SAFETY & LOCATIONAL CRITERIA FOR BICYCLE FACILITIES

USER MANUAL VOLUME II: DESIGN AND SAFETY CRITERIA

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16. Abstract

This manual is designed to assist a designer of bicycle facilities in providing a safe and effective environment for bicyclists, pedestrians and motor vehicle operators. The document discusses the bikeway design process and relates it to locational decisions. Route and right-of-way specifications are detailed. Various intersection treatments are presented. Signing and markings applicable to bikeways are also covered. Throughout the report, the emphasis is on the presentation of available information so as to allow the bikeway designer to choose the best alternative for his situation.

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CHAPTER 1

INTRODUCTION

In 1973 the Federal Highway Administration undertook a 2-1/2 year program of research in bicycle facility planning and design (entitled "Safety and Location Criteria for Bicycle Facilities" (DOT-FH-11-8134). This effort has included both an extensive study of experience on existing bike facilities and new experimental research. Its objective has been to develop methods and guidelines for effective planning and design of bikeway facilities.

This manual is one of three produced as principal products of the FHWA program. It deals with design, focusing on the process and details of laying out the physical features of bikeway facilities. A companion volume presents a recommended bikeway planning process and locational guidelines. These two volumes are intended as basic reference sources for jurisdictions at all levels engaged in the bikeway planning and design process. They expand upon an earlier interim product of the program, the FHWA report "Bikeways -- State-of-the-Art -- 1974" (FHWA-RD-74-56, available from NTIS). However, most of the information in that report remains relevant. The third product is a final report which provides an overview of the project together with documentation of research findings.

This manual focuses on the design of physical features of bikeways. As in the case of Volume I's presentation of locational criteria, there is a need to set these physical design decisions within their proper context. Design details must often be considered as options, to be traded off against constraints such as cost and specific needs such as those of the particular users expected on the facility. This tradeoff process must be understood by the bikeway planner-designer.

In addition, the role of design guidelines is not limited to the design of a facility after its location is chosen. The locational decision -- dealt with in Volume I -- is partly dependent on the cost, feasibility, and effectiveness of available design options for each candidate route. Thus the design guidelines of this volume are relevant to the choice of location as well as of the detailed design of the facility.

In some contrast to the case of Volume I's locational criteria, many of the design recommendations of this volume are quite specific. This is due both to the nature of the subject of detailed design, which lends itself more easily to precise specification, and also to the generally more advanced status of research in design treatments. The actual level of detail possible varies from item to item within the volume, but should accurately reflect the current state of the art.

Irrespective of the level of detail in these guidelines, however, it is essential that the planner-designer recognize the importance of good judgment in their application. Sensitivity to the unique requirements of a community, as well as of a specific location and situation, is essential. Only with this sensitivity can the necessary tradeoffs of competing requirements be made successfully.

In applying material from these manuals it is essential that the reader recognize that the field of planning and design of bicycle facilities is still a dynamically developing one; new findings on factors affecting bicyclist safety, amenity enhancement, and usage motivation as well as new techniques for planning and design continue to emerge. Although the content of these volumes is based upon evaluations of experience to date and the findings of most recent research, it is imperative that users keep abreast of developments subsequent to this date of publication.

STRUCTURE OF THIS MANUAL

Following this introduction, Chapter 2 provides an overview of the bikeway design problem, including definitions and classifications, common errors in design, and a summary of the essential points of recommended practice for each class of bikeway facility. Chapter 3 describes the use of this volume's design guidelines within a logical process.

Chapters 4, 5, and 6 present the design guidelines in detail. Their organization is as follows:

- Chapter 4: Route Specifications
- Chapter 5: Intersections
- Chapter 6: Signs and Markings

CHAPTER 2

AN OVERVIEW OF BIKEWAY DESIGN AND USER CHARACTERISTICS

INTRODUCTION

This chapter provides the basis for use of the design specifications detailed in Chapters 4, 5, and 6. It will define bicycle facility terminology including a bikeway classification system; identify several generic types of bicycle facilities; and briefly examine characteristics of potential users of the facilities. This material will give the designer an understanding of the design options available and the situations in which the options are best deployed.

BICYCLE FACILITY TERMINOLOGY

Most current terminology used in describing bicycle facilities is descriptive of the physical characteristics of the facilities. Another set of terminology is defined in "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. This terminology classifies bicycle facilities according to the degree of exclusiveness with which the facilities are preserved for bicycle use, and has been widely adopted in recent U.S. bicycle facility literature. That classification system and some of the associated 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 to gain access to driveways or parking facilities, is allowed; pedestrian cross-flows, to gain access to parked vehicles, 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 its through-traffic right-of-way with either moving motor vehicles or pedestrians is considered a Class III bikeway.

Definitions

Since there are a number of varieties and permutations within the basic three bikeway classifications, the following list of definitions has been prepared to clarify relationships of frequently used terminology.

- Bikeway, Cycleway: Generic terms encompassing all of the 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. (May be Class I, II, or III.)

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

- 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.)

- Independent Path: A bicycle 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).

- 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.)

- Bike Route: A street or system of streets and ways with signs denoting them as a "Bike Route." Most commonly, "Bike Routes" imply streets in mixed usage but they may include segments of the various types of exclusive bicycle facilities. (A Class III facility.)

- 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.)

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

- 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.)

OVERVIEW: GENERAL FACILITY DESCRIPTIONS

The following brief discussion and description of the basic types of bicycle facilities is intended as a frame of reference for the detailed design guidelines which follow in later chapters.

Independent Paths

Bikeway corridors in their own rights-of-way are usually desirable and attractive facilities. They may function as Class I or Class III bikeways depending on the level of pedestrian activity on them. Such facilities may be recreational in character or locational circumstances of the right-of-way may make them attractive for utilitarian travel as well. Promising corridors for independent paths include:

- green belts,
- park areas,
- utility rights-of-way,
- drainage rights-of-way,
- railroad rights-of-way,
- freeway and parkway rights-of-way,
- stream courses, and
- beach fronts.

An ideal situation occurs in new towns or "planned developments" where independent paths can be designed into the structure of the community to maximize their usefulness for both transportation service and recreational bicycling. However, it must be pointed out that poor planning can occur even with all of the opportunities in a "new town" if accepted bikeway design criteria are not considered.

There is often a tendency to seize the opportunity for providing independent paths without first considering the potential usefulness of the ultimate facility. This is more properly a locational rather than a design consideration. However, planners should be able to answer affirmatively to each of the following questions before provision of an independent path facility is considered:

Question 1:

> Is this corridor an attractive place to ride a bicycle, or does it provide a useful transportation linkage for utility bicycling?

Question 2:

> Is the corridor located close enough to population centers that a level of utilization of the facility can be anticipated which reasonably justifies its cost?

Question 3:

> Does the corridor offer sufficient safety or bicycling environment enhancement benefits to justify incremental cost over that of placing a facility in a parallel roadway corridor?

While independent paths have the obvious potential of minimal interaction with motor vehicle roadways and hence offer some latitude in design, the following caveats must be considered:

- Trails for bicyclists must be designed to more rigid standards than those for pedestrians. Specifications for basic width, grade profiles, curvature, sight distance and pavement surfacing must be adhered to.

- The bikeway must be designed as a functional facility, not as an artistic feature of landscape. Contrived curves and artificial hills are inappropriate.

- Where independent paths cross motor vehicle roadways at grade, traffic engineering details must receive appropriate attention.

- Considerable latitude is permissible with respect to signs and markings employed on independent paths, but it is essential that these remain readily perceptible and understandable. Where independent paths interface with motor vehicle roadways, standard traffic signs and markings should be used.

- Bicyclist security should be considered in design of independent paths, particularly in areas of high street crime. To the greatest extent possible, facilities should be designed to be open to public view and ready scrutiny of enforcement officers. For instance, a path passing through a park should preferably be located in an open meadow rather than in a secluded wooded grove.

- Where independent path facilities share right-of-way with other uses, care must be taken to design features which prevent possible use conflicts. An example might be provision of fencing to separate a bikeway on a water supply aqueduct right-of-way from the aqueduct itself. Similarly, measures should be designed to protect the privacy of properties abutting an independent path if privacy intrusion is a potential concern.

Bike Lanes

The concept of on-street bike lanes includes a broad range of design treatments. Typically lanes operating in the same direction as motor vehicle traffic are provided on each side of the street although other variations are in general use. Following are the principal bike lane configurations:

Type A: Bike lanes are placed between the parking shoulder and the motor vehicle travel lane as indicated on Figure 1. Striping on both sides of the bike lane provides clear intent of space utilization so drivers will not mistake the bike lane/parking shoulder areas as a travel lane during times of low parking utilization.

