percent of bike accidents involved striking fixed obstacles;

another 15 percent involved bike-bike collisions. By contrast, bike-moving motor vehicle collisions accounted for only 5 percent.[5] While the influence of inadequate widths and improper obstacle clearances on the above statistics can only be inferred, it appears clear that these elements warrant significant attention.

Another consideration in design width of new sidewalk and independent paths is method of pavement placement. Asphaltic concrete surfaces in the 8 to 12 foot width range are normally placed with mechanical spreaders and because of this fact may generally be constructed at less expense than narrower paths on which the pavement must be placed by hand. Thus, where ample right of way is available, a width of at least 8 feet is generally indicated.

Two other practices deserve mention in this discussion of bikeway widths and lateral clearances: "informal" bike lanes and bike lanes which shared space with parked vehicles.

"Informal" bike lanes are created when roadway shoulder areas are delineated from the travelled way by edge-lining under conditions and where the shoulder area so defined is used as a bike lane and has the characteristics of one with the exception that specific bike lane designation signs and markings are not provided. Since motorists generally respect edge lines,[19, 20] such treatment affords cyclists most of the protection of bona fide bike lanes and a number of jurisdictions, unwilling to develop

An informal bike lane - use of a rural suburban highway shoulder comprehensive bikeway plans, uncertain as to planning and design techniques or concerned with liability, have undertaken extensive programs of edge line striping in an effort to create informal bike lanes. (Note: Legal issues with respect to edge lining and bike lane demarcation are discussed in Chapter V.)

Principal drawback of this practice is that in the typical procedure for edge line striping, primary concern is focused on defining adequate motor vehicle travel lane widths and little attention paid to the width remaining in the shoulder or its pavement condition. Thus, the cyclist may be led along the points where less than adequate dimensional relationships prevail, the shoulder is unrideable due to pavement surface conditions or to a structure where there is no rideable shoulder area.

Lanes which share space with parked vehicles, usually placed where there are relatively few curb-parked vehicles and limited street space available, appear quite undesirable. Bike lane presence leads to motorist expectation that the cyclist will remain in the lane. But where a parked vehicle leaves insufficient bike operating space in the bike lane, a cyclist being overtaken by a moving vehicle will still attempt to encroach on the motor vehicle travel lane rather than stopping and losing momentum. The potential for cyclists striking the parked vehicle is also a concern but much of this problem relates to the sudden opening of car doors rather than the fact of bike lane occupancy.

DESIGN SPEED AND RELATED PARAMETERS

Travel speed achievable on a bicycle on level terrain ranges to more than 30 MPH, with higher speeds possible on down grades. Individual cyclist speed is affected by numerous factors, including air resistance, weather (wind, temperature, wet or dry roadway surface), type of bicycle (gearing, weight, maintenance), roadway conditions and the cyclist himself (physical condition and motivation). Average travel speeds on level pavement as observed in our studies in Davis and in numerous other works fall in the 0 to 12 MPH speed range and 10 MPH has been specified as a design speed for bikeways in many reports. Unfortunately, this recommendation has led to poor design. On level pavement, there are significant deviations above the average speed and on even slight downgrades, average speeds on the order of 20 MPH and above have been observed. The effect of the slower 10 MPH design speed is that many facilities have been planned with relatively sharp curves at the foot of downgrades and many level facilities have been designed with too low design speeds to accommodate those cyclists who normally travel at above average speeds.

The bikeway design standards published by the Oregon State Highway Division in January, 1974 appear to be a better attempt to accommodate a broad range of cyclists rather than the average. In these standards, a design speed of 20 MPH is recommended for bikeways with grades between +3% and -7%. On sections with grades steeper than -7%, a 30 MPH design speed is applied and on one-way climbing grades of greater than +3%, a 15 MPH design speed may be used.

Curve radius is one of the principal factors affected by design speed. Where bikeways are located along motor vehicle roadways, motor vehicle turning radii are normally the controlling factor. However, some care should be taken, particularly in the case of bikeways not paralleling motor vehicle roadways that minimum curve radii permit unbraked turns at the design speed. Recent experimental work at the University of California, Davis has resulted in development of a simple linear equation which relates curve radius to design speed at the relatively low speeds bicycles normally travel.

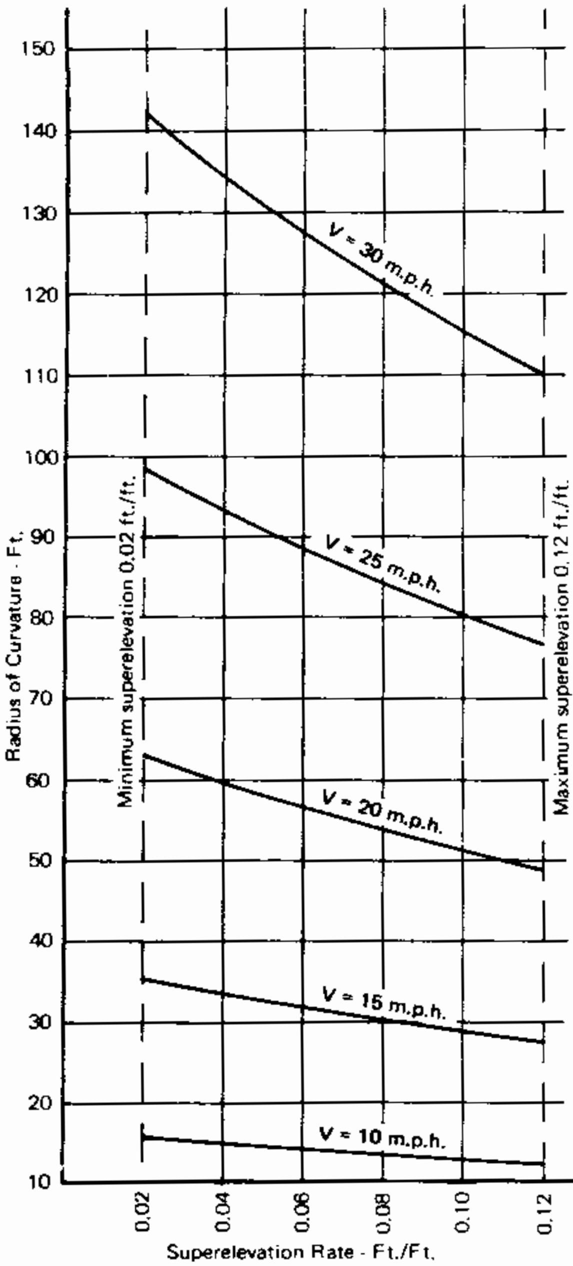
$$R = 1.25\,V + 1.4$$

where: V = Speed in MPH
R = Curve radius in feet

This simple equation enables evaluation of critical curves at the foot of downgrades where high cycle speeds can be anticipated and greater turning radii are desirable.

The State of Oregon[23] has developed more elaborate curve guidelines, including use of superelevation as presented in Figure 17, which are based on the standard highway curvature/superelevation equation. Note that superelevation should never exceed .12 foot per foor. The State of Oregon also recommends that a maximum of .06 foot per foot superelevation be used when pedestrians constitute 50% or more of the traffic. In areas where winter icing conditions are anticipated, the .06 maximum might also be advisable, even though little bicycle activity would normally be anticipated under such conditions. The subject of superelevation on bikeways merits further study because of the cyclists' capability of leaning into the turn which may obviate the need for superelevation in most circumstances.

Another aspect of curve design in curve widening. Cyclists lean to the inside of a turn, considerably increasing the lateral space occupied. Thus, a cyclist operating at high speed on the outside of a curve may physically overhang and, in effect, occupy a large part of the inside lane as well. To compensate for this, it is possible, and on two-way bikeways appears advisable, to widen the bikeway on short radius curves. The State of Oregon has developed standards for widening of bikeway curves with radii of less than 100 feet. Maximum widening is limited to 4 feet. The Oregon curve widening methodology is shown in Figure 18.



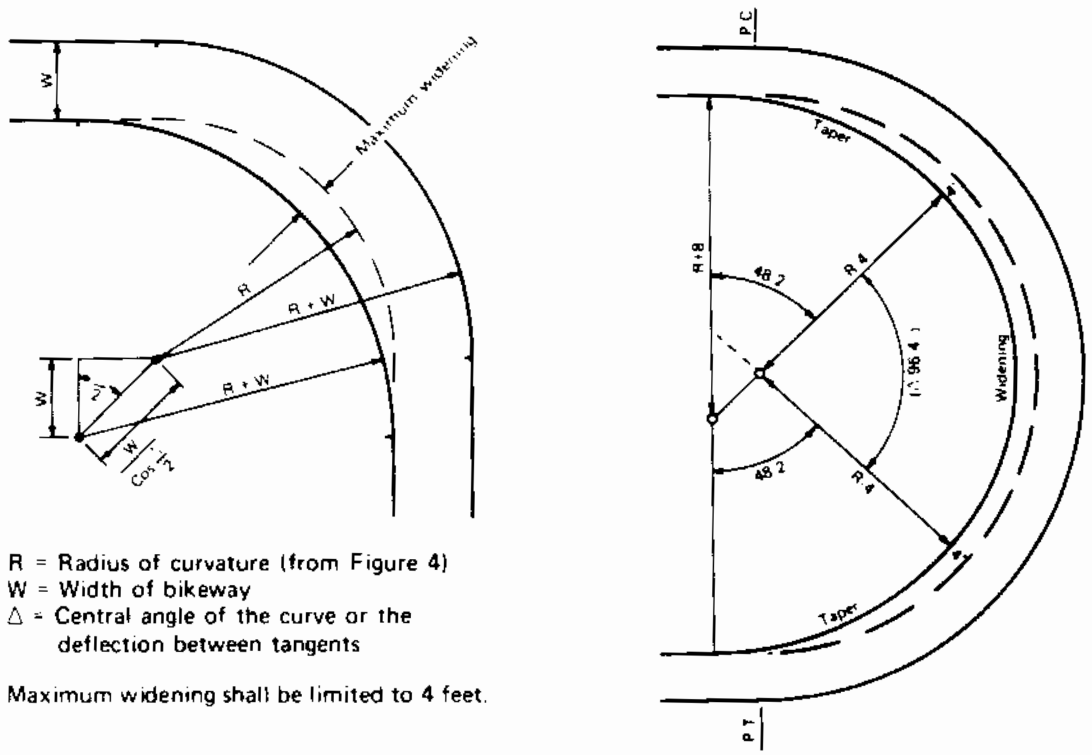
plot of: $\frac{V^2}{gR} = \frac{\tan\theta + f}{1 - f\tan\theta}$

where. V = velocity, ft./sec.
g = acceleration due to gravity, ft./sec.^{2}
R = radius of curvature, ft.
f = coefficient of friction on dry pavement = 0.4
tan θ = superelevation rate, ft./ft.

Curvature shall be based on a normal design speed of 20 m.p.h. Within limits shown, either the radius or the superelevation may be varied to fit individual situations. The dependent variable may be selected from the adjacent chart. Descending grades in excess of 7 percent will have a design speed of 30 m.p.h. Climbing grades in excess of 3 percent may use a 15 m.p.h. design speed. The descending grade determines the design speed on two-way bikeways.

Figure 17: STANDARD SUPERELEVATION FOR BIKEWAYS

Source: State of Oregon



R = Radius of curvature (from Figure 4)
W = Width of bikeway
Δ = Central angle of the curve or the deflection between tangents

Maximum widening shall be limited to 4 feet.

When widening reaches 4 ft. (Δ>96.4°), that width shall be carried on a radius of R-4 through the central portion of the curve (Δ-96.4°) as shown on the right.

Figure 18: CURVE WIDENING
Source: State of Oregon

Another factor closely associated with design speed is sight distance. Stopping sight distances can be computed using the standard highway equation presented below:

$$S = 1.47\ TV + V^2/(30\ f \pm G)$$

where: S = stopping distance in feet
T = perception/reaction time (usually 2.5 seconds)
V = initial speed in MPH
f = coefficient of friction (.25)
G = grade, ft/ft

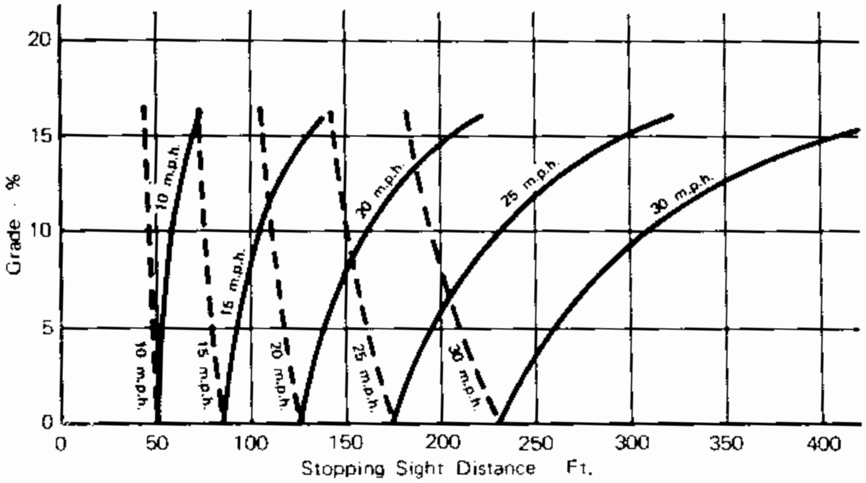
Figure 19 presents stopping distances as per this equation for the range of typical bikeway speeds and on various grade profiles. Stopping sight distances for cresting vertical curves are presented on Figure 20. Proper intersection sight clearance zones have not been well defined. Where bikeways are on street rights-of-way, the motor vehicle to motor vehicle sight clearance requirements normally control and where these are inadequate, normally a traffic control device is installed. But on sidewalk bikeways, the cyclists' view of cross traffic is frequently obscured by bushes at both driveways and intersection approaches. Maintenance of sight clearance areas is most critical at intersections of independent pathways with other independent pathways or with motor vehicle roadways. At the intersection of an independent bikeway with a motor vehicle roadway at a safe stopping distance from the crossing, the cyclist must be able to see any opposing vehicle which would pose a conflict threat at the crossing. Bicycle stopping distance, crossing width, and bicycle and motor vehicle speeds are parameters which fix the corners of a parallelogram which defines the intersection sight clearance area, as demonstrated on Figure 21.

The importance of safe sight distances cannot be overemphasized. A recent study[4] indicated that in more than 2/3 of the bicycle-motor vehicle accidents, either the motor vehicle operator or the cyclist did not see the other until a collision was unavoidable. In planning bicycle facilities, it is most desirable that the designer inspect sight distance conditions on-site, if possible from the seat of a bicycle. Where adequate sight clearance zones as specified above cannot be provided due to physical constraints, devices should be employed to slow or stop the cyclist so as to prevent unsafe entry into the crossing. Since cyclists tend to regard STOP signs as YIELD signs, use of berms, unramped curbing, deceleration curves, or use of posts and bollards to constrain operating space in the bikeway (hence constraining speed) is appropriate to ensure that the cyclist exercises due caution in entering the crossing.

Method for computation of sight distance and sight clearance area on horizontal curves is shown in Figure 22. Maintenance of sight clearance on curves is very critical on independent pathways which are used bi-directionally by cyclists. This sight clearance is also a critical hazard factor in the case of wrong way riding on motor vehicle roadways. Horizontal sight clearance on motor vehicle roadways is designed to allow safe stopping distance before a fixed object. Where existing sight clearances on motor vehicle roadways only barely meet requirements to enable a safe stop before a fixed object, safe stopping distance will not exist when a bicycle is travelling the "wrong way."

BIKEWAY CAPACITY

Bikeway capacity as a function of lane width as extrapolated from European sources is presented on Figure 23. The European reference material is not entirely consistent and further research on bikeway capacity is now being undertaken in conjunction with this study. But comparison of the



$$S = \frac{V^2}{30\, f \pm G} + 3.67\ V$$

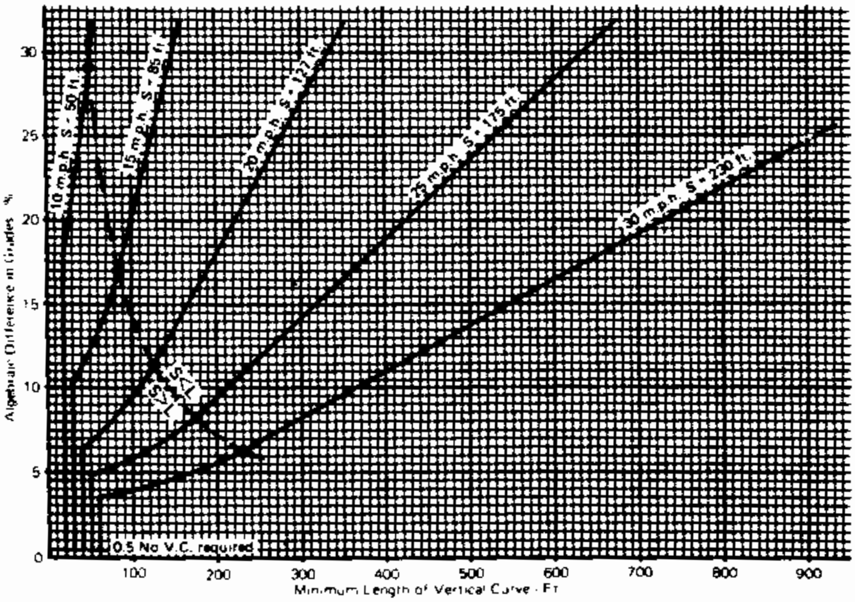
Where.
S = stopping sight distance, ft.
V = velocity, m.p.h.
f = coefficient of friction (use 0.25)
G = grade, ft./ft. (rise/run)

Descend ————

Ascend — — — — —

Figure 19: STOPPING SIGHT DISTANCE

Source: State of Oregon



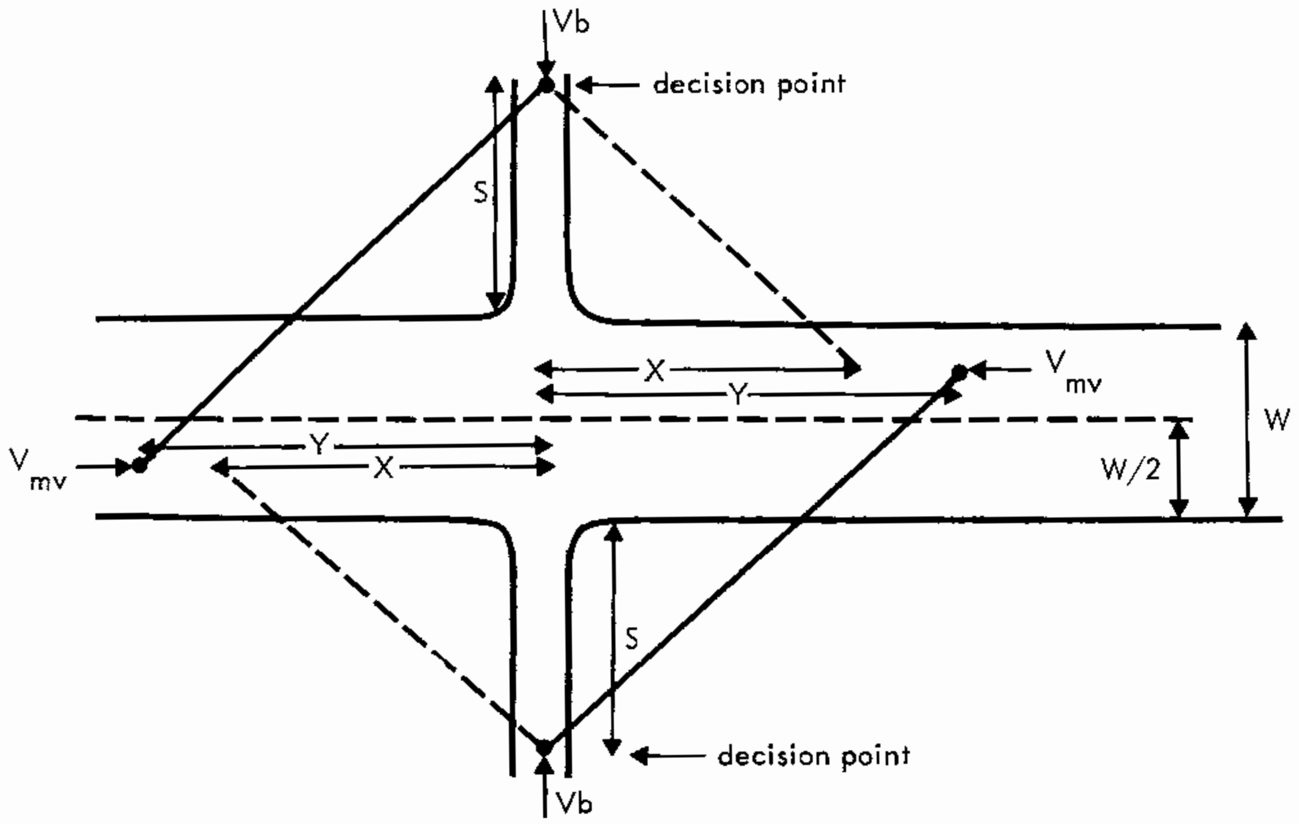
$$L = 2S - \frac{200(\sqrt{h_1}+\sqrt{h_2})^2}{A} \quad \text{when } S>L$$

$$L = \frac{AS^2}{100(\sqrt{2h_1}+\sqrt{2h_2})^2} \quad \text{when } S<L$$

where:
S = Stopping sight distance
A = Algebraic difference in grade
h_1 = 4½ ft.—eye height of cyclist
h_2 = ⅓ ft.—height of object
L = Minimum vertical curve length

Figure 20: BIKEWAY SIGHT DISTANCE FOR CREST VERTICAL CURVES

Source: State of Oregon



Time for full intersection clearance from the "stop-go" decision point is given by:

$$\frac{S + W + 6}{Vb} = t_1$$

Where S = Stopping Distance (including perception and reaction time) at design speed taken from Figure 19

W = Width of crossing

Vb= Actual bikeway typical approach speed (rather than design speed)

Time for near side lane(s) clearance is given by:

$$\frac{S + W/2 + 6}{Vb} = t_2$$

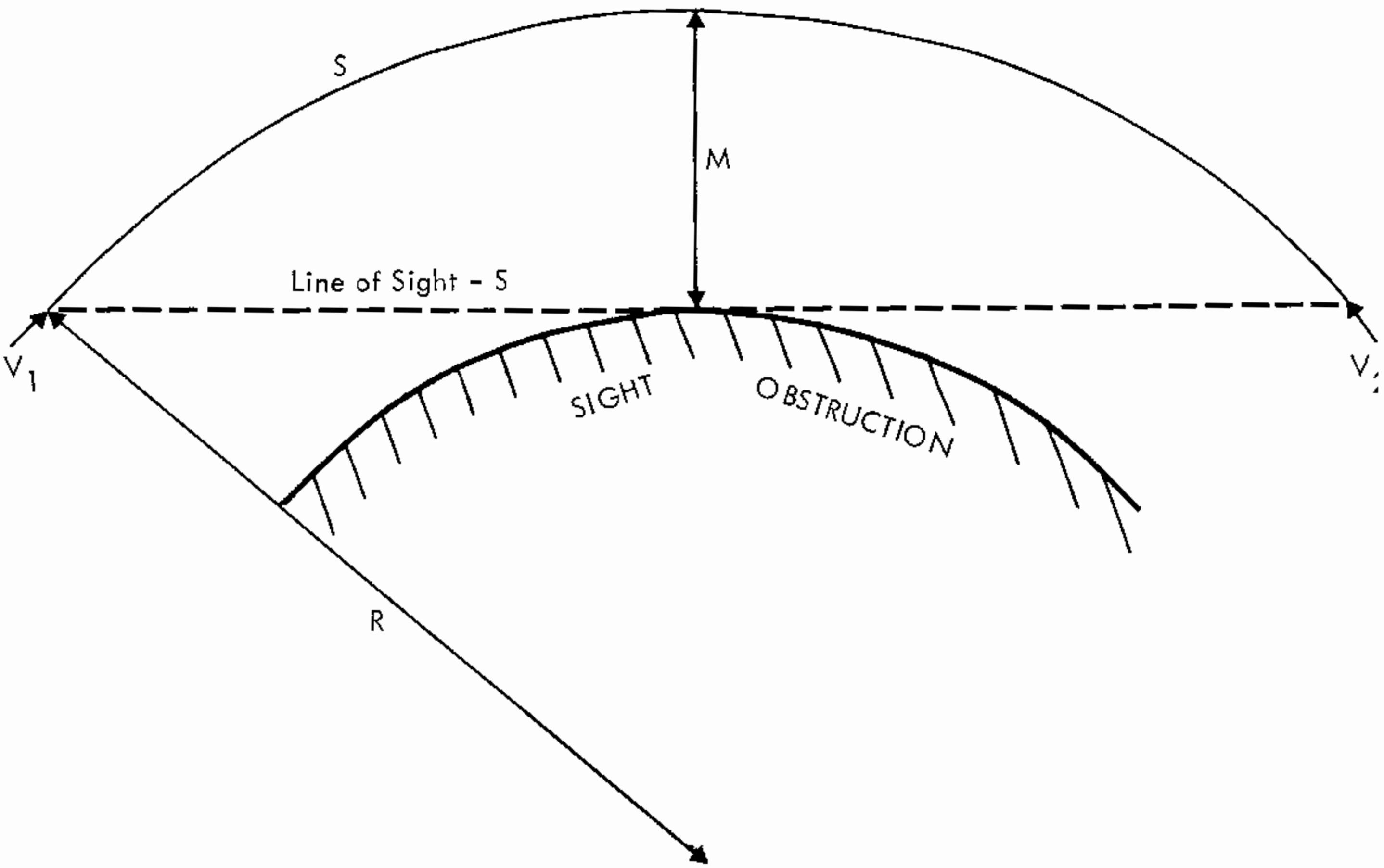
A crossing cyclist at the "decision point" must be able to see any vehicle which would threaten conflict in the crossing within time t_1 or t_2. Thus, the cyclist at the decision point must be able to see approaching vehicles at the following distances:

near side $x = t_2 V_{mv} = \frac{V_{mv}}{Vb} (S + W/2 + 6)$

far side $y = t_1 V_{mv} = \frac{Vmv}{Vb} (S + W + 6)$

Projections between the "stop-go" decision points and the points given by x and y define the sight clearance areas.

Figure 21: INTERSECTION SIGHT CLEARANCES



R = radius of curvature

S = Safe stopping distance along lane centerline (arc distance)

M = Obstruction offset from lane centerline

$$M = R \left(\text{vers} \quad \frac{28.655}{R}\right)$$

$$S = Sv_1 + Sv_2$$

Sv_1 = Stopping Sight Distance of Vehicle 1

Sv_2 = Stopping Sight Distance of Vehicle 2

Figure 22: HORIZONTAL SIGHT CLEARANCE

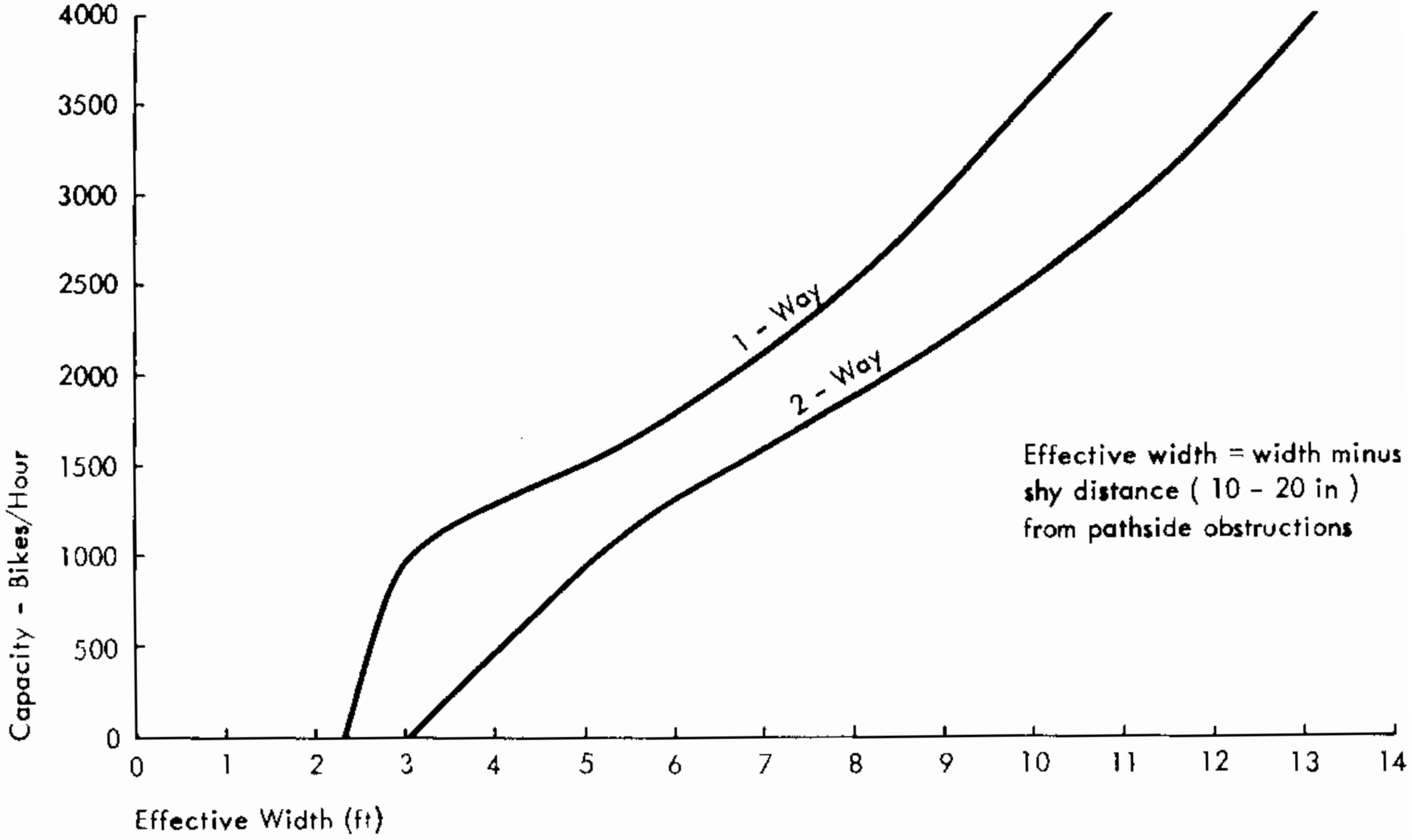


Figure 23: BICYCLE LANE AND PATH CAPACITY

figure with bikeway dimensional standards as presented on Figure 16 makes it apparent that once basic operating space requirements are met, the bikeway would have ample capacity for almost all situations. However, the planner should consult Figure 23 to insure adequate capacity in the vicinity of intense bicycle activity centers such as college campus areas or schools.

GRADES

Grade profiles permissible under several European standards are presented on Figure 24. Grade climbing ability varies with the physical characteristics of the individual cyclist, the characteristics of his bicycle and external conditions such as velocity and roadway surface. Thus the various profiles are based on some assumption of a "design cyclist" plus a "design bicycle" and an acceptable level of effort the cyclist might expend in climbing the grade. Background data and assumptions used in determining the various grade profile curves is not well documented. However, basic research toward establishing bikeway grade standards based on cyclist energy expenditures was initiated in the ITTE - State of California Bikeway Planning Criteria Guidelines Study[3] and is being continued at the University of California at Davis. The early findings of this work and the composite standards presented on Figure 24 make it clear that there is a sharp drop in length of grade which can be tolerated if gradients exceed 5% and that significantly shorter and less steep grade profiles than those often used on existing bikeways in the U.S. would be desirable. Minimized adverse grade and length of grade is essential on parallel pathways or independent paths designed to divert bicycle traffic away from motor vehicle roadways because if the grade and alignment of a bikeway is less favorable than that of a nearby roadway, many cyclists will use the roadway in preference to the bikeway. Desirable grade profile standards should be strictly employed in the case of grade separation approaches. For facilities paralleling roadways, application of the grade standards would be less stringent, principal criteria being that steepness and total change in elevation along the bikeway be no greater than that along the roadway. Where terrain makes steep gradients inevitable, it is at times possible to reduce the effect of grade along the bikeway. The Dutch[17] recommend provision of grade brakes (horizontal sections at least 30 feet in length) if maximum length-steepness relationships would be exceeded. Rest stops might be another alternative. The ITTE - State of California report suggests switchback curves to reduce steepness along pathways where ample right-of-way is available.

PAVEMENT SPECIFICATIONS

Pavement specifications will vary according to local soil conditions, drainage, and materials. But consideration should be given to the following factors: Pavement surfaces should be as smooth as possible, as bicycles generally do not have shock absorbing suspension systems, and travel

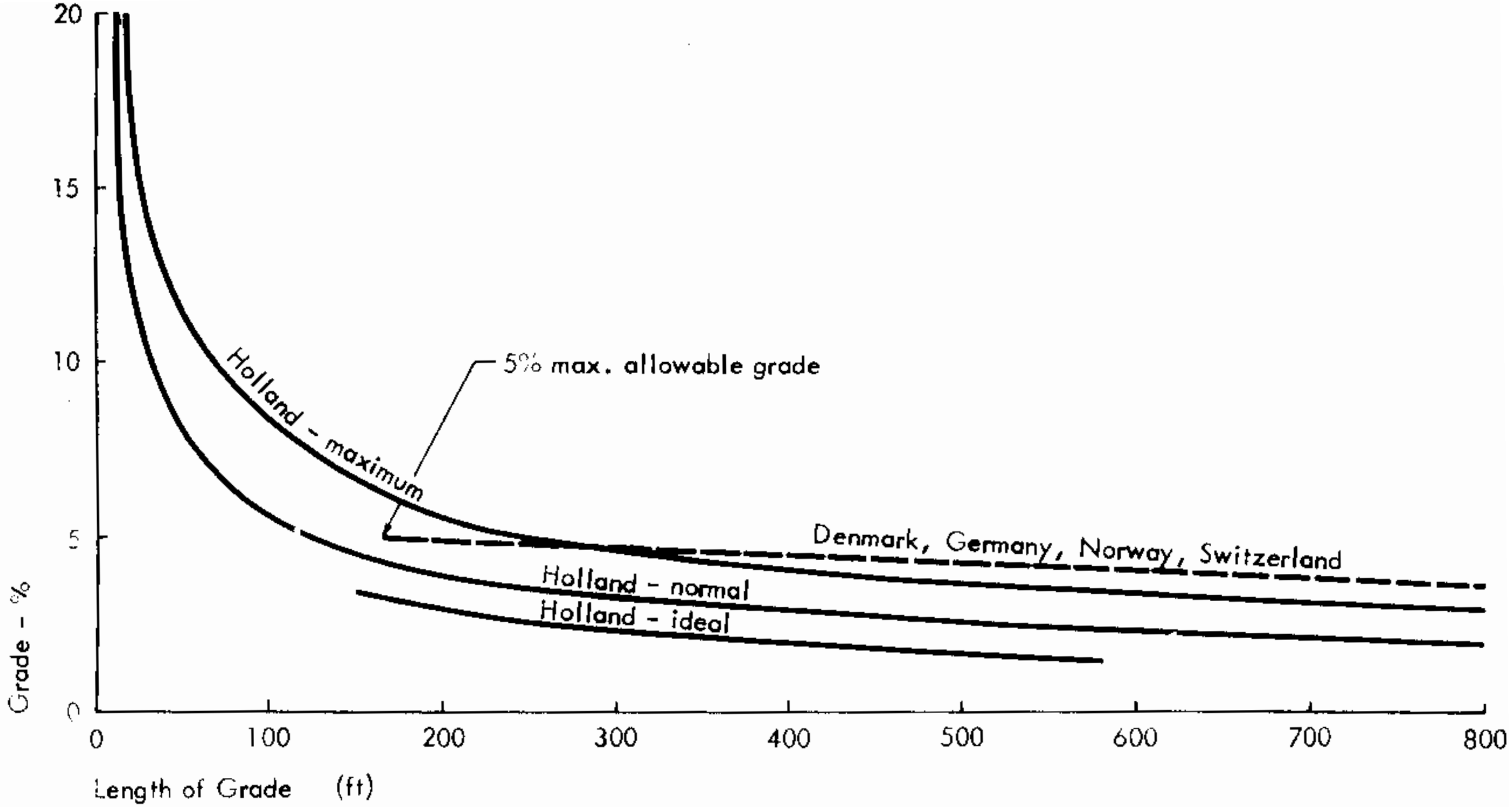


Figure 24: RELATIONSHIP OF GRADE TO ALLOWABLE LENGTH OF GRADE
European National Standards

on tires inflated to pressures on the order of 80 pounds per square inch, which give a very stiff ride. Particular concerns are expansion and paving joints, patching and chuck holes, and use of existing concrete sidewalks where considerable upheaval has occurred. Loose gravel or crushed aggregate which could induce skidding should not be employed. Cyclists have criticized recent bikeway construction in some areas for employment of what they consider excessive pavement standards. Off-the-road bikeways must be designed to support light maintenance vehicles. [illegible] 000 pound pickup truck making infrequent trips is an acceptable [illegible] design loading criteria. Specific details of pavement structural design are provided in [illegible] Guide for Bicycle [illegible] prepared by [illegible] of State Highway and Transportation Officials.