Type B: Curbside bike lanes are provided along streets where no parking is permitted or where parking has been removed to provide space for the bike lane. This treatment is illustrated on Figure 2.

Type C: Offset centerline treatments involve prohibition of parking on one side of the street, asymmetric location of the traffic directional "centerline," and provision of bike lanes of the Type A configuration on one side and the Type B configuration on the other. This is a particularly effective method of providing bike lanes on narrow streets in single-family residential areas where on-street parking needs can be met with parking on one side only. This treatment is indicated on Figure 3.

Surveys of bicyclist perceptions indicate that cyclists strongly prefer the Type B configuration over Type A. Stated reasons for this center on concern for hazardous conflict with parked cars in general and specifically with opening car doors. Cyclist concern appears excessive in light of the low rate of bicycle accident occurrence involving parked cars. This discrepancy may reflect a high rate of conflict incidents involving parked cars but a low ratio of collisions to conflicts. While desirable, Type B treatment is usually more difficult to implement because of conflicts posed by parking removal. Some variations in bike lane treatments are discussed in the following paragraphs.

Figure 1: TYPICAL TYPE A LANE
(Davis, California)

Figure 2: TYPICAL TYPE B LANE
(Eugene, Oregon)

Figure 3: TYPICAL TYPE C, OFFSET CENTERLINE
TREATMENT (Denver, Colorado)

- Bike lanes on one side of the street

  One-way bike lanes on only one side of the street have been employed with varying success. The most common location is on one-way streets. These are usually placed on the right hand side of one-way streets in either the Type A or Type B configuration. Left side positioning in either configuration is also effective on one-way streets.

Provision of directional lanes on one side of each of a pair of parallel bi-directional streets is a means of incorporating on-street lanes where limited street width is available. 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. This approach is susceptible to wrong way riding unless it serves the logical cyclist riding patterns.

- Left side positioning

  Left side lane positioning has been successfully employed on median-divided boulevards to avoid serious traffic conflicts on the right hand side with heavy volumes of right-turning vehicles. Left-turning drivers are immediately adjacent to the cyclist so visibility relationships are improved although proper positioning and driver/rider courtesy are important to minimize conflict between through-cyclists and left-turning vehicles. Seattle's treatment of left side bikes involves a weaving section prior to a left turn vehicle lane to further minimize the conflict at the intersection by having through bicyclists proceed from the right of the left turning vehicle. Knowledge of relative order of magnitude of right turn vs. left turn traffic is a parameter to help the designer judge the appropriateness of left side positioning of a bike lane. Effectiveness of this treatment is strongly dependent on the quality of transition treatments at the ends of the median section. Facility placement in boulevard medians (not an on-street lane treatment) such as along Commonwealth Avenue in Boston has proven less successful in terms of bicyclist acceptance.

- Bi-directional

  Bi-directional bike lanes (two-way operations on one side of the street) have been provided in some locations but are not a recommended design type. This design treatment directly induces riding against traffic, a major causal factor in bicycle-motor vehicle accidents. Bi-directional operations should be limited to independent paths and sidewalk facilities with long stretches uninterrupted by cross streets and driveways. Except in the most extraordinary situations, bidirectional bike lanes should not be considered.

- <u>Common Design Errors</u>

As on-street lane treatments have come into widespread use across the United States, their merits have become a subject of considerable controversy. In general, bike lane critics have confused improper or inadequate design applications with a failing of the concept itself. Principal problems with bike lane applications have included:

- provision of inadequate lane width or use of unrideable street surface as the bike lane area;
- abrupt termination of lanes at hazard or constraint situations creating a facility which leads bicyclists to a trap; also transitions which force awkward bicyclist movements at other termination points;
- use of non-standard and poorly visible lane demarcation signs and markings which create uncertainties in motorist and bicyclist understanding of lane presence and purpose;
- lane configuration and lane use ordinances which prevent the bicyclist from establishing proper position with respect to motor vehicle traffic at intersections as well as for mid-block turns into driveways; and
- lane use ordinances which conflict with reasonable bicyclist desires to leave the lane in order to avoid road hazards or to overtake other bicyclists, motor vehicles or pedestrians occupying the bike lane.
- violation of the cyclist's exclusive use of a bike lane by lack of enforcement or by imposing time limits allowing alternative uses such as parking or a motor vehicle travel lane during certain times of the day. At best, this causes confusion and promotes misuse of bike lanes by motor vehicle drivers. Such a practice can literally increase cyclist hazard by creating barriers and route discontinuities as result when motor vehicles park in bike lanes, especially where parking utilization is heavy. Once a bike lane is striped, it should remain a bike lane and not be capriciously shared with competing uses.

These problems are essentially failings of design and application, not basic weaknesses of the concept itself. As failings in application they are subject to correction, a primary intent of this manual.

- Benefits of Bike Lanes

  Until recently, benefits of bike lane treatments have largely been the subject of conjecture. Now these effects of bike lanes can be positively stated based upon more extensive experience and research findings.

  - Bike lanes have positive impact on traffic operational flow characteristics. Presence of lane delineation lines normalizes the tracking paths of bicycles and motor vehicles, decreasing the incidence of extremely close passes and wide avoidance swerves.

  - Bike lanes are significantly more effective in reducing bike-motor vehicle collisions than previously believed. Bike lane critics have alleged that the only type of accident bike lanes prevent is the "overtaking and sideswipe" accident. On the basis of data from a limited number of early accident causal studies, they point out that this type of accident accounted for less than one percent of all bicycle-motor vehicle collisions.

    Recent accident studies have provided a more extensive data base on accident causal factors and some direct evidence on the effectiveness of bike lanes in reducing collision incidence. These studies show that overtaking and sideswipe collisions occur far more frequently than bike lane critics alleged. Table 1 indicates observed sideswipe and rearend accidents as a percentage of bicycle-motor vehicle accidents. More significantly, studies indicate that bike lanes are effective in reducing the incidence of a number of other bike-motor vehicle collision types.

  - Bicyclists perceive significant benefits from bike lanes. Surveys of bicyclist perceptions indicate that most cyclists believe streets with bike lanes are far safer than they would

Table 1
OVERTAKING/SIDESWIPE ACCIDENTS

Study Area	Percent Sideswipe and Rear-End
Davis, California	4.0
Eugene, Oregon	9.5
Maryland, Statewide*	6.0
Oregon, Statewide	13.0
Santa Barbara, California	4.2

*Rear-end accidents only; sideswipe not included.

be without the lanes. On the average, cyclists feel that bike lanes decrease safety hazard to nearly half what it would be were no bike lanes present on the street. Belief in the relative safety of bike lanes was expressed in a great variety of street situations from commodious suburban streets with wide lanes and no auto parking to auto-impacted urban streets with narrow bike lanes and parked cars. This belief is pervasive among most bicyclist types. Only sophisticated bicyclists with highly developed skills of riding bikes in traffic and high levels of confidence in those skills perceive little value in and are critical of bike lanes.

- Bike lanes are more readily implementable than the comparable "wide outside lane" bike route treatment. If street space is to be allocated with specific intent of providing for bicyclists, in a pragmatic sense it is more likely to be implemented when the end result is a discretely defined space rather than a shared, undefined travel area. This is true whether space is to be provided by adjusting existing roadway uses or by construction of additional roadway width.

An analysis of critical behavior and fault in bike-motor vehicle collisions occuring on streets with and without bike lanes and used by a common motorist/bicyclist population indicates that bike lanes significantly reduce the following accident types in addition to reductions in the overtaking/sideswipe category:*

- Accidents in which cyclists exit a driveway or alley into the path of a motorist; (Up to 87 percent reduction with bike lanes. This category comprises about eight percent of all reported bicycle accidents where bike lanes are not present.)

- Accidents in which motorists exit a driveway or alley into the path of cyclists; (Up to 50 percent reduction with bike lanes. This category comprises about five percent of all reported bicycle accidents where bike lanes are not present.)

- Accidents caused by drivers opening car doors into the path of the cyclists; while analysis indicates substantial reduction percentages in this category, statistical reliability cannot be demonstrated on the basis of existing data. This category accounts for up to seven percent of total bike-motor vehicle collisions.

- Accidents caused by wrong-way bicycle riding. (Up to 72 percent reduction with bike lanes. This category comprises about 16 percent of all reported bicycle accidents where bike lanes are not present.)

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*The following data were derived from studies in Davis and Santa Barbara, California as detailed in the Final Report -- Safety and Location Criteria for Bicycle Facilities -- FHWA Contract No. DOT-FH-11-8134.

Protected Lanes

Protected lanes are a major variant of the on-street bike lane concept. They differ 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 common bike lane and the protected lane concept, but are similar in operation to the common stripe delineated on-street lane.

Figure 4 illustrates a typical form of protected lane with the lane placed between the curb and the parking apron. Bumper blocks normally employed in parking lots are used for protection. Raised berms, traffic bars, or possibly even right side parking lane stripe delineation would be equally effective.

Problems experienced with typical installation of protected bike lanes include:

- Conflict with opening of car doors into narrow and restricted bike lanes;
- Sight distance problems at driveways and intersections;
- Cyclist difficulties in crossing the street at mid-block to get into and out of the proper directional lane (leads to bi-directional use);
- Bi-directional use (creates bike-bike conflicts and accentuates conflicts at driveways and intersections);

Figure 4: TYPICAL PROTECTED LANE (Davis, California) NOTE USE OF CONCRETE "PARKING LOT BUMPER BLOCKS" AS BARRIER

- Maintenance problems (result in debris accumulation); and

- Barrier delineation, often interpreted as striping (thereby creating hazard for cyclist).

Because of these kinds of problems, employment of the protected lane is generally not recommended although in special situations this may be a valid treatment.

Bike Routes

Signing a street or system of streets and ways as a "Bike Route" has been a first step in many jurisdictions' attempts to provide bicycle facilities. Unfortunately, signed routes have been used as temporizing devices to create the illusion of providing facilities by public officials who are unconvinced of bicycle facility needs or uncertain of how to implement more advanced types of treatment. This is one reason why signed bike routes have frequently been criticized as being ineffective. Experience has also shown that:

- There is no evidence that safety is improved by the mere presence of a "Bike Route" sign.

- Cyclists are unwilling to ride any distance out of their way to use a signed bike route that offers no obvious travel or safety advantages.

Properly used, however, the signed bike route is an effective tool to designate specific linkages within the framework of a bikeway plan where provision of more advanced treatments is not possible. They are also useful in guiding bicyclists to streets having characteristics inherently attractive to bicyclists. This guidance is of particular value to the first-time or infrequent users who are unfamiliar with route alignment such as recreational riders.

Several treatments of signed bike routes have been utilized depending upon street characteristics, opportunities and policies. These include the following examples:

- Minimum width: conditions along the street require cyclists to ride within a travel lane which only minimally meets motor vehicle lane width requirements. Signing a bike route under these conditions is not recommended unless there is no alternative for providing bikeway system continuity.

- Wide outside lanes are available along some streets, thereby providing basic space for joint lane occupancy by motor vehicles and bicyclists. This is a desirable situation although one which does not always exist at the right location. If wide right-hand lanes do not exist along the desired street, then it may be possible to create them by removing parking form one side of the street and striping an offset centerline. A bike route must be located properly if it is to have value. Therefore, just because a street has wide curb lanes or can be easily modified does not necessarily mean that it should be designated as a bike route.

- Bike priority streets are intended to enhance bicycling while de-emphasizing the motor vehicle. This is a useful concept which can be achieved by taking advantage of special circumstances or modifying traffic control. One example is where neighborhood traffic control devices, such as diverters and semi-diverters are employed. This traffic management strategy can allow for continuous bicycle travel through an area while limiting motor vehicle travel to neighborhood access trips.

  Another type of bike priority street is one which essentially involves a change in the operating rules rather than a physical treatment. The street is declared a bikeway, a facility primarily intended to serve bicycles. Motor vehicles are allowed to travel on the street but required to yield to bicycles in any conflict situation. In Seattle, such a treatment has been successful along a street with low traffic volumes, low vehicular speeds, high parking density and low parking turnover rate.

Before signing a street as a Bike Route, hazards to cyclists must be corrected. This includes features such as gaping inlet gratings, pot holes, ragged pavement, critical sight distance restrictions and traffic control device deficiencies.

Sidewalk Treatments

In proper circumstances and settings, sidewalk bikeways can be attractive and effective facilities. But too often, sidewalk treatments are employed because space for more desirable facilities is not readily available or simply as a way to get bikes off the street.

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.

A Class II bikeway can be created by striping or otherwise visually delineating separate areas of a sidewalk for cyclists and pedestrians. These facilities suffer from many of the same deficiencies as the Class III facilities discussed below. Moreover, the extent to which pedestrians respect the spatial delineation varies considerably.

Experience with sidewalk bikeways, particularly those in the Class III category, has been largely unsatisfactory. Among the factors contributory to this experience are the following:

- Poor sight distances and visibility relationships prevail at driveways and intersections.
- Sidewalk bikeways appear to induce differences in bicyclist and motorist expectations regarding right-of-way at intersections.
- Bi-directional usage is prevalent despite signs and marking to the contrary.
- Sharing space with pedestrians creates substantial conflict. This is particularly true with the elderly and handicapped persons.
- Small children frequently use the sidewalk as a play area making the sidewalk ineffective as a travel lane for bicyclists.
- Sidewalk surfaces often offer a poorer quality ride than the pavement of the streets they parallel, particularly if an old existing sidewalk is simply pressed into service.
- Curb ramps at intersections are often poorly designed and at times cause bike tire or rim damage. In some cases no curb ramps are provided, increasing the inconvenience of using the sidewalk.
- In many cases, existing sidewalks are too narrow to function effectively.
- 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 sidewalk bikeway.

Interviews with bicyclists indicate that their willingness to use a sidewalk bikeway is related to the purpose of the bike trip and their skill and confidence. Commute riders expressed general dissatisfaciton with sidewalk bikeways. Recreational riders were at times satisfied with the level of service if the alternative was a busy city street. Young and unsure riders were inclined to accept sidewalk bikeways even though many were conscious of some problems cited above.

No substantive accident data is available to quantify the the effect of sidewalk bikeways on safety performance. Observational and inferential evidence does indicate that safety qualities of sidewalk bikeways are compromised when bicyclists exhibit behavior characteristic of motor vehicles; conditions are more satisfactory when bicyclists behave in a manner more typical of pedestrians. Regardless of safety performance, substantial cyclist avoidance of sidewalk facilities is observed particularly when functional quality of the specific bikeway is poor.

For these reasons the following recommendations regarding application of sidewalk bikeway treatments are made:

- Where opportunities exist to provide sidewalk bikeways of appropriate pavement width and surface quality on long stretches uninterrupted by cross-streets or driveways and where little pedestrian activity is anticipated, such provision is acceptable.

- Sidewalk bicycle facilities are generally unacceptable in areas of intense pedestrian activity such as along central business district streets.

- In areas having considerable pedestrian activity but with long stretches uninterrupted by cross streets and driveways, sidewalk bikeways are acceptable. A typical example is a beachfront promenade. In such instances, creation of a Class II facility by delineation of separate bicyclist and pedestrian areas may be desirable.

- Joint bicyclist-pedestrian use of sidewalks on bridge structures is frequently desirable. If space permits, creation of a Class II facility by delineating separate bicyclist and pedestrian areas is desirable.

- Sidewalk bikeways should generally not be provided in areas having inadequate sidewalk width, frequent cross streets and driveways, and probability of some conflict with pedestrians. Sidewalk bikeways may be provided in these circumstances if no other acceptable alternatives for bicycle facilities exist in the corridor. But such provision should be made only to provide an opportunity for those cyclists who desire it; cyclists should not be mandated to use sidewalk bikeways of this character.

- In some areas sidewalk bikeways specifically directed to a population of young and uncertain cyclists may be acceptabale. If these are to be effective as a safety measure, it is necessary that users yield posture to traffic at intersections. When facilities of this character are provided, other cyclists should not be forced to use them.

THE DESIGN CYCLIST

No single "design cyclist" can be identified as a basis for physical design. This is because of the range of variation in individual bicyclists' traffic judgment and riding skill, physiological capabilities to propel their bicycle, and purpose of riding. As a result, the emphasis placed on certain design qualities will depend upon the anticipated mix of user types; alternatively, planning objectives in providing the facility may dictate design for a specific user group.

Due to variance in user characteristics and differences in inherent constraints and opportunities on each site considered, no specific bicycle facility treatment can be identified as having universal applicability. Design cyclist as well as design treatment must be selected on a case by case basis considering potential users and site qualities.

User Characteristics

Functionally, there are two distinct types of bicycle activity -- utilitarian travel and recreational riding.