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Chapter IV

INTERSECTIONS

One of the key problems in dealing with the bicycle on or along street corridors is at intersections. Of the bicycle-motor vehicle accidents which are reported, a heavy share took place at intersections, although the percentage split between intersections and miblock varies substantially from one local jurisdiction to another (reported intersection share ranges from lows at 40 to 50 percent levels to highs of over 70 percent). While this might not seem particularly striking when one considers that intersections normally account for a similarly heavy share of motor vehicle accidents, the intense level of co-mingling and conflict between bicycles and motor vehicles at intersections, the varied and unorthodox patterns by which cyclists execute turning movements and cyclist obedience patterns to traffic controls dictate a focus on intersection performance. Following are some elements of bikeway intersection cesign, identified problem areas and possible countermeasures.

BIKE LEFT-TURN PROBLEMS:

Figure 25 depicts typical bike left-turning paths at intersections and conflict points with auto traffic. Path "a" is one in which the cyclist establishes position in the lane nearest the centerline (or turning pocket, if provided) and executes a turn similar to a typical motor vehicle left-turn. In executing such a maneuver the cyclist suffers no more delay at the intersection than a motor vehicle making a left-turn. However, weaving movements across traffic to enter and leave the turning position expose the cyclist. The tendency for cyclists to "double-up" with turning vehicles rather than fall in line also creates sideswipe exposure. And opposing vehicles tend to not see or fail to grant right-of-way to turning bicycles.

Path "b" indicates a turn pattern prescribed in several jurisdictions in which the cyclist enters the intersection in the right hand lane and, when unopposed by through motor vehicle traffic, executes a left-turn into the right lane of the cross street. This pattern exposes the cyclist to conflicts with right turning and through vehicles on its own approach as well as conflicts with vehicles on the opposed approach. Since bicycles generally do not have rearview mirrors, selecting an adequate gap in the "same approach" through vehicles is a problem. And because this pattern implicitly treats the bicycle as a lower priority user of street space which must yield to motor vehicles when adequate gaps are not available, cyclists must often wait for an extra signal phase at point "e" in order to proceed with cross street traffic. For this reason, even in areas where pattern "b" is prescribed by local ordinance, many cyclists elect to follow patterns "a" or "d".

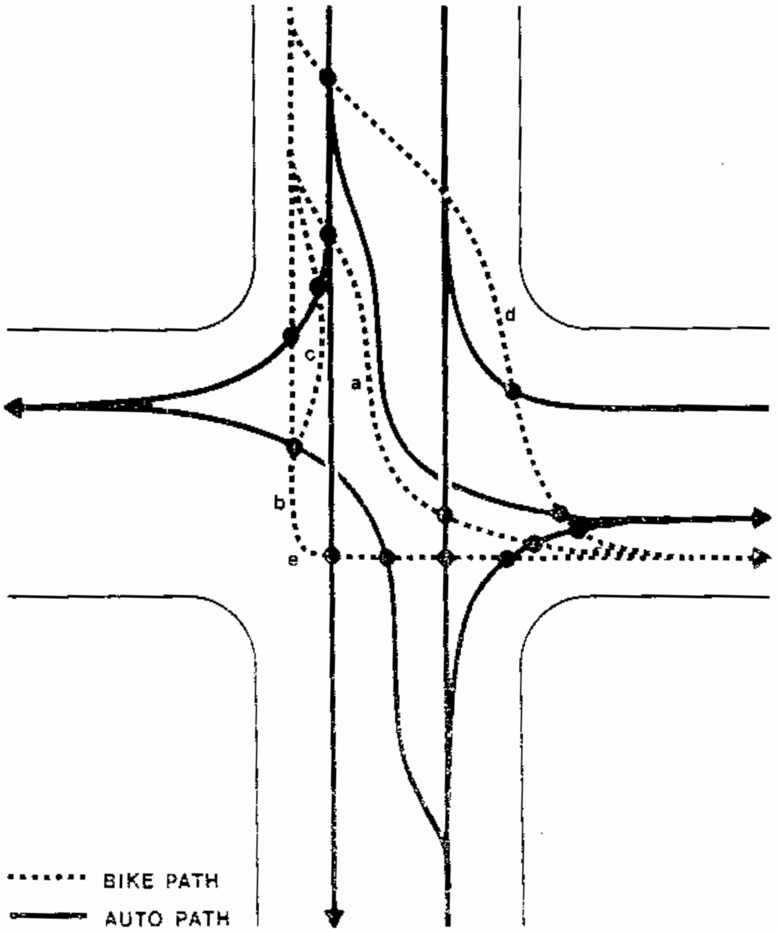


Figure 25: TYPICAL BICYCLE LEFT-TURN PATHS AND CONFLICTS WITH AUTOS

Path "c" is a modification of path "b" in which cyclists attempt to weave to the left of right-turning motor vehicles. It also approximates the path of cyclists attempting to execute turn "a" who are blocked by through traffic. Path "d" might be described as "turns of opportunity." On approaching the intersection the cyclist darts across his approach street at the first acceptable gap and proceeds "wrong-way" to the intersection. There he may cross directly to the proper side of the cross street or proceed "wrong-way" on it until an acceptable crossing opportunity presents itself. The attractive feature and basic motivation for this turn pattern is maintenance of momentum along the desired line of travel -- it enables the cyclist to avoid stopping at any intersection traffic control device or yielding to traffic. But due to the inherent hazards of an unpredictable movement such as this together with the possibility of a blind, head-on collision with a right-turning vehicle from the cross street, this left-turn mode should be strongly discouraged- A basic problem with all of these left-turn movements is the unpredictability with which a cyclist may execute any of them. Very few cyclists signal for left-turns and the act of signaling while maneuvering a cycle may itself be a problem.

CONFLICTS WITH RIGHT-TURNING MOTOR VEHICLES:

Cyclists riding to the right side of the roadway either straight through an intersection or executing a left-turn of type "b" above conflict with right-turning motor vehicles approaching the intersection in the same direction. Accident experience in this situation appears to result from:

- Poor visibility to the right rear of a motor vehicle coupled with limited target visibility of the cyclist.
- Lack of expectation on the part of a motor vehicle operator in the right hand travel lane for a "through" vehicle on his right.
- Poor driver perception of cyclist speed.
- Preoccupation of the motor vehicle operator with cross street traffic, particularly that coming from his left, or with pedestrian traffic in the crosswalk area.
- General expectation on the part of the motor vehicle operator that the cyclist will yield to a "superior" vehicle coupled possibly with cyclist insistence on through right of way.
- Failure to signal properly for the right-turn.

Mandatory right-turn lanes pose a particular problem, placing the bicyclist in a very anomalous situation. If a bicyclist intending to travel straight through the intersection keeps to the right (as is prescribed in most vehicle codes), either occupying the designated turning lane or hugging the curb line, he violates the lane mandate and travels contrary to the expectation of motorists observing him in the lane. If the cyclist moves left into the motor vehicle through lane, he violates the general mandate to keep to the right side of the road and, where bike lanes are provided, the more specific mandate to travel in the bike lane. The situation is compounded when an optional right-turn lane is provided in addition to a mandatory right-turn lane. A particular problem in this condition is motor vehicle operator and bicyclist recognition of each other's intent.

COUNTERMEASURES

Several forms of response to these turning problems have been proposed and/or employed. A number of jurisdictions have adopted the practice of terminating the bike lane demarcation some distance from the intersection. The contention is that this encourages establishment of better positional relationships of through and turning bicycles and cars on the approach and eliminates the cyclists' blind expectation of protected status in the bike lane (a problem because motorists don't always respect the lane at intersections). Unfortunately, what this effectively does is leave bicyclists to fend for themselves in mixed traffic at a point of most intense activity. An alternative is marking the last 100 feet of bike lane approach to the intersection with a dashed rather than solid stripe, inferring that through and left turning bicycles may move out of the lane to establish better positional relationships with motor vehicles and alerting cyclists that the lane is not a positive protection from right turning motor vehicles.

A common European design, shown on Figure 26, has the same basic intent as lane termination or dashed striping -- establishment of better positional relationships of turning and through bikes and motor vehicles. But unlike the passive inducement to approach positional weaving inherent in lane termination or dashed striping, the European design provides positive definition by providing designated bike lane space for each of the turning and through cyclist movements positioned alongside motor vehicle lanes reserved for the same purposes respectively. This legitimizes and provides an established pattern for the through and left-turn maneuvers many cyclists find preferable. Such a design shifts auto-bike interaction away from the area of intense activity at the intersection to its approaches. In theory, weaving movements on the approaches can be executed more safely than crossing movements at the intersection. However, because of the poor rearview characteristics of bicycles (cyclists must turn to look over their shoulders or beneath their arms) the safety of weaving movements might be questioned. It is also questionable whether young cyclists are sufficiently skilled and judgementally experienced to safely execute the movements required by such a design.

A designated bicycle left-turn lane similar to the concept indicated on Figure 26 is now being installed at an arterial intersection in Davis, California. Experience with this facility together with that on the Seattle demonstration system in which through-bike and turning motor vehicle lane positioning reflects this design will provide data on the effectiveness and applicability of this type treatment under U.S. traffic conditions.

A second European concept, illustrated on Figure 27, involves offsetting the bikeway crossings from the intersection, effectively placing a bikeway loop around the intersection. The offset crossings improve the angle of incidence between through bicycles and right-turning motor vehicles, placing conflicting motor vehicle traffic in the cyclists' forward field of vision. The design also moves the conflict area to a point at

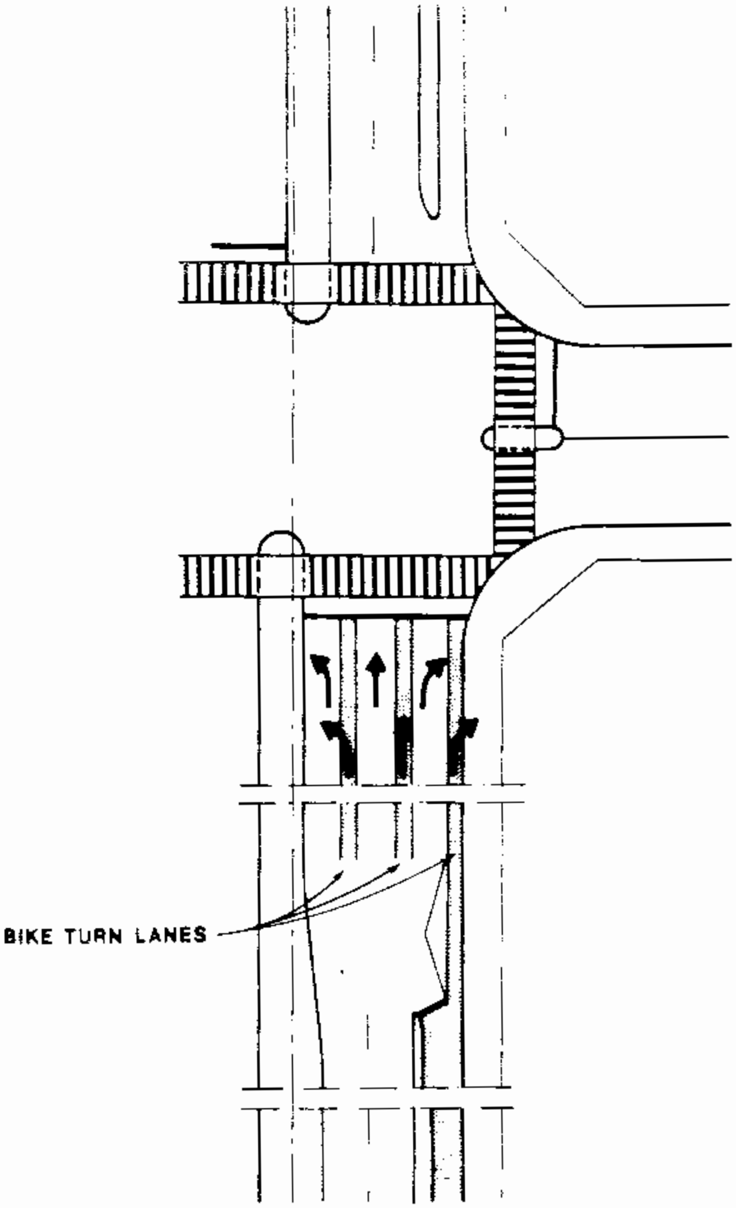


Figure 26: DESIGNATED DIRECTIONAL BIKE LANES

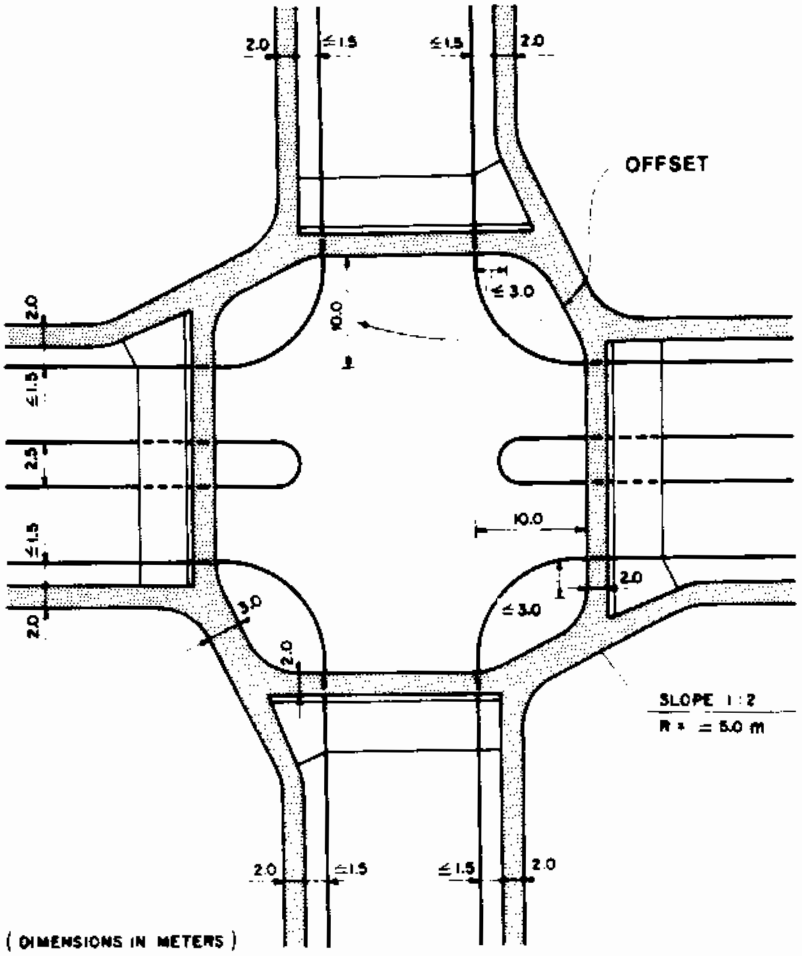


Figure 27: OFFSET PATHWAY CROSSING

which the turning motorist is no longer preoccupied with cross traffic from his left. Bicycle queuing space in the sidewalk area eliminates conflict between queued bicycles and motor vehicles making right-turns on red (in states where this practice is permitted). A modification of the concept conforming to more restricted right-of-way conditions and on-street lane approaches is shown on Figure 28. Deficiencies of the offset design are potential conflicts with pedestrians, the lack of sufficient right-of-way for such facilities in most already developed areas, the inconvenience to left-turning cyclists who would have to wait through an extra signal phase and travel by a circuitous route, and the fact that motorists entering the offset crossing area after passing through the intersection are likely to be accelerating and less alert to crossings under the assumption

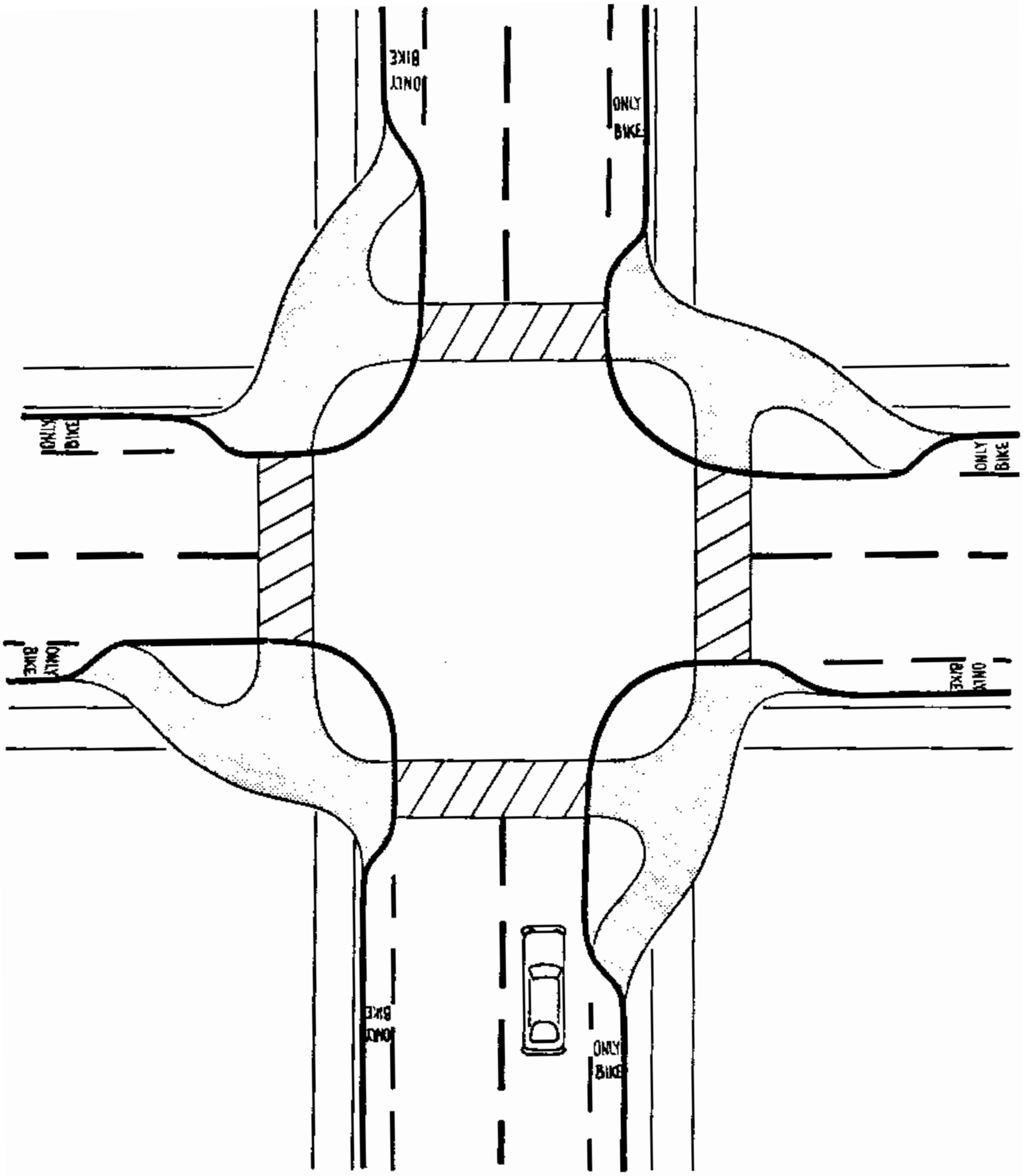


Figure 28: MODIFIED OFFSET PATHWAY CROSSING

that they are past the area of intersection activity. But the most serious drawback of this design lies in the fact that it inherently treats bicycles as pedestrians rather than vehicles. And experience to date in this country has shown a signal lack of success with facilities which treat the bicyclist more or less as a pedestrian.