- Utilitarian bicyclists use the bicycle for some purposeful trip -- to school, to work, to shop, etc. Utilitarian bicyclists tend to be sensitive to the functional service qualities of the bikeway. They are willing to trade-off amenity and, to some extent, safety in order to get where they wish to go and to maximize the efficiency of their effort in propelling themselves there.

- For recreational bicyclists, by contrast, the act of riding and the enjoyment of it is the total purpose of the trip. Recreational bicyclists tend to place higher value on amenity and safety qualities. Since the trip itself is the purpose, scenic routes with overlooks, meanders, points of interest and even hills to add challenge are desirable features of the recreation oriented facility.

Differences between utilitarian and recreational bicyclists should not be cast as differences of personal traits but rather a function of differences in the type of activity temporarily engaged in. While there are numbers of persons who use a bicycle solely for recreation or solely for utility purposes, there are equally large numbers of persons who ride a bicycle for both types of activities. Thus, except in unusual circumstances, it is not the specific traits of the population which dictate whether utilitarian-oriented design should be emphasized in considering bikeway alternatives within a corridor. Rather, it is the inherent character and siting of the corridor which dictates whether it will be used predominantly by individuals on utilitarian, recreational or both types of trips and, hence, whether recreation-oriented or utilitarian qualities should be emphasized in design.

Whether a facility serves predominantly utilitarian, recreational or both types of bicycle trips, there is large individual variation in types of persons who might use it. There is a wide range of bicyclist skill and experience:

- At one end of the spectrum are extremely young bicyclists having limited experience in traffic judgment, incomplete knowledge of or respect for the rules of the road, and incompletely developed motor skills for controlling a bicycle, who may well be riding a bicycle too big for them.

- At the other end of the spectrum are highly sophisticated bicyclists often riding bicycles specially designed for their physical needs and uses. They typically have highly developed physical and judgmental skills essential to effective riding in traffic, and a strong confidence in these skills and willingness to use them.

Falling in between are large numbers of cyclists with varying degrees of skill and experience and varying degrees of willingness to rely upon that skill and experience in traffic situations.

Equally significant are variances in physiological work capabilities -- the ability to propel oneself on a bicycle. The typical active "club cyclist" is generally capable of physical work efforts some 50 percent higher than the typical member of the casual cycling population, and nearly 100 percent greater than post-coronary patients who ride bikes as prescribed exercise. This tremendous variation in basic human capabilities, which affects such important design considerations as grade-climbing ability, acceleration potential and riding speed, cannot be overlooked.

In summary, bicycle design must be done in the context of the wide range of potential users. The design specifications which follow will provide several parameters related to several possible user types. <u>It is the designer's task, at the outset, to identify the probable users of the facility and to determine the extent to which needs of diverse user traits are served.</u>

CHAPTER 3

THE BIKEWAY DESIGN PROCESS

INTRODUCTION: THE ISSUES

While most of this manual focuses on specific criteria for such bikeway design features as horizonal and vertical clearance, design speeds, grades, intersection treatments, and signing, a framework for application of these criteria must be established which addresses the following three issues:

Issue 1

Where and how do design criteria enter the process of facility design?

Issue 2

How does the design effort fit into its larger context of bike facility planning?

Issue 3

How are conflicting design objectives used to create the most appropriate design?

These are not complex issues, nor do they require a complex design process. In this chapter a simple straightforward process is suggested for their resolution. In keeping with this simplicity, this chapter itself is brief, in contrast to the somewhat more detailed treatment of the overall planning process discussed in Volume I.

ORGANIZATION

In the next section is presented a brief description of the suggested design process and its relationship to the overall bikeway planning process. Following it is an explanation of the role of design criteria in the process.

The remainder of the chapter deals with each step in the design process.

THE PROCESS IN BRIEF: DESIGN VS. LOCATION

In Volume I is presented a detailed description of a bikeway planning process. That process has as its objective the selection of a route location. It emphasizes the need for a clear early definition of the problems and objectives to be addressed, followed by generation and detailed study of alternatives, their evaluation, and final selection.

This volume's primary concern is not with location but with specific facility design. However, its structure is similar, although simpler than the more comprehensive locational planning process. Its basic sequence is as follows:

1. Familiarization with design criteria

2. Field reconnaissance

3. Inputs to locational planning

4. Detailed study and evaluation

5. Final design and costing

More steps could be defined within this framework, but are generally unnecessary. It is important to recognize the linkage between this design process and the broader locational planning process. The connection is simple: One of the most influential determinants of location is the feasibility of acceptable design at the alternative locations. Thus design criteria are essential components of the selection of a location. This means that the field reconnaissance of alternative route locations must include at least a general evaluation of design possibilities. This then becomes a source of important information in the evaluation and selection of route locations.

Thus the design process must parallel the selection of a route location. Subsequent to the selection of a location, the design process continues with more specific selection of design solutions, their final design, and costing.

DESIGN CRITERIA IN THE PROCESS

As just shown, one important role for design criteria is to enable an early assessment of design feasibility as an aid in route location. This requires an awareness of design criteria before making a route reconnaissance.

Another role is presented later in the design process, in the detailed evaluation of design options along a selected route. Here the design criteria of this volume provide the basic rules for design, against which constraints such as cost can be balanced to arrive at a design choice.

STEP 1: FAMILIARIZATION WITH DESIGN CRITERIA

Little need be said about this step. It should be obvious that the planner must be familiar with design criteria before entering into any facility planning process. Thus a clear understanding of the material presented in this manual -- as well as its companion, Volume I -- is required as a first step.

STEP 2: FIELD RECONNAISSANCE

In the planning process outlined in Volume I a field reconnaissance of the areas to be served and their potential corridor locations is an early step. An important element in conducting such a reconnaissance is identification of route options which cannot meet -- or meet only with clearly unacceptable costs or difficulties -- the basic design criteria of this volume.

Identification of significant problem areas and opportunities along each route is mandatory so that bikeway design, mitigating safety measures, and alternative route considerations will be based upon factual criteria. The recommended solutions growing from these studies can then be sensitive to the composite of real life conditions and be able to provide optimum benefits.

The following listing summarizes the elements of a field reconnaissance process:

- Be familiar with site-specific data, such as land use, accident experience and traffic characteristics (e.g., traffic flow, speeds, volumes, etc.), before beginning the field review.

- Schedule review in a logical sequence so one route or site is completely analyzed before proceeding to the next and evaluation of connecting or adjacent locations is coordinated to maximize efficiency in the field.

- Perform evaluation during times most critical to the operation of the route. This implies peak periods for commute routes and weekends for recreation-oriented facilities. Particular emphasis should be given to analyzing locations generating bike trips along the proposed bikeway, such as schools, employment centers, and recreation attractions.

- Use a bicycle on the reconnaissance, in order to become thoroughly familiar with riding characteristics and potential conflicts with other travel modes. There is also value in viewing routes from the aspect of these modes -- automobile and pedestrian.

- Utilize a suitable map base as a reference document. Prints made from an aerial photo are a valuable resource for field reconnaissance.

- Record clear and concise notes and sketches to facilitate interpretation in the office. A portable tape recorder can be used to advantage here. Comments and proposed solutions can be keyed to numbered locations on the map base to avoid confusion.

- Carry a camera to record special features.

- Identify features particularly advantageous or critical to bicycle safety and operation, including:

  -- street (sidewalk) width

  -- parking restrictions (full and part-time), configuration and utilization

  -- travelway geometrics

  -- delineation

  -- channelization and striping

  -- exclusive turning lanes

  -- turning movements

  -- driveway frequency and usage

  -- sight distance

  -- congestion

  -- lighting

  -- pavement condition and maintenance

  -- drainage inlets gutters and swales

  -- grades

  -- grade separations

  -- barriers

  While some of these features may already be represented on the base map, evaluation of their effectiveness and implications for bicycle travel are necessary inputs to assure successful comparative analysis of route alternatives.

- Explore opportunities to improve bikeway system continuity and quality such as by:

  -- connecting two dead-end streets to facilitate bicycle and pedestrian access

  -- providing access through the back of a school yard

  -- paralleling or spanning a barrier such as a river or a freeway

- Conduct a brief final field review once all recommendations for route alignments and design have been established to confirm that the entire system is consistent with design and safety criteria and that route continuity is provided to enhance the system for potential users. This technique will allow one last critique with the full plan in mind to identify lingering inconsistencies so that minor modifications may be made before finalizing documentation.

STEP 3: INPUTS TO ROUTE LOCATION PROCESS

Based on the field reconnaissance and appropriate community involvement, some important design contributions can be made to the route selection process. Two questions regarding design must be answered at this stage:

- Are any of the alternative routes inherently incapable of meeting minimum design criteria detailed in this manual?

- Do any of the alternative routes meet acceptable design criteria only with extreme difficulty, cost, or impact?

This requires application of the criteria found later in this volume. In some cases rough cost estimates may be required as well, but generally the level of precision warranted here does not require formal cost computation. For example, if it is known that only a small amount of bikeway funding is available, a route which requires a new bridge across a river may have to be postponed and the funds spent on implementing other important but less costly elements of the bikeway system. Ultimate construction of an expensive bikeway link, such as a bridge, will probably require accumulation of funds as well as cooperative participation between agencies over a period of time.

STEP 4: DETAILED STUDY AND EVALUATION

This step typically commences only after a route location is selected. Its intent is to arrive at a design, including such elements as the route classification, width, location on the right-of-way, basic intersection treatments, and general type and placement of signing.

The elements of this step are as follows:

- Generation of options;
- Preliminary design and costing; and
- Evaluation and selection.

Community participation is vital at this point to assure acceptance of the final design.

Generation of Options

This involves listing of a range of possible design approaches for each identifiable segment of the route. These may include various classes of bikeway, different locations with respect to the street, alternatives to traffic and parking provisions, intersection treatments, and the like, in accordance with the criteria of the chapters to follow in this manual. Community participation or review may be involved, and is especially appropriate at this point.

Preliminary Design and Costing

Here the intent is to specify the alternatives only in enough detail to allow their comparative evaluation. At a minimum, design alternatives of especially high cost or impact on their surroundings (parking, traffic, pedestrians, etc.) should be identified. This information then becomes a major input into the next element, the evaluation.

Evaluation and Selection

A detailed discussion of evaluation of alternatives which involve several criteria at once is provided in Volume I. Although the focus of that discussion is on locational choice rather than design, the principles are the same. Most important is the requirement that the final selection be based on the community's priorities among any conflicting criteria (e.g., facility attractiveness, safety, and cost).

STEP 5: FINAL DESIGN AND COSTING

At this step all the major planning and design decisions have been made. The route is located and the design has been established. What remains is technical engineering design and implementation. This concludes the planning and design process. Yet to follow, although beyond the scope of this manual, is the process of operation, monitoring, and improvement of the facility.

CHAPTER 4

ROUTE AND RIGHT-OF-WAY DESIGN SPECIFICATIONS

INTRODUCTION

This chapter presents eleven sets of specifications for designing the basic physical characteristics of a bicycle route. These sets include requirements for basic width, level of service, capacity, overhead clearance, design speed, horizontal curves, curve widening, stopping sight distance, grades, pavement specifications, and bicycle terminal facilities. (Design elements at intersections are best addressed separately and are covered in Chapter 5.) Except for sight distance, each of the specification sets can be addressed independently in the design process; each must be addressed over the entire route to be designed.

1. BASIC WIDTH REQUIREMENTS

The basic width required for a bicycle facility is related to the quality of service which the designer (or the community) wishes to provide. Research conducted in preparation of this manual has identified six levels of service and defined one level as a minimum. The following paragraphs will detail these service levels and the basic width requirements of each. (See Table 2)

These requirements supercede those which have been presented in previous bikeway planning studies; earlier guides were based on judgment and European specifications which do not completely correspond to American conditions.

2. LEVEL OF SERVICE

Level of service criteria for bicycle facilities (which parallel those defined for motor vehicles and pedestrians in the "Highway Capacity Manual"* and "Pedestrian Planning and Design"**) are as follows:

Level A

> Free flow with low volumes and full choice of velocity and lateral lane position. Average velocity usually above 11 miles per hour.

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*Highway Research Board Special Report 87 "Highway Capacity Manual" National Academy of Sciences National Research Council, Washington, D.C., 1965.

**Fruin, J.J. "Pedestrian Planning and Design" Metropolitan Association of Urban Designers and Environmental Planners, New York, 1971.

Level B

Stable flow with significant volumes and slight slowing of average stream velocity (10.5 to 11 miles per hour), but there is still a reasonably wide range of velocities present.

Level C

Flow is still stable, but speeds are markedly depressed. Maneuverability is restricted and velocity is largely determined by stream/velocity rather than choice. Average velocity is in the 9.5 to 10.5 mile per hour range.

Level D

Flow speed is greatly depressed and maneuverability is highly restricted. Velocity is in the 8 to 9.5 miles per hour range.

Level E

Flow speed is tremendously reduced. Maintaining balance may become a factor. Velocity is in the 6 to 8 miles per hour range.

Level F

Traffic may be stop and go. Flow is very unsteady. Velocity is unpredictable.

SELECTING LEVEL OF SERVICE

Level C conditions should be specified as minimum service quality for engineering design. Levels below this are presented simply to describe service quality, not as design standards. Where feasible and where usage appears to warrant, provision of multiple lanes and level of service A or B conditions is desirable. Where multi-lane facilities are not feasible but width reservation above Level C minimum is possible, such reservation is recommended.

LANE WIDTH REQUIREMENTS

Lane width requirements for bicycle facility design are composed of three components:

1. A basic width related to Level of Service;

2. A "shy distance" to separate the lane from adjacent boundary obstructions; and

3. Space for pedestrians if present.

Basic Lane Width Requirements

Basic bicycle lane width requirements corresponding to levels of service on "free" or boundary-less paths are given on Table 2. Each minimum lane width described in Table 2 serves one bicyclist.

Table 2
BASIC LANE WIDTH

Level of Service	Minimum Lane Width*
A**	50 inches
B**	47 inches
C (Minimum Design Level)	43 inches (Minimum Design Criteria)
D	36 inches
E	30 inches

*Lane widths are defined for a single lane.
**Implicit by definition in Levels of Service A and B is provision of at least two lanes.

Adjustments for Boundary Obstructions

For facilities which have various obstructions at the boundaries of the lane, the following adjustments should be made to the basic lane width (see Table 3).

Table 3
LANE ADJUSTMENT DISTANCES

Boundary Condition	Shy Distance
Bike lane line	- 9.5 inches
Free path	0 inches (by definition)
Continuous lateral obstruction (walls, fences)	+12.0 inches
Curb/Gutter	+12.0 inches, or width of gutter if unrideable
Parked vehicle	+14.5 inches
Intermittent lateral obstruction (poles, trees)	+18.0 inches

Pedestrian Width Requirements

If a bicycle facility shares a right-of-way with pedestrians, a minimum three-foot additional space allocation over that made for bicyclists should be provided.* Only where there is no other reasonable choice should this requirement for additional space allocation be reduced. If a substandard facility is provided and is found to operate poorly under shared use then consideration must be given to requiring cyclist to dismount and walk the bicycle through the critical section. An example of where this might occur would be on a bridge spanning a barrier where there was no other way to cross. Figure 5 shows basic dimension requirements for pedestrians and bicycles.