Another possible solution at signalized intersections would be employment of a "scramble" phase -- a phase in which motor vehicle traffic on all approaches would be stopped while bicycle and pedestrian movements including left-turns and diagonal crossings would proceed. Two drawbacks to this are apparent: At intersections of multi-lane streets, time allowance requirements for diagonal crossings by pedestrians would be substantial and significantly reduce intersection capacity. And most cyclists, while they would use the "scramble" phase when convenient, would not wait for it but proceed with motor vehicle traffic on their respective approaches.

ISOLATED (MID-BLOCK) CROSSINGS:

There is some evidence of high accident experience at isolated intersections of independent pathways (Class I facilities) with motor vehicle roadways. This appears to stem from four factors:

- Failure to establish proper sight clearance zones as defined in Figure 21,
- Poor perception of or reaction to crossing signs and markings,
- Motorist expectation of entries to the crossing at pedestrian speeds rather than at typical bike travel speeds,
- Cyclist disobedience of STOP or YIELD controls.

Beyond provision of proper sight clearance zones at isolated crossings and prominent placement of crossing warning signs and markings, several counter-measures offer some possibility. One would be to place STOP or YIELD controls on the motor vehicle roadway rather than or as well as on the bikeway. Since motor vehicle drivers tend to respect such controls more than cyclists, this proposal might have some merit at locations where traffic volumes are low and roughly equal to bicycle crossing volumes.

A second possibility involves the use of berms or unbroken curb to force the cyclist to stop. Unfortunately, this can cause bent wheel rims or spill a cyclist who fails to stop. Placement of posts or bollards at the edge and in the center of the bikeway, by constraining operating space, causes the cyclist to slow down. This also discourages motor vehicles from entering the bike path. But cyclists preoccupied with squeezing between the bollards may become less conscious of the traffic conditions in the crossing and the possibility of collision with the bollards is of itself a problem.

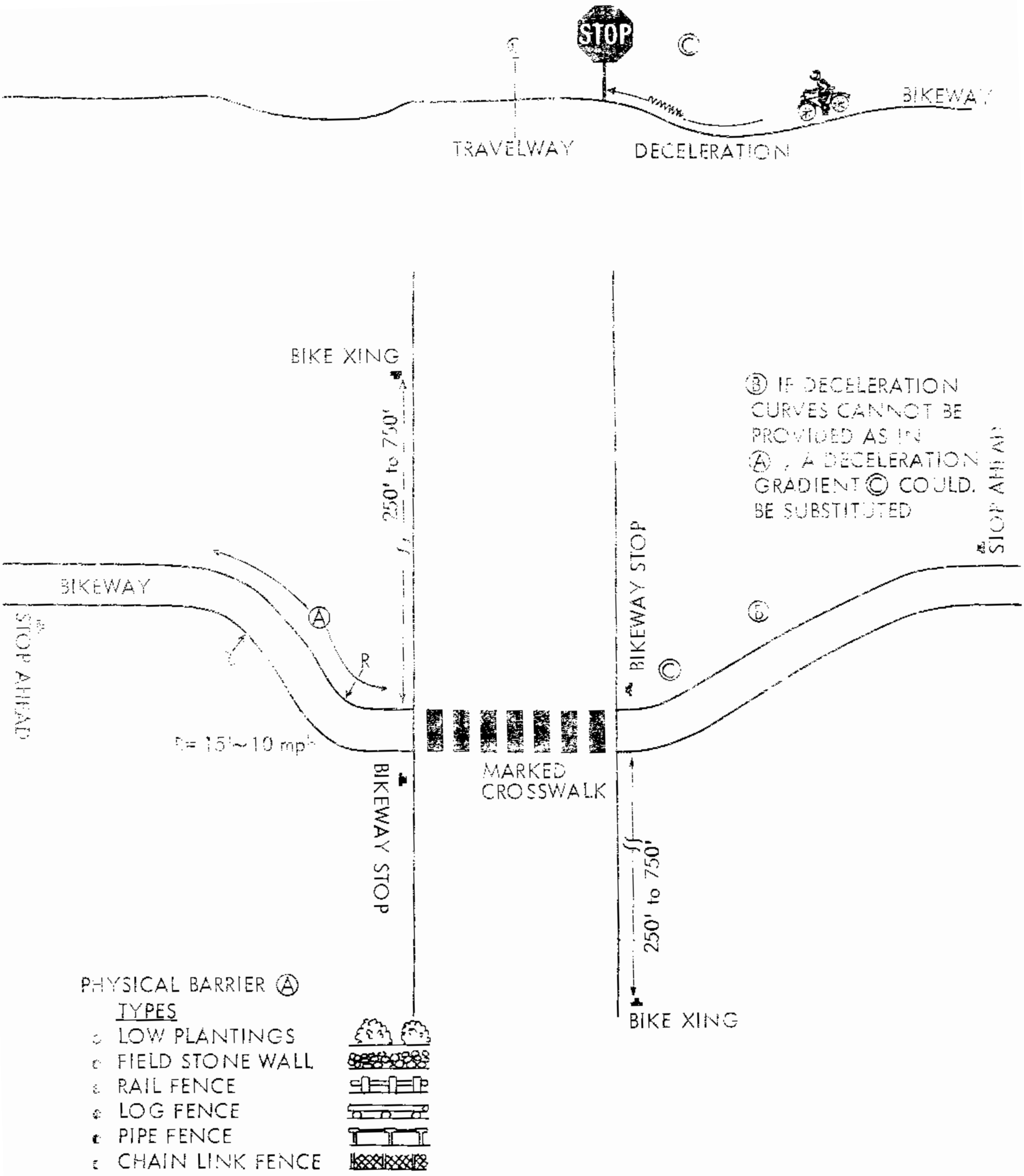


Figure 29: ISOLATED CROSSINGS

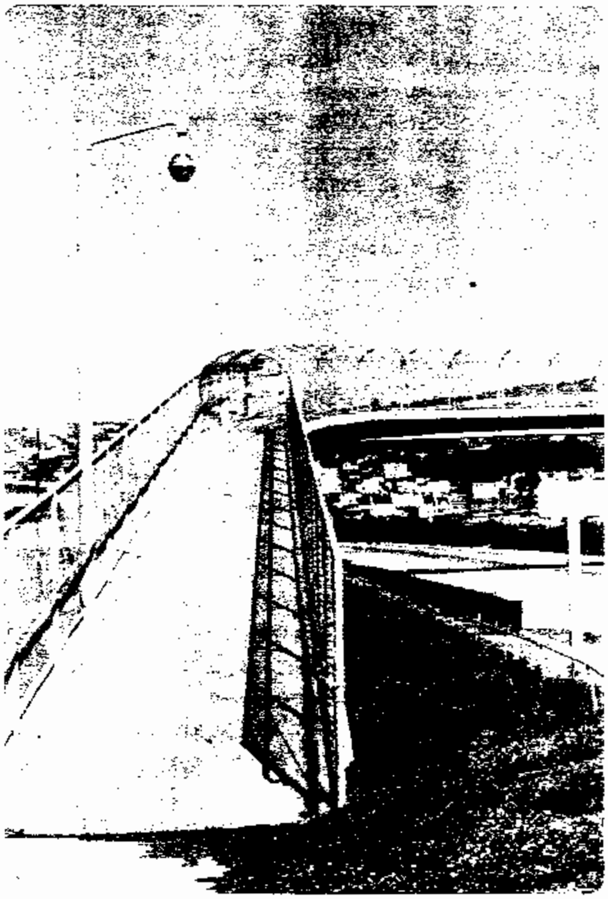
Another possibility is the use of a curve on the bikeway approach (as shown on Figure 29) to slow the cyclist. In some cases, cyclone fence or bollard baffling is used to confine cyclists to the curve and prevent short-cutting across country.

Safety is most positively ensured by grade separating the bikeway crossing. However, because of the substantial cost involved, structures are normally employed only at extremely busy crossings, at crossings of high speed roadways, or when new development allows grade separations to be planned and economically implemented with initial construction.

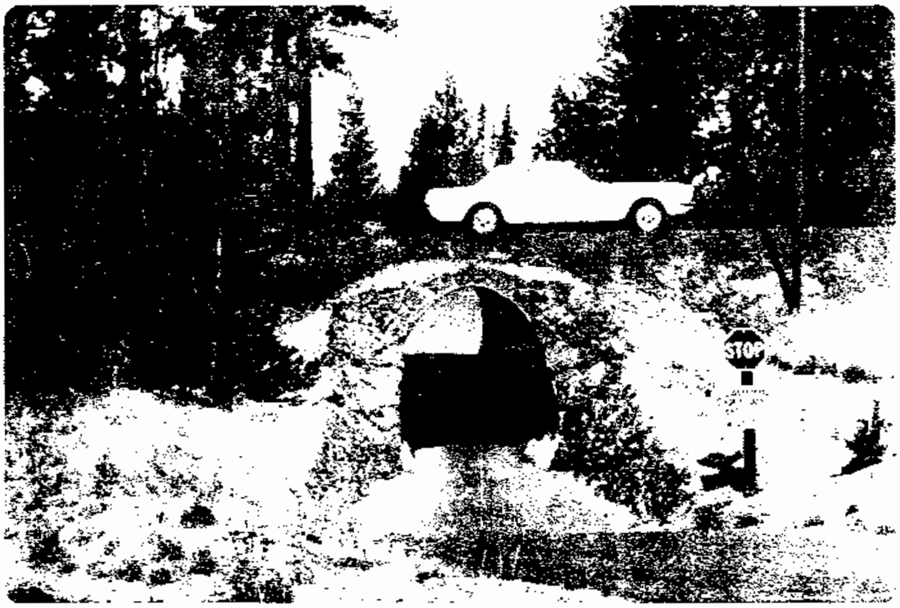
GRADE SEPARATIONS

Grade separations are the most positive means of resolving intersection or crossing conflicts, but opportunities to employ them are limited by cost and the constraints of existing development. Separations are essential where physical and psychological barriers such as freeways, expressways, major surface highways and rail lines isolate portions of a community or disrupt the continuity of a bikeway system. When employed at points where independent pathways cross roadways, they not only improve safety but enhance the auto free character of the facility. At intersections where heavy flows of motor vehicles and bicycles (and pedestrians) cannot be jointly accommodated, grade separations also appear justifiable. However, bikeway grade separation warrants have not as yet been quantified and, for the most part, separations constructed to date have been justified not on traffic operational and safety criteria, but on issues of route continuity or sub-area connectivity across obvious physical or psychological barriers or for specific facility service. If a bikeway grade separation is to be used by cyclists (and pedestrians), perceived safety (and possibly travel time) advantages must outweigh any disadvantages in use of the structure as compared to continuing to cross at grade. To minimize inconveniences, overpass designs which force cyclists to ride up overly long and steep grades (see Figure 24), up stairs where they must carry their bikes, up sharply curving ramps which force cyclists to walk their bikes or any structure which takes cyclists significantly out of their way should be avoided.

Where a grade separation is to be employed, the choice of overpass or underpass is largely dictated by local conditions such as topography and existing roadway geometrics, soil conditions and ground water, utility locations, right-of-way and adjacent development constraints. But where there is opportunity for choice, the underpass is normally preferable for cyclists, concerns for light and security in enclosed structures notwithstanding. This is because bikeway vertical clearance requirements (8'4" minimum) are less than roadway vertical clearances (15 feet on modern local roads, 16.5 feet on interstate highways and freeways -- many states require an additional 2 foot clearance on light structures) hence less steep grades on the underpass. And since on the underpass the cyclist first builds momentum on the downgrade approach which then eases the



A major bikeway grade separation structure.



A simple bikeway grade separation of corrugated pipe. Note minimized adverse grade profile on bikeway made possible by elevation of roadway and use of underpass.

"climb-out" while on the overpass the cyclist must supply all grade climbing power himself, the overall effect of grade is far less on underpasses. Ideally the bikeway would remain at-grade with the roadway either depressed or elevated. Where the bikeway is depressed beneath the roadway the approach grades should be carefully designed so that bicyclists do not achieve high speeds at which instability is incipient in the confined area of the underpass. Costs of bikeway grade separations vary substantially with site specifics such as span, materials and construction methods. Typically, reinforced concrete bike-pedestrian overpasses spanning 4-lane divided roadways constructed of corrugated pipe in open cut might cost on the order of $40,000.

One particularly effective way of cutting costs is through use of existing structures. Although this may at times force compromises from the ideal design, such opportunities can be taken to meet basic needs and maximize the extent of the bikeway system which can be provided with generally limited bikeway funds.

Design of effective bikeway grade separations at street intersections is a difficult chore. Unless service of a single specific bicycle movement is the target, provision for completely grade separated bicycle movements at the intersection site involves an elaborate structure. Figure 30 illustrates one such structure. Where facilities of this extent are deemed necessary, consideration might be given to grade separating the motor vehicle roadways as well. Even where the intent is to grade separate only one bike movement pattern, since the structure will be used bi-directionally, cyclists in one direction will be forced to enter and exit the structure from the "wrong" (against traffic) side of the street. This can create

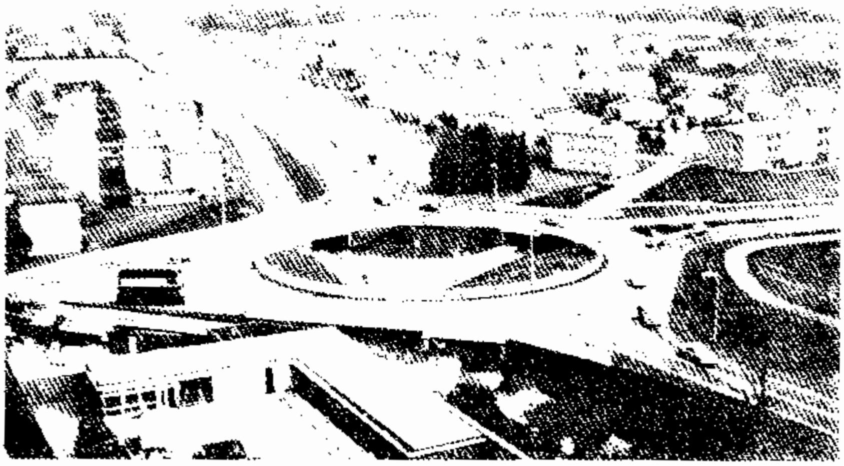


Figure 30: BICYCLE - MOTOR VEHICLE GRADE SEPARATION AT INTERSECTION (Stevenage, England)

[illegible] opportunities to utilize [illegible] such as this does save [illegible] traffic

...such as the risk of washouts...

...or acceptance of poor sight relationships and horizontal clearance obstructions.

need for additional street crossings by cyclists or lead cyclists in the "unfavorable" direction to avoid use of the separation. And to prevent cyclists from continuing to cross the intersection at grade, the bikeway approaches must positively channel cyclists onto the structure. Where possible to achieve the same service objectives by location of the bikeway (and grade separation) away from the critical intersection, this would appear to be more desirable than provision of a bikeway grade separation in the immediate vicinity of the intersection.

Proper design of bikeway grade separations is heavily dependent on design responsiveness to specific site conditions and opportunities. Hence, the suggestions and caveats presented here should be regarded as such and any design should be the product of a specific site study.

SIDEWALK BIKEWAY INTERSECTION INTERFACE

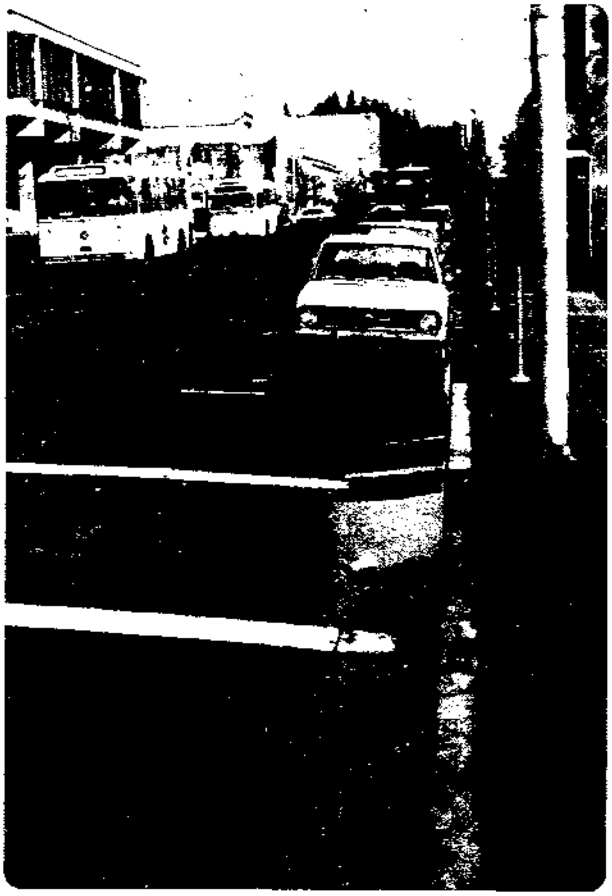
Curb ramping is normally provided at intersections along sidewalk bikeways. Minimum recommended width of curb ramps is four feet (to provide basic operating space for standard bicycles and permit passage of adult tricycles, wheelchairs and baby carriages). Maximum recommended ramp slope is 12:1.

Problems associated with sidewalk bikeways at intersections relate largely to motorist expectation of entries to the crosswalk area at pedestrian rather than typical bicycle travel speeds. This problem is accentuated by the fact that motorist-cyclist visual relationships are often screened by trees and shrubbery, parked vehicles and roadside signs. Where sidewalk facilities are used bi-directionally, motorists' inherent preoccupation with traffic from the left and expectation of "right hand rule" operations is an additional accident causal factor. Many jurisdictions have attempted to reduce the accident hazard posed by cyclists rapidly emerging in the crosswalk area by maintaining unbroken curbs rather than by providing curb ramps at intersections. But rather than forcing the cyclist to stop, dismount or cautiously bump over and enter the crossing at more or less the equivalent of pedestrian speed, the decision to not provide curb ramps usually results in the cyclist entering the street at the nearest driveway prior to the intersection or not using the sidewalk facility at all.

UNSIGNALIZED INTERSECTIONS

At intersections which are uncontrolled or controlled by YIELD or STOP signs, motorists frequently fail to properly grant right-of-way to cyclists. This is usually due to either reluctance to wait the longer time (as compared to a motor vehicle) it takes the cyclist to clear the crossing, improper assumption that the cyclist will automatically grant right-of-way

. . .a good sidewalk bikeway curb ramp. . .



. . .and a poor one.

to a motor vehicle, or the judgement that the motor vehicle can clear the conflict point before the cyclist arrives. Striping the bikeway through non-signalized intersections may make drivers of crossing or turning vehicles more conscious of cyclist presence and alert the drivers to right of way situations. Such delineation through the intersection might employ the standard lane line used to define the bikeway at midblock. However, special zebra stripe treatments such as shown on Figure 31 give extra emphasis. Cyclists' natural reluctance to lose momentum may lead to acceptance of marginal gaps in crossing traffic as well as violation of STOP and YIELD controls. This is a problem of education and enforcement rather than one of design. However, the bikeway planner should be conscious of typical cyclist behavior at these control devices.

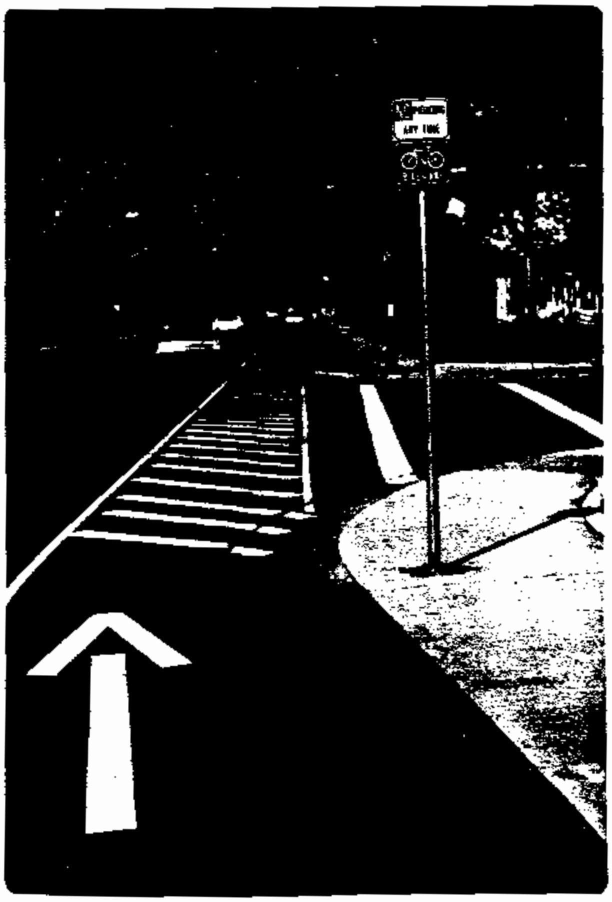


Figure 31: BIKEWAY MARKED THRU INTERSECTION WITH DIAGONAL LINES FOR ADDED VISIBILITY AND EMPHASIS (Cupertino, California)

OFFSET INTERSECTIONS

At skewed or offset intersections it may also be useful to delineate the bikelane through the intersection area. Cyclists naturally tend to follow a diagonal path across the jog which brings them into conflict with motor vehicle traffic executing the same move. "Cat track" delineation of the proper cyclist path through the intersection would help alleviate the problem.

However, the inherent confusion of motor vehicle maneuvers at such intersections is a continued problem. In particular, cyclists have difficulty distinguishing a right-turning car from through traffic in time to avoid conflicts. Generally, if acceptable alternate routes are available, it would be advisable to locate bike lanes so as to avoid passage through jogged intersections.

SIGNALIZED INTERSECTIONS

At signalized intersections where cyclists must cross multi-lane roadways, the amber signal phase, which is normally timed to provide an interval for motor vehicle clearance of the intersection, may not provide sufficient clearance interval for slower moving bicycles. Thus a cyclist who legally entered the intersection on a green phase may be left in the intersection when cross traffic gets the green. If cross traffic keys solely on the signal rather than checking for residual intersection occupancy, accidents may result. At signalized intersections on bike lane streets or where significant bike traffic occurs, amber phasing should be timed to allow a proper interval for bike clearance of the intersection. At heavily travelled intersections where extended amber phasing might create capacity problems, a possible solution might be a separate signal head for bikes with an advanced amber setting.

Another problem occurs where cyclists key on pedestrian crossing signals rather than on the motor vehicle traffic heads (typically at intersections with sidewalk bikeways). Cyclists know that because of their greater speed they can safety complete the crossing if they enter the intersection at the beginning of the pedestrian clearance (flashing WAIT or flashing DON'T WALK) interval and so they do continue to initiate crossing movements during this period. However, cyclists who don't know how much of the pedestrian clearance interval has elapsed (because they could not see the indicator or weren't paying attention) or misjudge it still attempt to make the crossing as well and are caught short. Separate crossing control indicators for bicycles appear appropriate at locations where this is a problem. The above problems illustrate the need for better procedures and treatments for evaluating and managing bike flows through signalized intersections. Currently, the cyclist is treated either as a pedestrian or as a motor vehicle yet operationally the cyclist differs significantly from both categories. The cases above point up the consequences of fail-

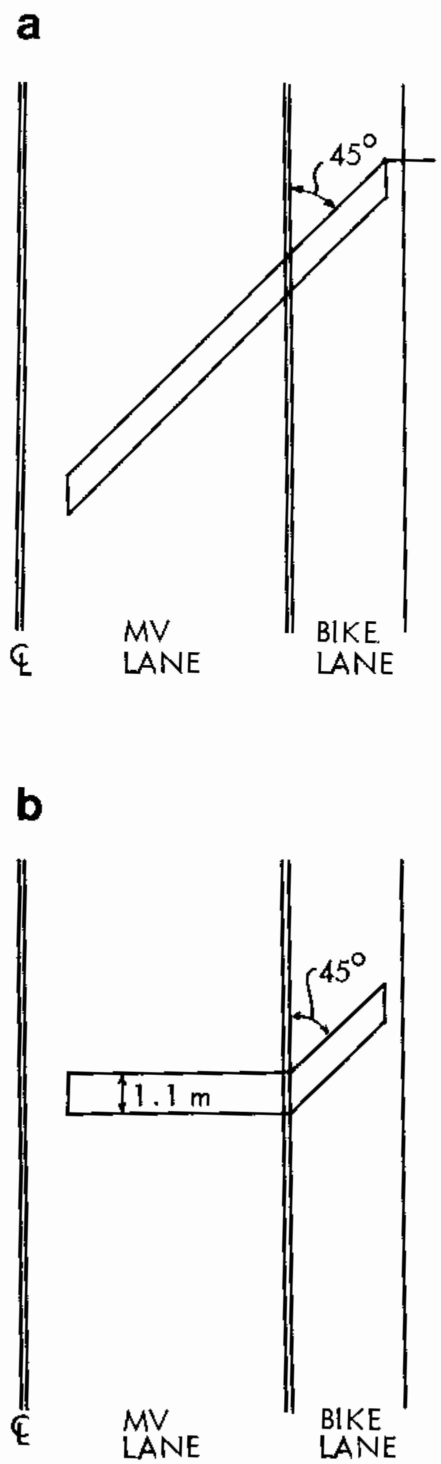


Figure 32: EUROPEAN INDUCTANCE LOOP PATTERN

ure to recognize and adjust for such differences. European cities, particularly in Germany and The Netherlands, have employed special signal provisions for cycles (separate signal heads and phasing) at busy intersections. The applicability of this technology to U.S. conditions as well as procedures for specific consideration of cycle movements in intersection operational evaluations and traffic signal design and phasing is now under study.

Another problem relating to traffic signals involves provisions to enable bicycles to actuate the signals. Magnetic induction loops have been successfully employed on bikeways for bike traffic counting purposes and some detection equipment manufacturers are marketing detectors said to be sufficiently sensitive to detect bicycles for signal actuation. A loop pattern in which the loop is laid at an angle of 45° across the roadway as illustrated in Figure 32a increases the sensitivity of the detector to detect bicycles and is patented in several European countries. An arrangement as shown in Figure 32b will detect the bicycle in the bike lane but only motor vehicles in the other traffic lane. Such a pattern would give cyclists extra incentive to stay in the bike lane.

Despite this apparently available hardware and technology, signal installations in the U.S. specifically designed for magnetic inductance actuation by bicycles have not been reported. (At this writing the County of Sacramento, California, is engaged in design of a signal capable of magnetic inductance actuation by bicycles.)

Several jurisdictions have facilitated cyclist actuation of traffic signals by mounting a standard pedestrian actuation button on a post at curbside within easy reach of cyclists. A possible improvement to this (where the bike lane is at curbside) would involve locating the curbside ped button about 50 or 60 feet in advance of the intersection and enlarging the button. This would enable a cyclist travelling at slow speed to actuate it on the fly and possibly have the green "called" to his approach by the time he reached the intersection, allowing the cyclist to maintain momentum. Even if the signal phase change is not completed by the time the cyclist reaches the stop line, the advance actuation minimizes overall waiting time involved.

ENCROACHMENTS AT INTERSECTIONS

Right-turning motor vehicles frequently encroach upon bike lane space on intersections approaches. In some jurisdictions this is a permitted practice while in others it is considered a violation. Opinion as to whether motorists should be able to make right-turn approaches through the bike lane area is mixed and conclusive data is lacking. The argument that a better interaction occurs when motorists gradually weave into the bike lane area on the intersection approach rather than when motorists execute a sharp right-turn across the lane at the intersection appears to have merit from an operations standpoint. However, legitimized encroachment

Typical motor vehicle encroachment on bike lane at intersection

Same intersection as above with protective berm in place.

Same intersection. Berm flattened by repeated vehicle encroachment defeats the purpose of designated space and reinforces motorists' typical disregard for cyclists' right to street space, whereas forcing the right-turning motorist to stay out of the bike lane until reaching the intersection emphasizes motorists' obligations to be aware of cyclists' presence and respect their right to street space. And if motorists are permitted to encroach on bike lanes on intersection approaches, they are likely to lose respect for them at midblock as well.

The critical problem currently is the lack of uniformity in local traffic ordinances relating to the subject. Motorists do not know whether they can or cannot make a right-turn approach in the bike lane and cyclists, even where encroachment is prohibited, are subject to unexpected conflicts with motorists unfamiliar with the local practice. Where "encroachment" is permitted, it appears desirable to adopt treatments such as lane termination, dashed marking, or designated through and turning approach lanes for bikes as discussed previously. Where encroachment is prohibited but turning traffic continues to enter the bike lane, deployment of raised traffic bars, berms or plastic pylons offers some deterrent.

Another common encroachment at intersections involves motor vehicles entering the bike lane area to maneuver around a stopped vehicle awaiting a left-turn opportunity. At 4-legged intersections this is usually not a problem as cyclists usually can and do tend to "belly-out" into the pedestrian cross-walk area to avoid just such encroachments. However, at T intersections (and at driveways), no such flexibility exists and encroachments can create serious conflict. Where this type of encroachment problem is identified, raised traffic bars can be deployed along the bike lane demarcation line to discourage intrusions.

FREEWAY RAMPS AND TURNING LANES

An important facet of intersection design is the treatment of bikeways at freeway ramps and "free" right-turn lanes. The bikeway should always be aligned to cross these turning roadways at right angles as indicated on Figure 33. Such an alignment places conflicting traffic in the cyclist's forward field of vision, minimizes the distance and time of cyclist exposure in the crossing and eliminates the situation of forced weave with high speed traffic.

Traffic channelization islands at major intersections can pose barriers and/or hazards to bicycle traffic. Unlike the pedestrian who readily steps up onto an island or median and is offered shelter from traffic by it, the cyclist will remain on the roadway surface and ride around the island.

Frequently, this forces the cyclist into maneuvers at conflict with desirable flow patterns. Ramps or breaks in islands and medians should be provided to channelize cyclist flow into desirable patterns and to enable them to use the islands as traffic shelter areas.

Figure 33: RIGHT ANGLE CROSSING OF INTERCHANGE RAMP. BETTER PAVEMENT MARKING OF CROSSING AREA AND BERMS TO POSITIVELY CHANNELIZE CYCLISTS INTO PROPER CROSSING ANGLE WOULD BE DESIRABLE

BI-DIRECTIONAL OPERATIONS AT INTERSECTIONS

Bi-directional facility operations appear to be particularly hazardous at intersections primarily because of motorists' ingrained anticipation that traffic will flow according to the "keep right" rule. The authors have observed operations at numerous intersections involving bi-directional bikeways and analyzed accident experience at them. Motorist preoccupation with opposing traffic crossing from the driver's left to right and almost total lack of expectation of "contra flow" bike traffic is readily evident and a clear causal factor in auto-bike accidents at these locations. This is most graphically illustrated in Figure 34, an accident diagram for an intersection in the Netherlands in which a bi-directional sidewalk bikeway crosses one of the legs. Of the 13 auto-bike accidents recorded, 12 involve bicycles travelling in the "against traffic" direction although actual directional use is about equal. Another problem with bi-directional facilities is the impaired or total lack of visibility of traffic control devices for bicycles travelling against traffic.

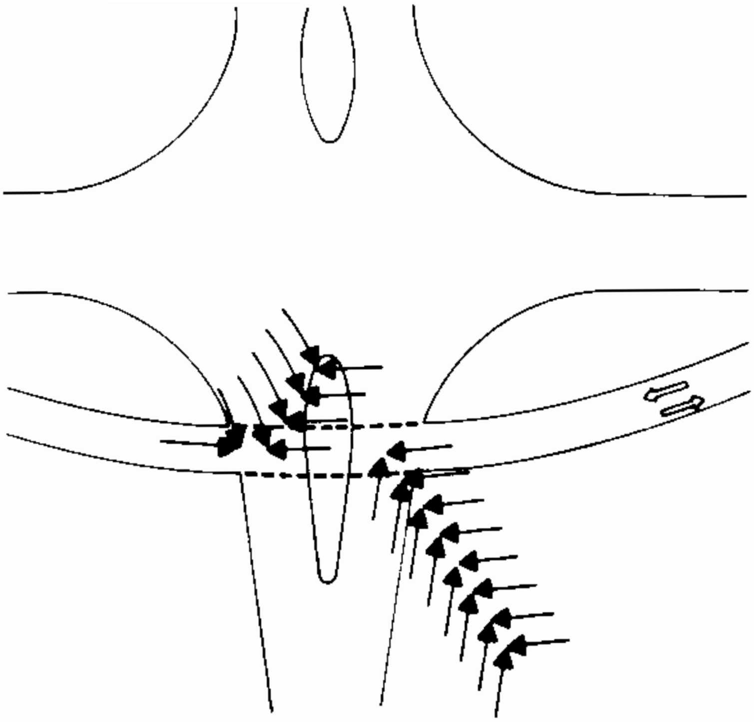


Figure 34: INTERSECTION ACCIDENT HISTORY

CONCLUSION

In summation of this discussion of bicycle-intersection phenomena, the following points merit reemphasis.

Among the causes of bicycle-motor vehicle conflicts at intersections, principal of those respondent to physical design appear to be breakdown in visibility relationships, incorrect perception of intent and behavior contrary to anticipated patterns. The latter two points are particularly important since the decision making demands on drivers (or bicyclists) are such that movements of certain other vehicles are not visually monitored (or only partially visually monitored) where non-conflicting intent is felt to be preperceived or non-conflict can be anticipated through established behavior patterns. However, such practices as bicycle left-turns and through movements from the right side of the road and contra-flow travel conflict with preperception and anticipated behavior. Positive treatments for bikeways at intersections would reinforce good visibility relationships (avoid sidewalk bikeways for instance), facilitate true pre-indication, hence preperception, of turning intent (as in the designated turning lane scheme shown in Figure 26); and reinforce anticipated behavior patterns (as in avoidance of design which mandates contra-flow travel or encourages wrong-way riding).