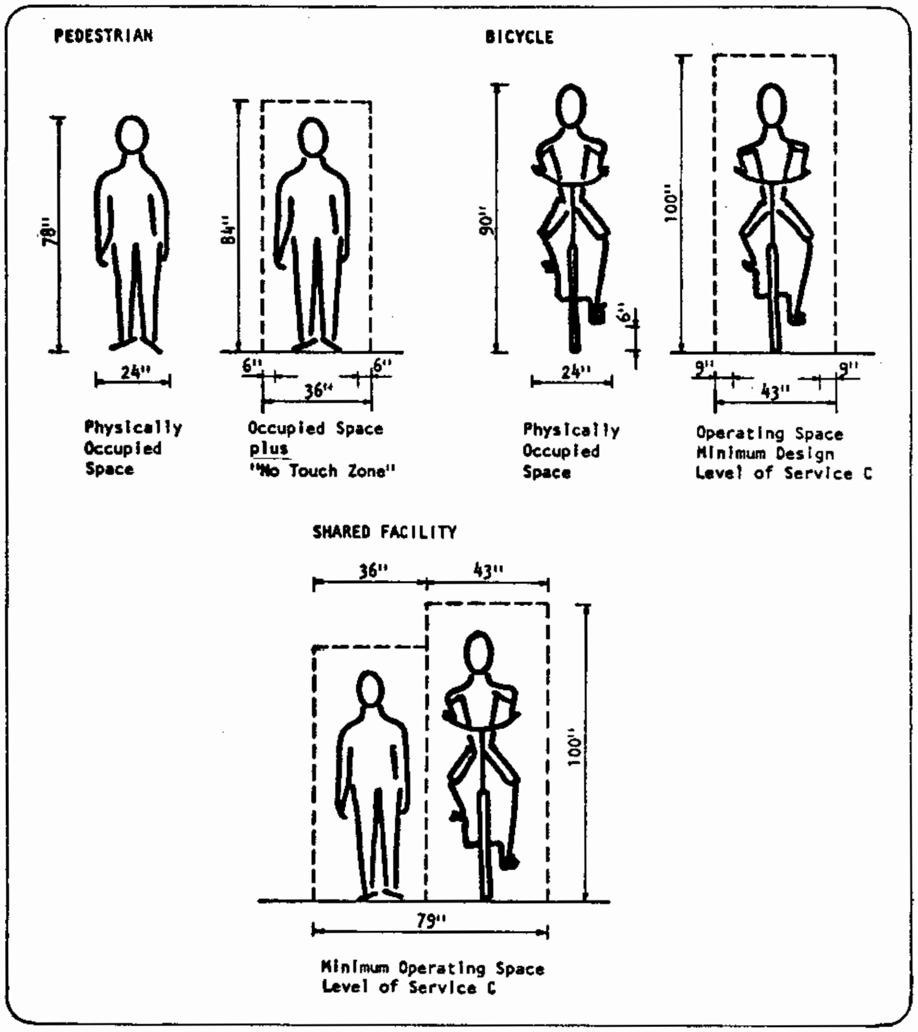


Figure 5
BASIC DIMENSIONS

*Fruin, J.J., "Pedestrian Planning and Design" Metropolitan Association of Urban Designers and Environmental Planners, New York, 1971.

OTHER ROADWAY DIMENSIONS

In providing on-street space for bicyclists, adequate space for other roadway uses must be maintained. Minimum widths for motor vehicle travel lanes are presented on Table 4. Where parking is permitted an eight (8) foot allowance from curb face should be made for the parking shoulder (except where rolled-pan curbs are employed -- seven (7) foot parking shoulder reservations are then acceptable).

Table 4
MINIMUM MOTOR VEHICLE TRAVEL LANE WIDTHS

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

Source: Traffic Engineering Handbook[16]

DESIGN EXAMPLES

Three examples are presented in the following paragraphs where width requirements for bikeways are determined by summing the cumulative effects of various design elements. This exercise should be helpful in establishing an orderly technique for evaluating bikeway width requirements.

First Example

Determine the width of an on-street bike lane located between parked cars and the motor vehicle travel lane where the level of service is C.

Element	Adjustment		
Bicyclist Level of Service C width	+43.0"		
Bike lane line		-9.5"	
Shy distance from parked vehicle	+14.5		
Width requirement	57.5"	-9.5"	= 48.0"

This value compares quite closely with the four feet recommended as a minimum acceptable dimension for bicycle lanes in the "Bikeways -- State-of-the-Art -- 74" report.

Second Example

Assuming "free path" boundary conditions at Level of Service C, determine the pavement width requirement for a one-way bikeway shared with pedestrians. (Note: In addition to walking space requirements a pedestrian might also be considered as having the same effect as an "intermittent lateral obstruction" on a facility where bicyclists encounter only occasional pedestrians.)

Element	Adjustment
Bicyclist Level of Service C width	+43.0"
Free path boundary	0.0"
Intermittent lateral obstruction shy distance	+18.0"
Pedestrian space	+36.0"
Width requirement	97.0" (approx. 8 feet)

Third Example

Determine width where facilities are used bi-directionally only by bicyclists, (Note allowance of shy distance for an intermittent lateral obstruction as in Second Example appears desirable.)

Element	Adjustment
Two bike lanes at Level of Service C	86.0"
Intermittent lateral obstruction shy distance	+18.0"
Width requirement	106.0" (8'8")

This would give a minimum "free" path paved width of 8'7", at Level of Service C, consistent with common recommendations of eight feet in many bikeway planning guides.

It is not always necessary that external shy distance adjustments be made by providing additional paved surface width. Shy distance allowances from obstructions such as trees and fences can be provided by leaving space between the obstruction and the edge of paved surface.

A sample form for use in tabulating bikeway width requirements is shown in Figure 6.

3. CAPACITY

Figure 7 indicates the relationship between bikeway capacity, lane width and level of service. Note that Level of Service A and B conditions cannot be achieved until width for multiple-lane operation is provided.

Typically, bikeway capacity requirements are not readily definable in terms of daily or hourly flow rates. Critical capacity conditions occur when individual bicyclists or groups of bicyclists encounter one another for brief periods of time, and are defined by brief, temporal flow rates.

This does not imply that designers must measure or estimate bicycle flow rates in bikes per second. Level of service conditions as defined in Figure 7 remain constant over virtually the full range of flow rates normally encountered in the most intense urban situations.

Only when flow rates above 0.6 bikes per second -- 36 per minute -- are anticipated (such as at class change periods on a college campus) need the designer be particularly concerned about specific flow rates.

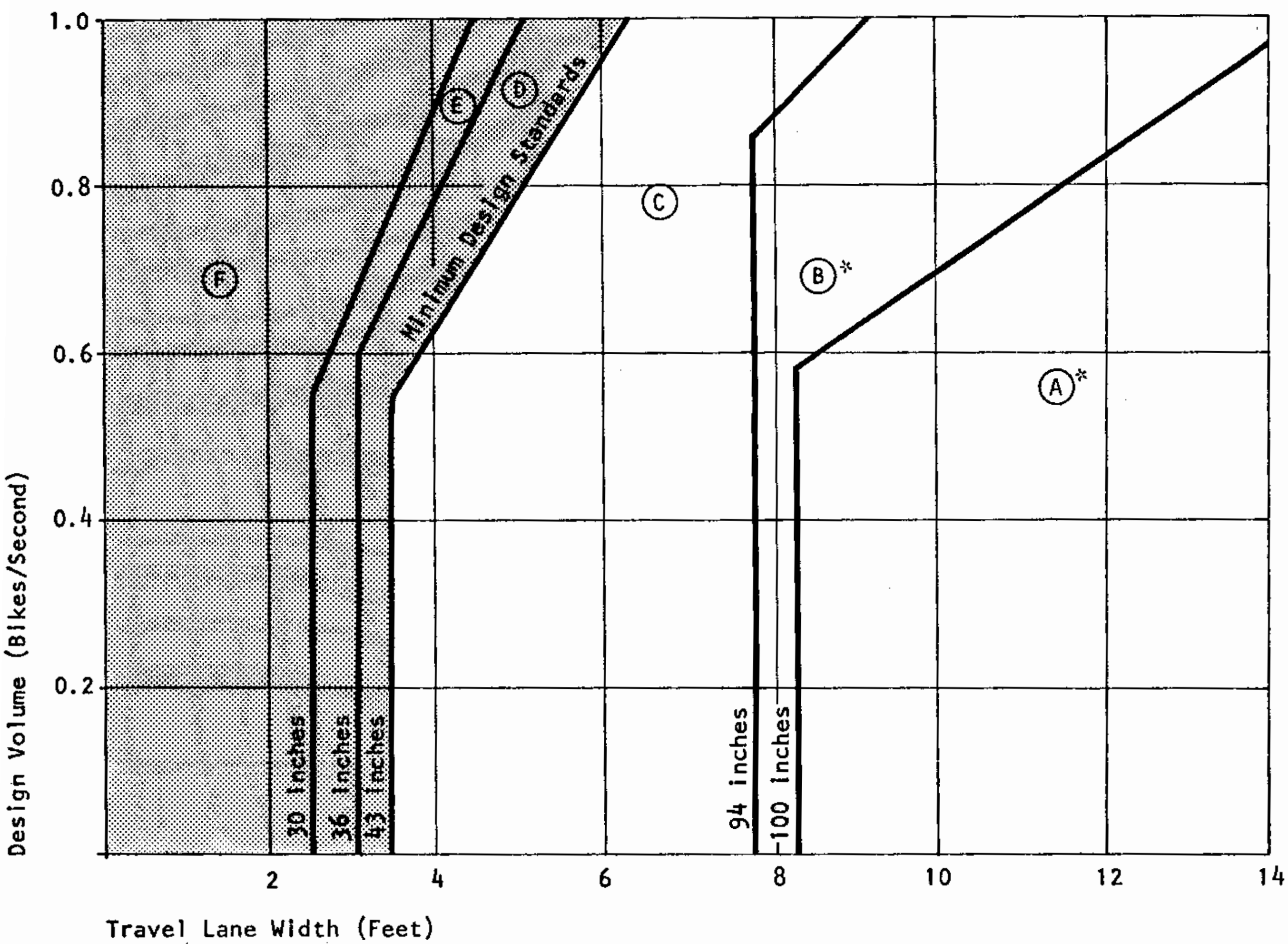
Normally, theoretical capacity is not the critical factor in determining facility width. Once basic service minimums are met, width becomes either a question of how much space can be made available (physical or economic feasibility) or a design policy decision of whether to provide enough width to permit bicyclists in company to ride side by side.

4. OVERHEAD CLEARANCE

Clearance from pavement surface to intermittent overhead obstructions (tree branches, wires, gate portals, etc.) of eight to ten feet is acceptable to users. In the case of continuous overhead obstructions (i.e., the ceiling in an underpass), greater clearance is desirable to improve lighting and sight distance but is not mandatory.

Figure 6
TABULATION FORM
Bikeway Pavement Width Requirements

Element	Factor	Summary (+)	Summary (-)
Level of Service			
A (Two Lanes)	100.0"		
B (Two Lanes)	94.0"		
C One Lane	43.0"		
Other	____		
Boundary Conditions			
Bike lane line	-9.5"		
Free path	0.0"		
Continuous lateral obstruction	12.0"		
Curb/gutter	12.0"		
Parked vehicle	14.5"		
Intermittent lateral obstruction	18.0"		
Other	____		
Pedestrian Requirements			
Minimum pedestrian width	36.0"		
Other	____		
Subtotal			
WIDTH REQUIREMENT			



(D) Level of Service

* Double lane widths required as minimum condition to achieve levels of service A and B.

Figure 7
WIDTH - CAPACITY - LEVEL OF SERVICE RELATIONSHIP

5. DESIGN SPEED

Design speed is a critical factor in providing for adequate horizontal curvature and stopping sight distance; it is also an element in assessing the feasibility of grades. The following paragraphs identify the basis for selecting a design speed.

Speeds achievable on a bicycle range to well above 30 miles per hour on down grades. While on relatively level surfaces speeds are significantly slower as indicated on Figure 8.

From this distribution of bicyclist speeds these points stand out:

- Few cyclists travel at speeds in excess of 20 MPH on level terrain; 85th percentile speed is approximately 15 MPH.
- There are no meaningful differences in typical speed distributions on level Class I, II, and III facilities.
- A design speed of 20 MPH on level terrain would permit free selection of desired speed by nearly all bicyclists. A design speed of 10 MPH as recommended in many early bikeway planning guides would constrain nearly 80 percent of all bicyclists below speeds at which they would normally choose to operate. This could pose a safety concern in addition to frustrating bicyclists.

Different design speed standards must be employed on and in the vicinity of long and/or steep grades.

- On long or steep upgrades, speed of most bicyclists may fall to a range from just above walking pace (4 MPH) to about 10 MPH. Designers must take into account this lower operating speed range in situations where bicyclists mix with or cross motor vehicle traffic on upgrades. In addition it is recommended that upgrade facilities be designed for 20 MPH sight distances and curvatures so that bicycle speeds and not design features are the constraining factors.
- On long or steep downgrades, bicyclist speeds may range well above the distribution shown on Figure 8. In such situations design speeds as high as 40 MPH may be desirable.

6. HORIZONTAL CURVATURE

Empirical studies of turning radius requirements were conducted. A limited number of adult cyclists, riding a standard sized ten speed bicycle made unbraked (coasting) 180 degree turns at various speeds under instructions to turn as sharply as they felt comfortable. Turning approach speed was measured at turn initiation. Full turning trajectory

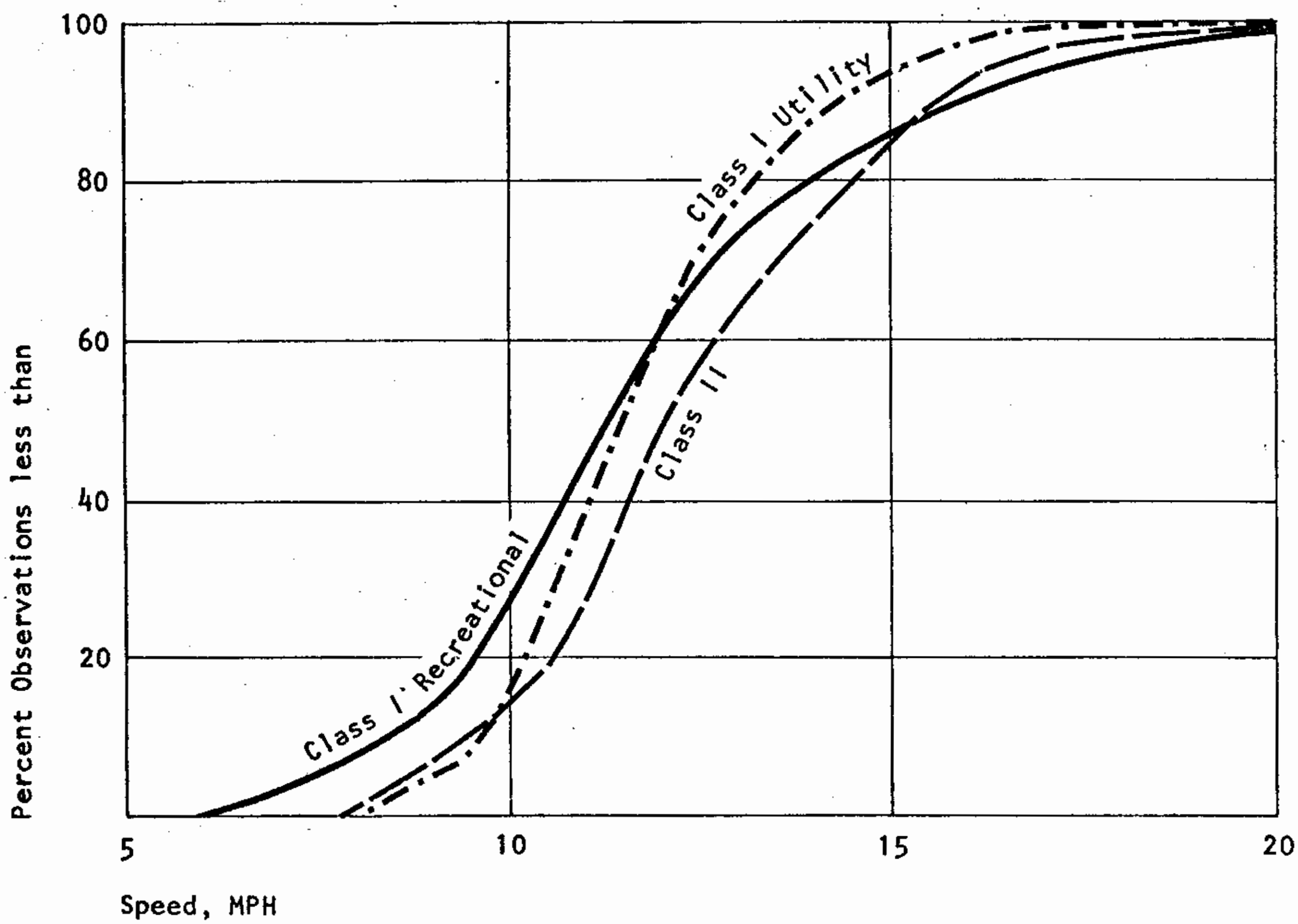


Figure 8
BICYCLIST SPEED DISTRIBUTION

was recorded in polar coordinates about a point on the line perpendicular to the original trajectory which served as the demarcation line for initiation of turns.

Analysis of this data indicates that turning radius of bicyclists can be given by the formula:

$$R = 1.528V + 2.2$$

Where:

V = design speed in MPH

R = curve radius in feet

This equation gives significantly sharper turning radius for bicycles at any given speed than does the adaptation of the standard highway engineering equation for curvature shown on Figure 9. This is partially due to the deceleration (due to air and rolling resistance) of the coasting bicyclist during the turn. The standard highway engineering computation assumes maintenance of constant speed around the curves. It is believed that the empirically derived relationship is more realistic in this regard as cyclists do coast (hence decelerate somewhat) on turns where radius of curvature is limited.

For cases where bicyclist speed is expected to range above 25 MPH, or where it is desirable to permit bicyclists to pedal through turns, curve radius values given in Figure 9 should be used. This figure is based on the standard highway engineering equations and includes provision for superelevation. (Normally, superelevation is unnecessary for bikeways beyond the pitch needed for drainage.) Information for ASSHTO bicycle facility radius of curvature were derived from values shown on Figure 9.