Chapter V

BIKEWAY GRAPHICS

The field of bikeway graphics (signs and markings) is another area in which variance in practice among state and local jurisdictions is most evident, yet this is an area in which uniformity and standardization is most essential. Bikeway signs and markings, like other street and highway graphics, should have unequivocal meaning and be understandable at a glance. This can only be achieved through uniformity. But due to the fact that most bikeway planning in the U.S. to date has taken place through individual local initiatives, a broad range of practices have evolved, a wide variety of symbols are in use across the country and these do not convey clear meaning to the cyclist or motorist unless each is familiar with the specific state or local ordinance relating to the symbol.

ROUTE SIGNING

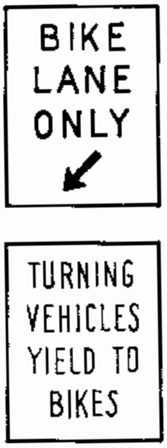
Standard BIKE ROUTE signing has been included in the Manual on Uniform Traffic Control Devices. This sign shown on Figure 35 displays a white message on green background and is now being widely employed. However, many local jurisdictions had developed unique signing before inclusion of this sign in the Uniform Manual and have continued to use them. Hopefully, these jurisdictions will convert to standard signing and jurisdictions contemplating new bikeway systems will not devise and employ unique bike route signs. A related and perhaps more confusing practice in some jurisdictions is variation in the shape or color of the route designation sign to denote specific characteristics of the facility operation -- the designation of the bikeway as a specific "school route," a parking ban in the lane during certain hours of the day or whether the lane is used with traffic or bi-directionally.

Such variances should be indicated by supplementary signs and markings or by attachment of supplementary plates. The basic bike route sign should not be altered. This is particularly important in areas with low profile bikeway systems where the most important aspect of the signing is to alert the motorist to the existence of bike traffic. The standard BIKE ROUTE sign where uniformly employed conveys the primary message that "there is a bikeway here." Details of operation are secondary.

Adequate signing should be deployed at all decision points along a bikeway. This includes both signs informing the cyclist of directional changes and confirmatory signs to ensure that route change has been correctly perceived. Such signing is particularly important on "single-strand" bikeways where the cyclist who misses a turn is not likely to

MOTOR VEHICLE DIRECTED AND WARNING SIGNS

Black on yellow Background
(Uniform Manual W 11-1)



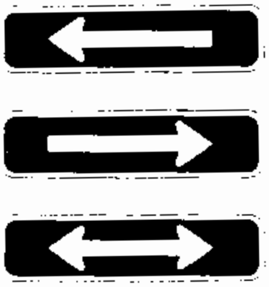
Black on white Background

BIKE ROUTE DESIGNATION SIGNS (White on green Background)

Standard Route Sign
(Uniform Manual D 11-1)

Message Plates

To be mounted above the official marker to designate the beginning and ending of the bike route, and to trailblaze to the bikeway.



Directional Plates

To be mounted below the official marker to guide cyclists along the bikeway and to trailblaze to the bikeway.

Figure 35: BIKEWAY SIGNING

CYCLIST DIRECTED WARNING SIGNS
(Black on yellow Background)

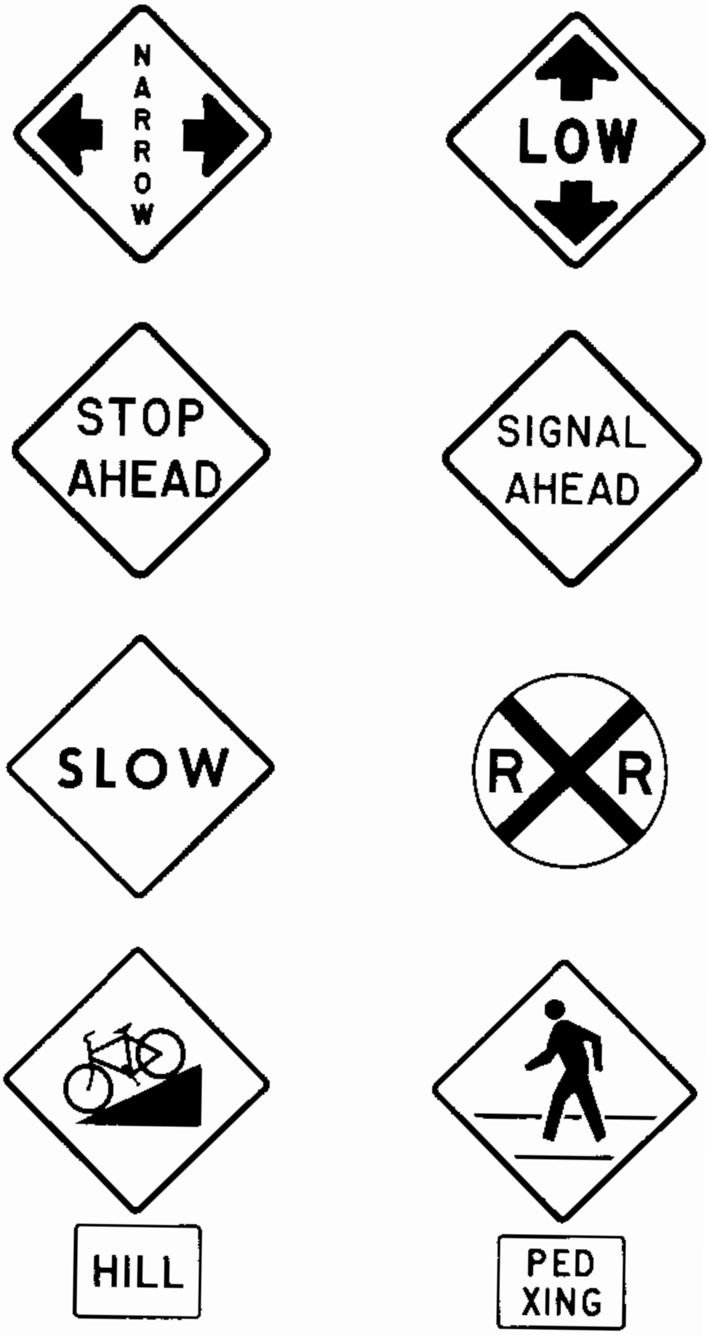


Figure 35: BIKEWAY SIGNING (Continued)

soon encounter another segment of the bikeway network on which to travel. Another area where signing continuity is essential is along segments of a bikeway system designed to lead cyclists around especially hazardous or impassable points on the roadway system.

Additional route signing should be provided at regular intervals to inform newcomers to the route (both cyclists and motor vehicle operators) of the presence of the facility and the likelihood of encountering cyclists. Such signing has the added value of confirming decision point signing for persons already on the route.

BIKE, PEDESTRIAN AND ROADWAY CROSSING SIGNS

Warning signs indicating to motorists that bicycles should be anticipated and to cyclists that motor vehicles or pedestrians may be encountered should be installed on the approaches to points of potential conflict and at high activity areas. Included are:

- Points where a bikeway crosses a roadway or sidewalk,
- At bikeway starts and terminations or transition areas involving potential conflict movements,
- At intense activity areas such as the vicinity of parks, schools, recreational facilities and community centers.

Motorist directed warning signs on urban streets should be placed at least a half block in advance of the conflict point, and in all circumstances such signing whether directed to motorists or cyclists should be placed sufficiently in advance of the conflict point to permit appropriate perception and reaction. Additional cyclist directed warning signs may be installed as required to warn cyclists of specific hazardous conditions. Most of these signs, displayed on Figure 35, are standard highway (Uniform Manual) warning signs or adaptations of them. Where the bikeway is located in a street or highway corridor, special cyclist warning signs should not be employed if duplicative of existing highway signs marking the same hazard.

A sign which deserves special mention is that shown on Figure 35 mandating that turning cars yield to bikes. When employed at intersections this device may ease intersection conflicts, particularly between right-turning motor vehicles and bicycles in an on-street lane or on sidewalk bikeway.

SIGN PLACEMENT

The <u>Manual on Uniform Traffic Control Devices</u>[36] prescribes that signs erected at roadside be mounted with lower edge of sign higher than a specified minimum above the edge of pavement elevation. Specified minimums include 5 feet on rural roadways, 7 feet in business, commercial and residential districts and 7 feet on expressways. These specifications reflect normal driver field of vision characteristics. However, because of bicyclist head inclination, bicyclist field of vision appears to be focused lower than typical motor vehicle operators'.

It therefore appears logical for signing along independent pathways to be mounted at slightly lower heights than those specified for motor vehicle roadways with about 4 and 5 feet difference in elevation between edge of pavement and sign bottom. Along motor vehicle roadways, consideration might also be given to lower sign placement where signs are specifically bicyclist directed (rather than for both motorist and bicyclist informational purposes). However, where lower sign heights are considered, sight conditions which might impair sign visibility (such as parked cars) must be taken into account. Bicyclist directed warning signs should be positioned in advance of the condition toward which they are directed so as to provide sufficient perception and response time. Appropriate distances may be estimated based upon the specific subject condition and the stopping distance profiles presented on Figure 19. Lateral placement of signs should be such that full horizontal shy distance, as illustrated on Figure 15, is maintained between the bikeway and nearest projection of the sign.

LANE DEMARCATION

Perhaps no facet of bikeway design has evoked more controversy than the demarcational striping of on-street (Class II) bike lanes. In most jurisdictions, bike lanes are delineated by unbroken white stripes. Jurisdictional practices with respect to stripe width vary, width ranging from 3 to 10 inches and many employ double stripe delineation. But many traffic engineers hold that such bike lane delineation striping is of little value as it does not convey a specific message to drivers that the bike lane area is not to be used as a travel lane by motor vehicle traffic.

The Uniform Manual on Traffic Control Devices specifies that white lines be used to delineate the separation of traffic flows in the same direction. Solid white lines are specified for delineation of the edge of a travel path where travel in the same direction is permitted on both sides of the line but crossing the line is discouraged and as a pavement edge marking. Thus the argument that the solid white line delineation does not inherently prohibit motor vehicle travel in the bike lane is technically correct. Principal concern is for cases where the bike lane together with an unutilized parking strip has the appearance of an additional motor vehicle travel lane. As a result of this argument, several jurisdictions have used distinctively colored paint in demarcating their on-street lanes. Unfortunately, many of the colors used have poor visibility characteristics in shadow, on wet pavement, or at night. Seattle has employed the "Strong Yellow-Green" shade which is a Uniform Manual approved color for conveying traffic control information but for which a specific use has not been assigned. There is considerable support for designation of this color for use solely on bikeway related pavement markings. However, the case for distinctive bikeway pavement marking coloration does not appear overwhelming since motorists generally perceive and respect bike lanes with white paint markings along with supplementary pavement markings and signs (intersection encroachments being the exception and these are resultant primarily from variations in local permitted practice or deliberate violation rather than failure to perceive the facility as a bike lane).

It is very important to maintain bikeway lane lines and other pavement markings in good condition. A faded bike lane delineation stripe looks quite similar to an old traffic lane marking which is no longer applicable and has been partially eradicated.

PAVEMENT MESSAGE MARKINGS

Pavement message markings should be deployed on all bike lane departures from intersections to ensure that turning vehicles do not stray unknowingly into the bikeway. Form or pavement message markings is another area of considerable variance in current jurisdictional practice and in which less than desirable practices have become common. The two most common problems seem to be unemphatic messages and markings insufficiently discernible to motor vehicle operators travelling at normal operating speeds.

Figure 36: TYPICAL "BIKE SYMBOL" PAVEMENT STENCIL

A typical bike lane pavement marking is shown on Figure 36. It conforms to the recommended practice of the Uniform Manual to emphasize symbolic rather than word messages. However, it is difficult to paint a bike symbol in the bike lane area of sufficient size to be discernible to auto drivers operating at normal speeds. Some communities have attempted to adjust for this by aligning the long axis of the bike symbol along the bike lane with results less than satisfactory.

Word messages such as BIKE LANE or BIKE ONLY, if painted in at least 5 foot letters, appears to be more effective in informing motorists of lane function. Use of BIKE ONLY rather than BIKE LANE is preferable as this conveys the message of lane exclusivity more emphatically. Several forms of bike lane markings in use are very unspecific or cryptic in message and, if visible to motorists, do not convey to motorists the concept of exclusivity of the lanes. Examples of these include the simple directional arrow and the block arrowhead with the word BIKE shown on Figures 37 and 38.

Figure 37: DIRECTIONAL ARROW USED AS BIKE LANE DESIGNATION MARKING. PROVIDES LITTLE INDICATION TO MOTORISTS OR CYCLISTS THAT THIS IS, IN FACT, A BIKE LANE

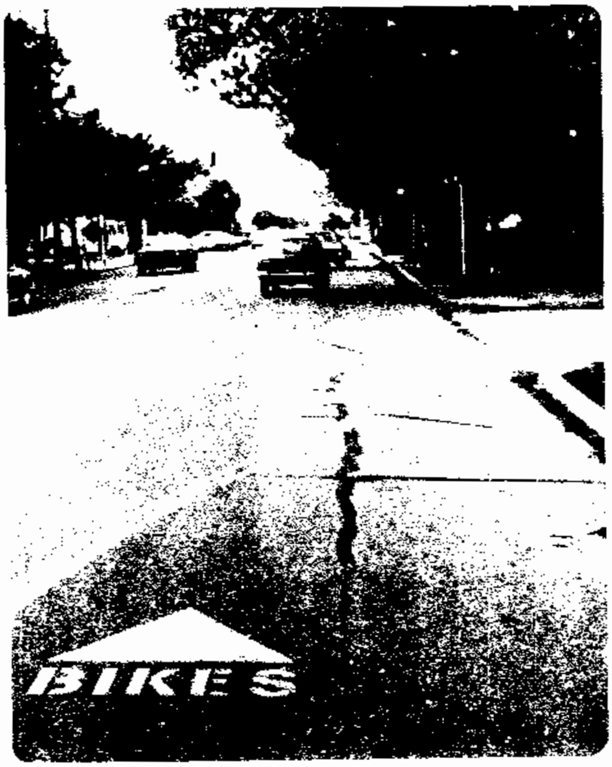


Figure 38: BLOCK ARROWHEAD MARKING (Palo Alto, California) WITH CRYPTIC "BIKE" MESSAGE. VISIBILITY POOR FOR MOTORISTS.

Pavement markings in the form of directional arrows should not be used in bike lanes at intersections to indicate that the bike route turns at that point. Such pavement arrows are likely to be interpreted by drivers as indicating a motor vehicle right-turn lane.

The symbolic bike stencil (lower right of photo) is indistinct from a driver's eye view.

Chapter VI

DESIGN PITFALLS

Outlined in this chapter are a number of miscellaneous general and specific problem elements associated with bikeways and practices to be avoided.

PLANNER'S PERSPECTIVE

Normally the engineer's or planner's design perspective is shaped by experience related to motor vehicles and to a lesser extent pedestrians. But the cyclist is very different from an auto driver or a pedestrian and bikeways should be designed with the perspective of the cyclist in mind. The implication of this is that the bikeway planner, if at all possible, should inspect prospective bikeway routes from a bicycle. Actually riding the route on a bicycle brings details important to the cyclist to the planner's immediate attention -- details which might be overlooked in a windshield tour and not even contained on a plan map.

The bikeway planner must be continuously conscious of cyclist typical behavior patterns, particularly the tendency to rationalize and trade-off safety for convenience and maintenance of momentum, the tendency to be less scrupulous in observing certain traffic ordinances and to avoid unnecessary grade climbing and out of direction travel. Cyclists will not meekly go wherever the planner might find it convenient to place bicycle facilities unless these facilities offer obvious advantages over travel in mixed traffic. Cyclists consider themselves legitimate roadway users and will reject facilities which provide inferior treatment.

TRANSITION AREAS

The termination of an on-street bike lane, a sidewalk facility or even an independent bike path at its intersection with a roadway, the change from a two-way street to one-way facilities on both sides of the street or the shift of a two-way path from one side of the street to the other are common examples of transition areas. Transition areas warrant special design attention due to the forced mixing of cyclists and motor vehicle traffic at these points and because elements of inconvenience in the transition may cause cyclists to ignore the special facilities provided for them. Figure 39 presents design treatments for several types of transitions. Shown on Figure 39 is an example of the termination of a one-way sidewalk pathway with continuation through a curb break to an on-street

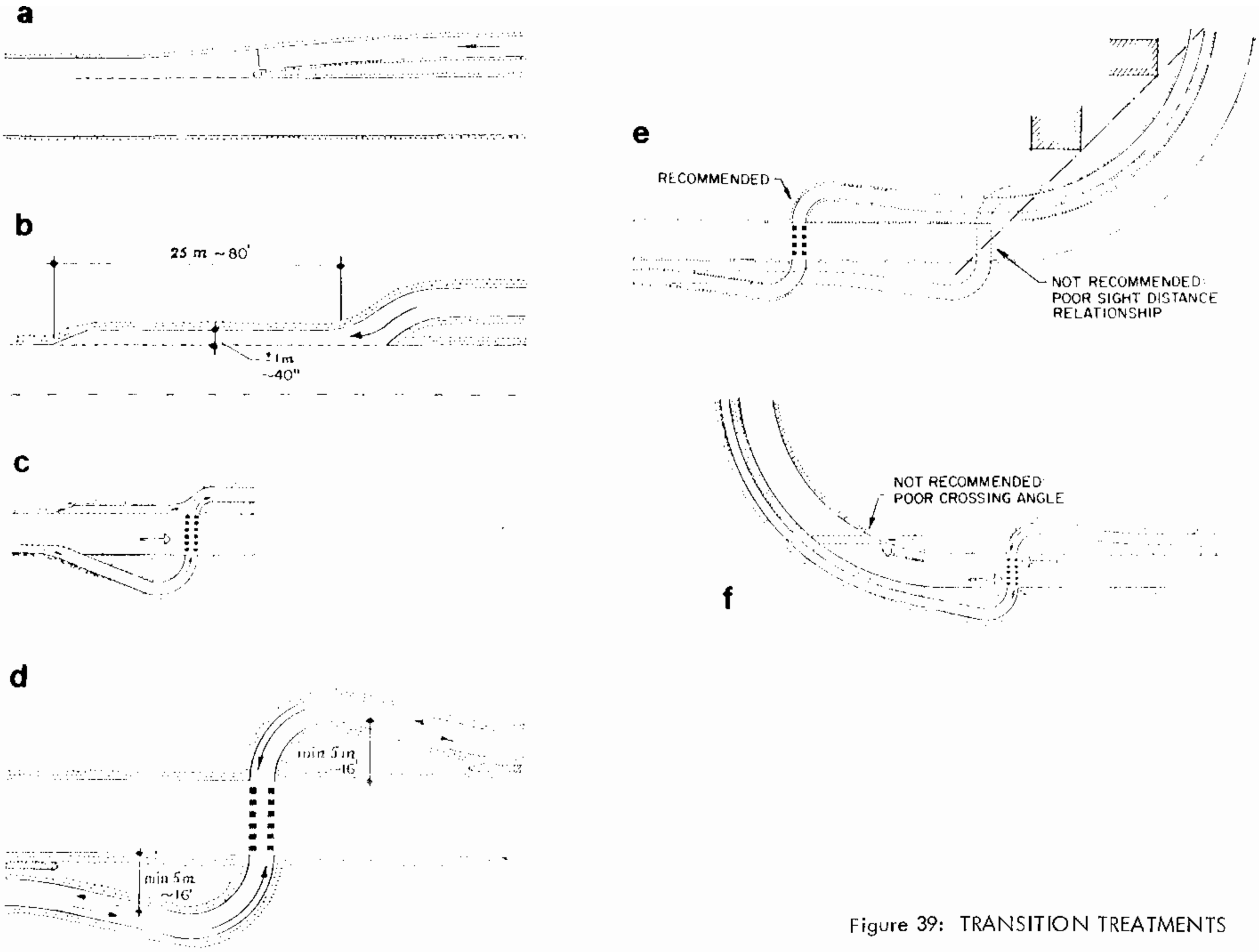


Figure 39: TRANSITION TREATMENTS

bike lane on a widened roadway pavement section. While the continuation to a widened roadway section is uncomplicated, at termination of a sidewalk path onto an unwidened roadway section, a more sophisticated treatment is desirable, as illustrated on Figure 39-b. It shows an 80 to 100 foot widened transition area to enable the cyclist to establish a visual relationship with and weave into the motor vehicle traffic stream. Figure 39-c illustrates the transition from on-street lanes or mixed traffic to a one-side, two-way sidewalk pathway. The "jughandle" treatment results in an improved angle of incidence between crossing bikes and motor vehicles and makes the cyclist's intention of crossing quite apparent to the motorist. Placement of traffic bars leading into the "jughandle" is desirable to lead the cyclist into the handle and eliminate short-cut, diagonal crossings. Figures 39-d, e, and f show two-way sidewalk pathways shifting from one side of the roadway to the other. The jughandle treatments to provide right angle crossings and forward field of vision sight relationships are illustrated on 39-d with improper and preferred treatments illustrated on 39-e and 39-f.

The most striking examples of poor current practices relate to terminations of on-street lanes or bi-directional sidewalk facilities. Many terminations are well marked (possibly due to liability considerations). But the critical factor is easing the cyclist's entry to the mixed traffic situation. While the treatment illustrated on Figure 39-b is an ideal design which may not be achievable in many cases, the designer should attempt to achieve a smooth transition rather than an abrupt termination. Where a bi-directional facility on one side of the street terminates, the design should incorporate a safe crossing so that cyclists will not simply be dumped into the street flowing "against" traffic.

CONTINUITY

A subject related to terminations and transitions is system continuity. Whether a bikeway system is an area wide network or a set of single-strand routes, the network or each route should have continuity and disruptive gaps, terminations and strained transitions should be eliminated or minimized. A common failing in the current practice of many jurisdictions is termination of designated bikeway facilities wherever an obstacle is encountered -- at a narrow section of roadway, a structure with little or no shoulder or pedestrian way, a freeway interchange area where severe conflicts at ramps are likely.

Such gaps and terminations are partly the result of a shortage of available funds and the high cost of providing bicycle facilities through constrained areas. But too often a "helter-skelter" bikeway planning process or on only superficial commitment to bikeways leads to their provision only where it is convenient -- where design is relatively straightforward, right-of-way ample and construction requirements minimal. In either case, the product is a series of disconnected system elements which may or may not be useful of themselves. And the gaps which the cyclist must cross to

An illustration of the problems of transitions and route continuily. The bike lane termination is well marked...

...the transition is indicated...

... and cyclist are directed to an unattractive sidewalk area.

get from one element of the system to another not only decrease system imageability; they leave the cyclists to fend for themselves in areas where greatest hazard exposure is likely. In such circumstances, a discontinuous bikeway in effect leads the cyclist into a trap.

No set distance over which a bikeway should have continuity can be specified. Each facility must be considered in relation to its specific functional role as a single-strand route and/or an area network element. Thus a bikeway extending only 3 or 4 blocks and providing accessibility between a school and a neighborhood area might have good continuity in relation to its function whereas a recreational route of several miles interrupted at two or three points due to physical constraints might be described as having poor continuity. It is not the intent here to imply that identification of a few points of constraint on what ought to be a continuous bikeway might be grounds for not providing what otherwise appears a promising or needed facility. Rather the emphasis is on the need for design of expedient yet functional facilities to serve until long term solutions can be funded and constructed, and the caveat to avoid leading cyclists to areas of compromise and simply abandoning them there.

LOCATIONAL ASPECTS

The discussion of continuity and transitions fringes on the subject of bikeway locational criteria, a topic not specifically the object of this bikeway report. However, the following points are relevant.

A bikeway system, be it comprised of single strand routes or an area network should have imageability. That is to say, the route(s) should be laid out in such a way as to give the cyclist a clear sense of where the system will take him. This is important for the recreational cyclist as well as for the utility rider. In addition to gaps, tortuous routings in which the facilities continuously shift from one street to another or from streets to independent corridors and back again impair the imageability of the system. In urban areas, efforts to achieve imageability result in location of bikeways on or along streets which have continuity through the community -- and streets having such continuity tend to be the arterial and collector streets. This works out particularly well for utility cyclists since they seem to place a premium on directness of travel and since the activity centers which are their principal destinations tend to be located so as to be best accessed from arterial or collector streets. Provision of facilities in the arterial and collector corridors also appears logical in the sense that this provides protection to cyclists at points where they are most exposed to traffic hazards.

The contrary argument advanced is that among the riders attracted to a bicycle facility are young and inexperienced cyclists who may not be competent to negotiate the more intense traffic of arterial and collector street corridors. Casual observation confirms that bikeway facilities attract youth and family riding, among other users, and where bike lanes are located along arterial streets, these streets are more likely to be used by families and children than if there were not bike facilities there.

But this reasoning is an outgrowth and a symptom of the psychology of scarcity which pervades current bikeway planning and use. If a community's bikeway system advances to the point where it provides good area-wide accessibility and a variety of facilities responding to differing skill levels, a given facility in a major street corridor would not have the great attractive effect and induce cyclists into areas where their riding competence is less than sufficient.

Parallel arguments have been advanced in relation to the question of whether to place bike facilities in central business districts. Moreover, some planners hold that bike facilities, particularly on-street lanes, are completely ineffective in central business districts because of the intense activity -- the sheer volume of traffic, high turning movements, high turnover parking interference, double parking in the lanes, pedestrian interference, access and egress traffic from parking garages and lots,

A downtown on-street lane (Chicago, Illinois).

buses intruding on the lanes to reach curbside load points, inevitable construction zones -- bike lanes are completely disfunctional and the cyclist is better off left to fend for himself. The Denver commute route system has been planned on this premise with the CBD feeder bike lanes terminated as they reach the edge of the central core. Other large cities have been deterred from implementing downtown bike lanes due to these same concerns. Unquestionably, all of the above factors do affect the performance quality and safety of the bike lanes in CBD areas. But the real question to be answered is, given that cyclists will commute to intense urban activity centers, would their safety and amenity be greater if designated lanes were provided or if they were left to their own devices. Definitive answers cannot be given at this time. As noted above, in many downtown cores, bike lanes have not been provided so that empirical evidence of their effectiveness or ineffectiveness in these areas is lacking and most planning opinion is based on conjecture.

Hazardous parallel bar grate.

BUS ROUTES

Buses in local transit operations and bicycles tend to move at about the same overall average speed along urban streets -- 10 to 12 miles per hour. But while bicycles tend to move relatively continuously at this speed, buses alternate periods of movement at higher speeds with brief stops to pick up and discharge passengers. As a result, either of two undesirable conditions are apt to occur where cyclists travel on street along local bus routes (whether or not on-street lanes are provided). One is "leapfrogging" where the cyclist moves to the left (out of the bike lane if one is present) to pass a bus stopped at a load point only to be in turn overtaken by the bus at midblock. The sequence of passing and repassing can continue ad infinitum with the cyclist making potentially dangerous forays into the traffic stream with each passage of the stopped bus. But many times the "leapfrogging" condition degenerates to a "catchup - pullout" sequence. In this condition the cyclist catches up with the bus just as boarding or discharge of passengers is completed and the bus roars away, saluting the cyclist with a blast of noise and noxious exhaust, the situation repeating itself block after block. More serious from a safety sense is the case in which the cyclist is initiating a passing maneuver as the bus pulls out.

Because of this problem, it appears inadvisable to locate on-street bicycle facilities on roadways with low headway local bus operations if suitable alternatives are available. On streets with moderate to long headway bus services (perhaps 10 minutes or more), this problem is less a concern and can be regarded as a low priority consideration.

CURRENT USER DATA

The bikeway planner should be conscious of the limitations of data related to current cyclist travel. Bike volume counts, origin-destination patterns and route choice information does have some value for indicating how many cyclists there are in a community and where they are going. Likewise, cumulative plots of bike accident locations over several years give a rough indication of the streets cyclists use and identify specific hazard points. But all of this information reflects cyclist behavior under the constraint of the existing transportation system in the community -- usually a system which includes few if any good cycle facilities. Many persons who would like to cycle may do so very little or not at all. And route choice of those who do cycle is affected by barriers to cycle travel and obvious hazard areas. Hazardous areas or streets reflected in accident location plots may not be the most hazardous areas in the community for cyclists; rather they are the most hazardous areas where cyclists do dare to travel now.

LOCATION AND DESIGN SELECTION CRITERIA

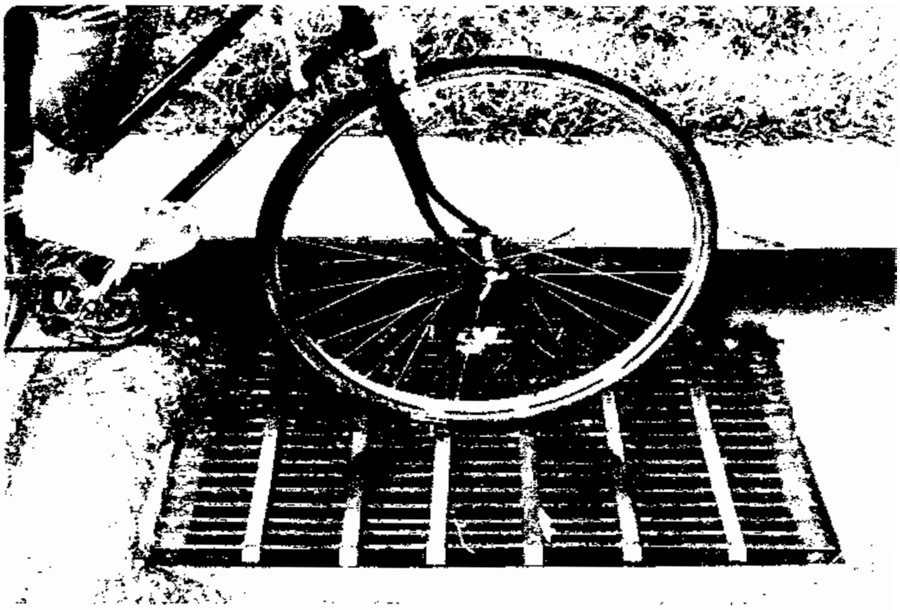
A number of jurisdictions have developed bikeway locational or design specification criteria. Typically these are based on such factors as bike volume, available roadway width, motor vehicle volume and travel speed, volume of heavy truck traffic and similar factors. By and large, such criteria are based on judgmental decisions and, in some cases, European criteria rather than specific analytic studies, but most appear good efforts to provide a rational basis for planning and design.

Many of the warrants incorporate specific quantitative criteria. But bikeway plan decision making should always be tempered by judgmental analysis on the part of the planner. For instance, while current bike traffic volume does constitute prima facie evidence of the need for a facility (several jurisdictions have specified 200 bikes per day), the need or opportunity to link disconnected facilities in a logical fashion or to serve activity centers which might be expected to attract cyclists are equally valid reasons for location of a bikeway. Minimum street widths suitable for on-street bikeway treatments may be considered absolute; a minimum of 28-30 feet (see Chapter III) for on-street lanes or signed routes. (Note that if a street does not have sufficient width to accommodate a cyclist in a designated lane, it should not be used as a signed route either). But if there is valid reason for bicycle facilities in the corridor (continuity or network linkage, service to activity centers) insufficient width or street width fully utilized to meet motor vehicle traffic and parking needs should not preclude provision of some kind of facility -- a sidewalk bikeway or use of a parallel street. Motor vehicle volumes, speeds, percentage of heavy truck traffic, and presence of parked vehicles should not be taken as individual absolute criteria. For instance traffic volume, speed and width of shoulder or lane area which can be designated as a bike lane should be considered in combination. Frequency of intersections and motor vehicle turning volumes are considerations perhaps more important than actual midblock traffic counts.

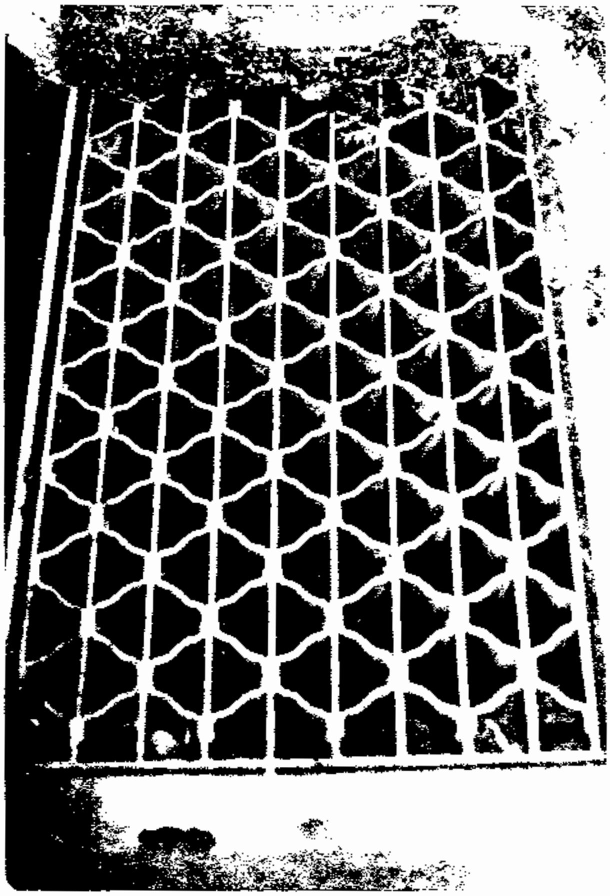
The designer should have sufficient sensitivity to cyclist capabilities so as to be able to judge where departures from recommended standards in constraining circumstances would be safe and functional. However at instances of such departures, the designer should be aware that expedient temporary solutions often become permanent.

DRAINAGE GRATES

Drainage grate problems have been well publicized. Most cycle tires will drop through commonly employed parallel-bar grates, damaging wheel rims and giving unwary cyclists a nasty, over the handle-bars spill. Some communities have welded transverse bars over existing parallel bar grates to protect cyclists, others have employed transverse bar or honeycomb designs. All, however, are judged inferior to parallel bar grates in terms



Grate with retrofitted transverse bars.



A honeycomb grate.

of hydraulic properties. Curb inlets pose no problems to cyclists. Every effort should be made to avoid use of the hazardous parallel bar grates in areas where cyclists are likely to be riding. Where such grates are used they should be clearly marked and they should never be employed within a specific bikeway facility. It should also be noted that cyclists will normally try to avoid riding over almost any type of grate, partly due to uncertainty whether or not it is "wheel-proof", partly because some of the supposedly "wheel-proof" grates can still catch or pinch a tire (although preventing it from dropping through) and partly because of the rough ride quality and potential slippage on the metal surface. Because of this, drainage gratings narrow the effective width of the bikeway and may cause cyclists to swerve in the path of traffic.

BIKEWAY MAINTENANCE

For bicycle facilities to be effective and attractive, they must be properly maintained. This does not simply imply maintenance of pavement structural condition, although this is very important. Of equal concern is clearing the surface of glass, stones and other debris. Even bikewavs

Where bikeways are poorly maintained, with weeds , debris, standing water and faded markings, cyclists will not use them.

adequately dimensioned for normal operations may not provide sufficient room for cyclists to swerve around chuck holes or debris or to recover balance after slipping on them. And where bikeways are heavily strewn with sand, debris or standing water, cyclists are likely to completely avoid it.

RAIL CROSSINGS

Another potential hazard involves bikeway-railroad grade crossings. Smooth, metal surfaces particularly if wet, can be quite slippery and if the bikeway crosses the track at an oblique angle, this can cause a skid. Other problems with grade crossings include possible loss of tire pressure and tracks are poorly leveled and "concealed" chuck holes between the rails where filler surfacing often breaks loose.

EDUCATION, ENFORCEMENT -- RELATION TO PHYSICAL PLANNING

Physical design to promote safety and utility of bikeways has been the primary focus of this report. But it should be recognized explicitly that, to be effective, engineering must be complemented by education and enforcement -- education to indicate proper use of facilities and behavior patterns; enforcement to ensure compliance and corrective action. It should be further recognized that engineering can likewise complement education and enforcement efforts by creating facilities the use of which is logical and comprehensible through uniformity and consistency with natural behavior patterns. On the other hand, the mutual enforcement can be lost if facilities are irregular, ambiguous or inconsistent with common sense and natural behavior patterns.

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APPENDIX

CYCLISTS' PERCEPTIONS

The foregoing chapters present basic bikeway design criteria, details of typical in-use facilities and overviews of experience to date on the facilities. But how do cyclists themselves relate to these bikeways?

This is a particularly important question and one largely unanswered to date. Feedback to bikeway planners is usually oblique in nature: accident data, changes in bicycle traffic volume, or informal observations of facility performance by the system planners themselves. The limited direct comment received from actual bikeway users normally emanates from highly skilled riders, typically affiliated with organized cycle groups. These persons' bicycling behavior is quite untypical of the vast majority of bicycle users and their comments often reflect an elitist viewpoint of bicycle facility performance and needs. In the limited instance where general cyclist reaction to facility provisions has been elicited, responses have been site or facility specific and not generalizable to other facilities or areas.

In an attempt to illustrate techniques for obtaining direct and broad based user reaction to bikeway provisions, and to develop measures of user reaction to various bikeway design types and design parameters having general rather than site specific significance, surveys of bicyclists are being conducted on urban and interurban bikeways in the U.S. Preliminary findings reported herein are based on some 350 interviews with randomly selected cyclists on West Coast bikeways, conducted in the fall and winter of 1973-74.

As indicated above, interviewee sampling was random and bicyclists of all degrees of experience were interviewed, from persons just learning the art of balancing a two-wheeler to competitive racers and touring cyclists on interurban bikeways. The great majority, however, were neither amateur or expert, they simply rode bikes a lot. Over 75% reported riding their bikes almost every day for school, work, or pleasure. Most cyclists were making short trips -- 60% said the bike trips they were on would last less than half an hour (1-way), but the length of trips was very dependent on what kind of bikeway the cyclists were on. All trips of three hours or more were on long, interurban bikeways or in large urban parks.

Bicyclists in general appear to be extremely willing and cooperative survey respondents. Very few persons refused to be interviewed and while the basic interview lasted 7 to 10 minutes, some stretched as long as 20 minutes, with cyclists volunteering expansive comment.

A pervasive bias observed in the interviews was that many cyclists were so grateful for any kind of bikeway that they were reluctant to be critical of it. This seemed to be mostly a function of cyclists' past experiences in being excluded from many roads and in having to ride in such residual road space as gutters or narrow shoulders. The applicable analogy is that after a person has been on a restricted diet for many years, he is unlikely to be critical of any extra rations he can get. Although gratitude for existing facilities is a notable and important finding, the interviewer pressed respondents who held this view for an additional evaluation which would yield improved criteria for future bikeways. This is a particularly important factor which should be considered in design of bikeway evaluation surveys. A number of bicyclist surveys have been undertaken using mailout-mailback, hand distribution-mailback or newspaper cutout-mailback questionnaires. Although such surveys can be conducted relatively inexpensively, they suffer problems from non-response, non-contact, and poor respondent selection control. These drawbacks of self-administered questionnaires may not be serious or critical when the subject matter is one of more or less objective facts such as trip length, trip frequency, trip purpose, origin-destination pattern (though even in these areas, survey bias may be a concern). But when the purpose of the survey is to critically evaluate bikeway facility design, an on-site interview format is particularly essential to assure contact with the respondents at a time when their image of and interest in the subject -- the bikeway -- is sure to be high, and to overcome the "uncritical gratitude" bias through interviewer probing.

Marked exception to the tendency toward uncritical gratitude was found among the experienced touring or commuting cyclists, who were much more critical of both the concept and the form of bikeways they were on. Whereas inexperienced riders lack familiarity with the range of safety and design alternatives that might have improved their route and tended to perceive the bikeway in a very gross way, experienced riders were aware of many adverse structural and exogeneous components of the bikeway, and were more often resentful at what they considered the cyclist's inferior status on the roadway. One frequent comment was that "cyclists have rights too." Strong statements about the dangers of cycling were common among experienced commuters: "I feel physically that my life is in the breach," and "When you ride your bike you find out how violent a nation we are." Commuters often had accident experiences or near misses involving motor vehicles that had convinced them of inordinate danger existing on city streets in general, and to a somewhat lesser extent, on bike-lanes.

With this introduction, let us now examine some specific findings of the survey.

ON-STREET LANES

Respondents almost universally indicated that streets with bike lanes are far safer than streets without them. When asked to rate the bike lane they were on for cycling safety, giving it a number from 1 to 10 (where 10 meant very dangerous and 1 meant very safe), and then to rate that same section of street if it had no bike lane, bicyclists always rated the street as safer with the bike lane than without. The mean safety rating for bike lanes was 3.8, and the mean rating of streets without those bike lanes was 7.1. Thus on an average, cyclists used a third of the scale to describe the improvement in safety attributable to the bike lane. The amount of improvement attributed to the bike lane ranged from a high of 6.3 (given a bike lane separated from 50 MPH traffic by a full motor vehicle lane width and a raised berm) to a low of 2.0 (a lane which cyclists seldom bothered to use because there was so little auto traffic in the street). It is curious to note that even cyclists not using the lane at this latter location rated the street safer for cycling because the lane was there. They commented that even though they did not often use the lane, it was beneficial since they could resort to it if a car were coming.

Belief in the relative safety of bike lanes was expressed in a great variety of street situations, from commodious suburban avenues with wide lanes and no auto parking to auto-impacted urban streets with narrow bike lanes and parked cars. But the general response is at odds with the opinions of those who seriously question the value of bike lanes.

LANE WIDTH EVALUATION

Although the formal bike lane widths at interview locations ranged from four feet to eight, the actual widths (within the blocks being rated by cyclists) dropped as low as one foot. This occurred where telephone poles or beach sand and debris protruded into the bike lane. In spite of these irregularities, a clear-cut and statistically significant picture of cyclists' preference for wider lanes emerged from the interviews. When the 15 bike lane interview sites are grouped according to width, cyclists' ratings of the bike lane width (as Good, OK, or Poor) were indicated on Table 2. Differences between the ratings of the three categories are statistically reliable.

Table 2

CYCLIST EVALUATION OF LANE WIDTH

Rating	Width: less than 5 ft.	5-6 feet	greater than 6 feet
Good	48%	65%	97%
OK	32%	31%	3%
Poor	20%	4%	0%

As can be inferred from the table, virtually all find lane widths above 5 feet satisfactory and above 6 feet very ample. However, one of the narrowest bike lane interview sites was, in addition to being only 4½ feet wide, a bi-directional lane at the edge of a narrow, crowded urban street. Most people rated its width as "Poor," describing it as a "hairy" stretch where cyclists had to look out for not only cars but opposing bike traffic and roadside telephone poles as well. Commonly, if a bike lane is abutted by a roadside shoulder area with a decent surface that cyclists can resort to in a pinch, the formal width of the paved bike lane will not be viewed as critically as otherwise. However, the sloping dirt frontings of roadside businesses at this location did not serve as a spillover area for cyclists because of the necessity of coming back to the roadway at the frequent property-line fences. If interviews from this and two other bi-directional lane sites are dropped from the analysis, no statistically reliable differences between the ratings of the under 5 and 5 to 6 foot categories are identified.

LANE POSITION EVALUATION

In an attempt to assess cyclist preference for lane positioning -- curbside with no parking (Type B) or between the parking apron and motor vehicle travel lane (Type A), cyclists were interviewed at locations where these two types of lane positioning were employed on opposite sides of the street. These sites present a comparative situation free of variables which might obscure real differences between the two design alternatives -- variations in street width, traffic volume, traffic speed, parking turnover and the like. In the western cities employing such Type C bike lanes, cyclists were interviewed and asked to rate the lane treatment of each side of the street. At each test site, the bike lane width was the same on both sides of the street; the only variable was that of parking condition.

Cyclists were asked to rate the bike lanes for safety on a scale from 1 to 10, (1 very safe, 10 very dangerous), and to comment on their ratings of the two sides. Results are indicated on Table 3. Every cyclist on the Type B (no parking) bike lanes held that the side with parking permitted (Type A lane) was more dangerous, and almost all of them attributed the difference to the presence of parked cars.

Table 3

COMPARATIVE SAFETY RATINGS
TYPE A VS. TYPE B LANES

	Berkeley, Calif. (4 foot lanes)	Isla Vista, Calif. (4.5 foot lanes)	Combined Rating
TYPE A (With Parking)	4.95	4.08	4.51
TYPE B (No Parking)	3.39	3.28	3.33

Most cyclists in the Type A (parking allowed) bike lane rated the other (Type B) side as safer. However, on one site rating differences were partially attributed to difference in the quality of pavement surface on the two sides of the street. Yet with the unanimity of opinion about the relative danger, the differences in ratings are highly reliable.

Cyclists' comments on the difference between the two types of lanes were considerably stronger than the differences between the ratings suggest. Many said there was a "terrific difference," that the side with no parking was "much safer, or that they'd be wiped out by car doors" on the bikelane with parking. Probably the basic nature of the interview sites (width, surface material, and traffic volume) was an important factor keeping the ratings fairly close together for both sides of the street.

Cyclists on both sides were also asked to rate the protection from cars in their bike lane as good, OK or poor, and to comment on the other side of the street. Results for the two cities are presented on Table 4. Reliably different ratings were obtained on the two lane types. The modal response by cyclists in the no-parking bike lane is OK, and in the bike lane-with-parking, poor. Most cyclists said that the with-parking side was less protected from cars because of the problem of parked car doors opening suddenly.

Table 4

RATING OF PROTECTION FROM CARS
TYPE A VS. TYPE B LANES

	Good	OK	Poor
TYPE A (With Parking)	21%	34%	45%
TYPE B (No Parking)	33%	44%	23%

In total, cyclists were interviewed at 15 bike lane locations on the West Coast, five of which had Type A lanes, 10 Type B lanes. On the whole, bike lanes without parking (Type B) were not necessarily rated as safer than bike lanes with parking. Rather the safety ratings seemed to reflect primarily the general nature of the street, with very safe ratings going to bike lanes on wide streets without much auto traffic, and very dangerous ratings going to bike lanes where auto traffic was heavy and often spilling over into the bike lane. Although the danger of parked cars was almost always mentioned spontaneously by cyclists riding on Type A lanes no matter what the street situation, it appears that other factors than parking condition are dominant in the cyclists' safety evaluation.

SIDEWALK BIKEWAYS

As indicated in Chapter II, the term sidewalk bikeway describes a broad variety of treatments. These range from normal pedestrian walks converted to bikeways by signing and curb ramping and used jointly by cyclists and pedestrians to broad pathways along roadway rights of way with little pedestrian traffic and few interrupting cross streets or driveways.

Interviews with bicyclists at six sidewalk bikeway locations in four western cities seem to indicate that bicyclist willingness to use a sidewalk bikeway is closely related to purpose of the bike trip. Commute riders indicated general dissatisfaction with sidewalk bikeways while recreational riders were generally satisfied with the level of service provided since the alternative was usually a busy city street, the use of which would have detracted from a quiet, enjoyable ride. These differences are most marked where sidewalk facilities are poor, particularly on converted narrow pedestrian walks. The commute cyclist appears much more sensitive to sidewalk bikeway problems -- intersection conflicts with cars, poorly constructed ramps, pedestrian conflicts, bumpy pavement and driveway conflicts.

Palo Alto, California provided an ideal site for evaluating cyclists' perceptions of sidewalk bikeways. The City has a high level of bicycle traffic and an extensive bikeway system comprised primarily of on-street lanes, but with considerable mileage of 5-foot sidewalks in bicycle-pedestrian joint use. Although cyclists there gave sidewalk bikeways a good safety rating, they generally felt on-street lanes were safer. Table 5 presents mean safety ratings (scale 1-10, 1 = very safe, 10 = very dangerous) indicated by cyclists on lanes and sidewalks in Palo Alto. Rating differences as indicated on the table are statistically reliable. In only one case did a sidewalk bikeway receive a safety rating as good as any of the on-street lanes. This sidewalk facility was along a street bordered by a park -- a place where there were no conflicts with residential driveway traffic.

Table 5

COMPARATIVE SAFETY RATINGS
SIDEWALK FACILITIES VS. ON-STREET LANES

Type	Mean Rating
Sidewalk Facilities	3.4
On-Street Lanes	2.5

In a second test, cyclists riding in on-street lanes were asked to rate as a bicycle facility the sidewalk adjacent to the street they were on. (Interview sites were carefully chosen so that the quality of the sidewalk at the site was equal to or better than those in the City designated as bikeways.)

Again, as indicated on Table 6, cyclists perceived the sidewalk bikeways to be less safe than on-street lanes but a substantial improvement over no provision of designated bike facilities.

Table 6

MEAN SAFETY RATINGS

Facility	Location 1	Location 2
On-Street Lane	3.0	2.1
No Designated Facility	7.1	6.6
Sidewalk Bikeway	5.0	4.5

(1 = very safe, 10 = very dangerous)

Nearly 75 percent of the respondents felt sidewalk bikeways were more dangerous than the lane they were on; slightly over 20 percent felt sidewalks were less dangerous. Actual rating values of the sidewalks in Table 6 are deceptive. Since the cyclist was asked to rate first the bike lane, then the condition of no designated facility, if the respondent felt the sidewalk fell somewhere in between, the safety rating value placed on this was somewhat pegged by the prior responses. This probably accounts for the fact that the ratings for sidewalks as per Table 6 were higher (worse) than ratings of actual sidewalk bikeways. Yet the controlled comparison data still validly shows a marked preference for on-street lanes over sidewalk facilities. Not only is there reliable difference among the ratings given the three possible situations, but the difference between sidewalk and on-street lane ratings is statistically significant. Bicyclists also appeared to be using the rating to describe more than safety perception in evaluating sidewalk bikeways.

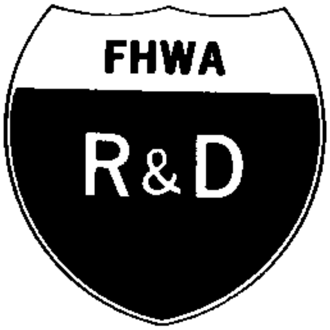
Convenience factors such as stopping for pedestrians or negotiating curb ramps seem to be taken into account by most cyclists. One cyclist who did rate the sidewalk as safer than the on-street lane indicated he wouldn't use it despite this belief -- it was "too much of a pain". The utility-recreational dichotomy is strongly reflected in issues of convenience as indicated by interview subjects' comments. Cyclists whose use of the bicycle was for transportation rather than recreational purposes always complained that a satisfactory travel speed could not be maintained on the sidewalks or that traveling on them was a "pain in the neck". They said their progress was slowed by overhanging tree branches, untrimmed bushes and vines on front lawns, pedestrians, ane badly tilted and cracking sidewalks. One complained that toddlers wandered out from their front lawns and threw toys at passing cyclists. Another complained about the number of older persons strolling on the sidewalk, and an adult cyclist said that elderly pedestrians couldn't hear or see him very well, and that he never knew which way they were going to "jump" when he rode up behind them and honked his horn.

Cyclists indicated that their progress at intersections was impeded by steeply ramped curbs which cyclists, especially ten-speed riders, described as giving them flats or bending their rims while they were trying to maintain a good traveling speed. Commute riders maintained that autos were not expecting bikes to come barreling off sidewalks at commute speed, or any speed for that matter, and that having to slow down to look out for cars at intersections and driveways made the sidewalk inconvenient for travel.

Recreational riders, on the other hand, often commented on how dangerous the adjoining street was for cyclists, and that they appreciated the option of having a direct route to their destinations without all the danger and bother of riding on arterial streets. Female children tended to show more acceptance of the sidewalks than adults or boys, although they too frequently mentioned problem of parked cars protruding from driveways and the danger of being struck by cars backing out of them.

A quite different type of sidewalk in Santa Barbara, California was also evaluated. This involved a Class II facility in which 6 feet of the 18 foot sidewalk width was set aside for cyclists by a blue demarcation stripe. Most cyclists on this facility which served a beach area were recreational riders and gave the bikeway good safety ratings. This rating is probably reflective of the recreational character of the users and the fact that, because it was located along the beach, it was uninterrupted by cross streets and driveways rather than due to the demarcation of separate bike and pedestrian areas. What was most interesting was the cyclists' assessment of the spatial adequacy and disregard for the delineation of separate bike and pedestrian areas. Although Table 2 would seem to indicate a high level of cyclist satisfaction with 6 foot lanes, cyclists on this facility usually described the width as simply adequate (ok). Most indicated that so many pedestrians walked in the bike lane that they had to ride in the pedestrian area and a few indicated they took advantage of the full sidewalk width as a matter of course as this was easier than trying to stay in the bike lane.

A Sacramento, California sidewalk bikeway along a route used largely by commute cyclists was another subject of this evaluation. But despite the fact that the facility was fairly wide (8 feet), marked (with a bike symbol painted on the surface) and for the most part had ramped curbs at intersections, it was difficult to interview cyclists on the facility as most, rather than using the sidewalk, rode on the street itself. These cyclists were not interviewed because they were extremely difficult to stop -- riders on 10-speed bikes pedaling furiously to keep up with traffic and remain in the traffic signal progression band. Instead, a self-administered form of the standard interview form was attached to bicycles parked in areas tributary to the bikeway with a return mailer. Over 80 percent of the forms distributed were returned, many with extensive written commentary. Of the respondents who traveled along the bikeway route, more than half (55 percent) indicated they generally used the street rather than the sidewalk bikeway. A third of those continuing to use the street indicated that despite the pavement stencils and ramped curbs they were unaware of the sidewalk bikeway's presence though they routinely rode through the area. It appears that signing is generally necessary and desirable to inform and direct cyclists to sidewalk bikeways. Cyclists who did use the sidewalk facility commented about the large numbers of pedestrians in commute hours and occasional curbs which have been left unramped but still felt the sidewalk bikeway was safer than riding in the street. Cyclists who used the street but knew of the sidewalk facility characterized it as "frustrating, slow, and boring." There was some difference between sidewalk and street riders' ratings of the sidewalk facility with users perceiving the facility as somewhat safer than did those who remained in the street.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