7. CURVE WIDENING

Curve widening is recommended at short radius (less than 100 foot) curves on two-way bikeways or bikeways shared with pedestrians. This is to compensate for increased lane width occupancy due to bicyclists leaning to the inside of a turn. Methodology for curve widening is presented on Figure 10. Maximum widening is limited to four feet.

8. STOPPING SIGHT DISTANCE

Stopping sight distance is given by the formula:

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

Where:
S = Stopping sight distance, ft.
V = Velocity, MPH
f = Coefficient of friction (use 0.25)
G = Grade, ft/ft (rise/run)

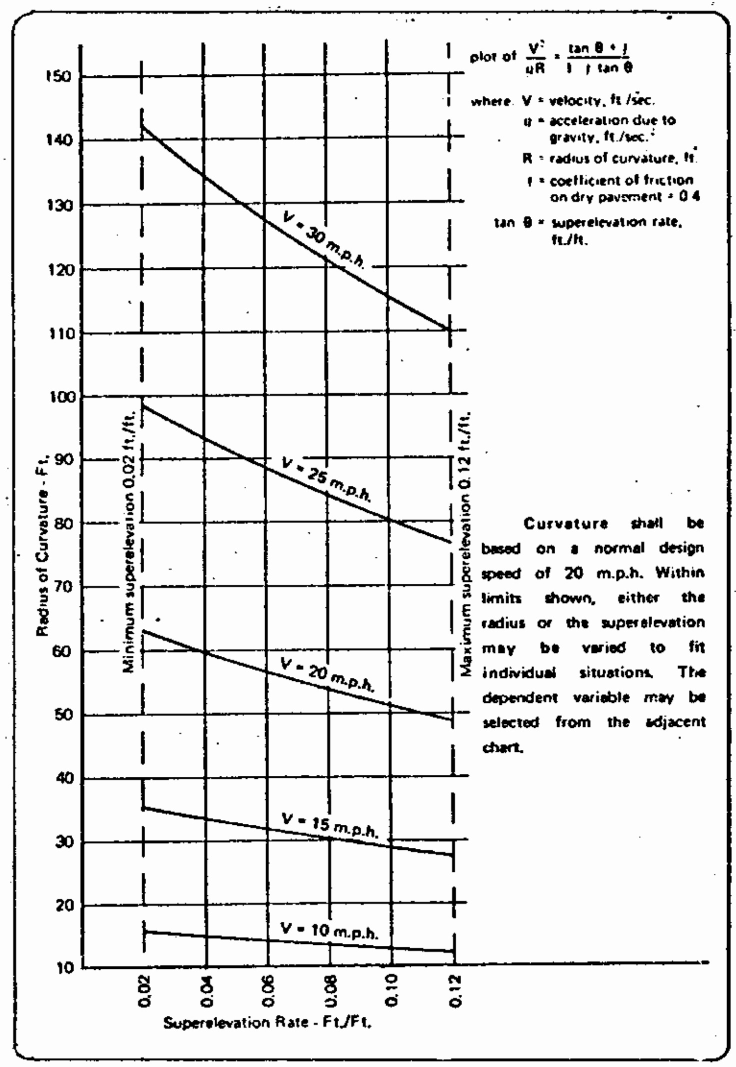


Figure 9
STANDARD SUPERELEVATION FOR BIKEWAYS

Source: Oregon State Highway Division
"Bikeway Design" Manual 1974

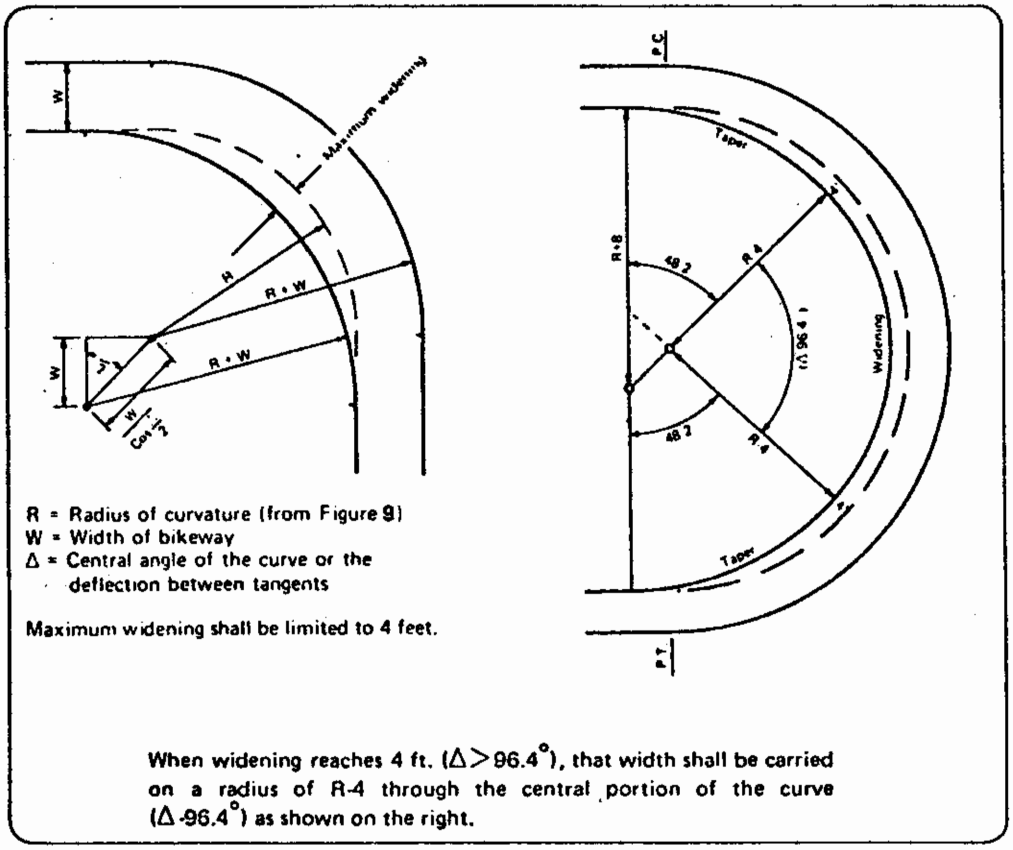


Figure 10
CURVE WIDENING

Source: Oregon State Highway Division
"Bikeway Design" Manual 1974

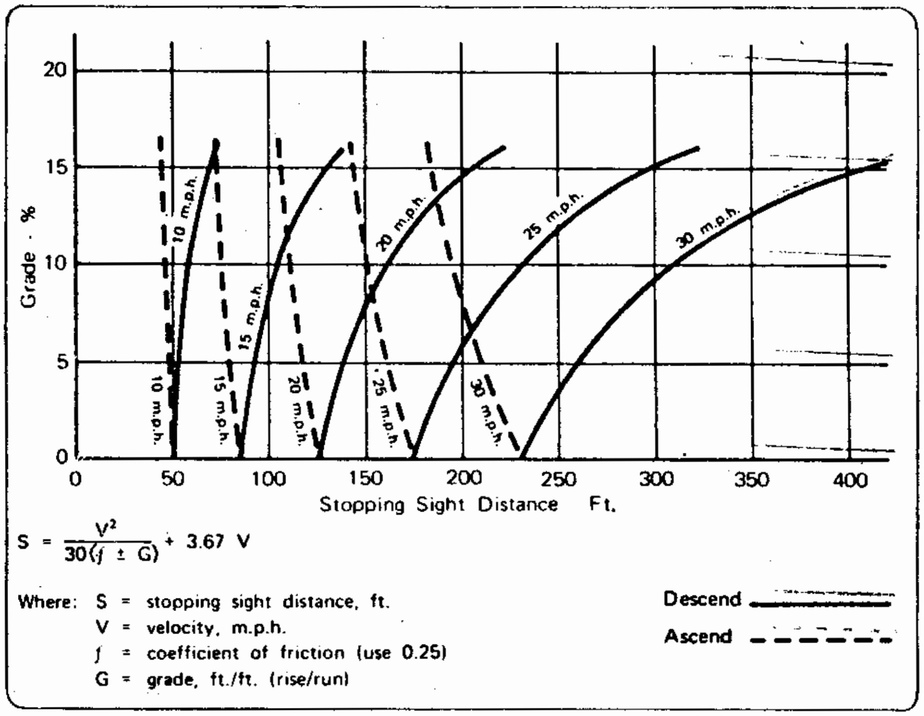


Figure 11
STOPPING SIGHT DISTANCE

Source: Oregon State Highway Division
"Bikeway Design" Manual 1974

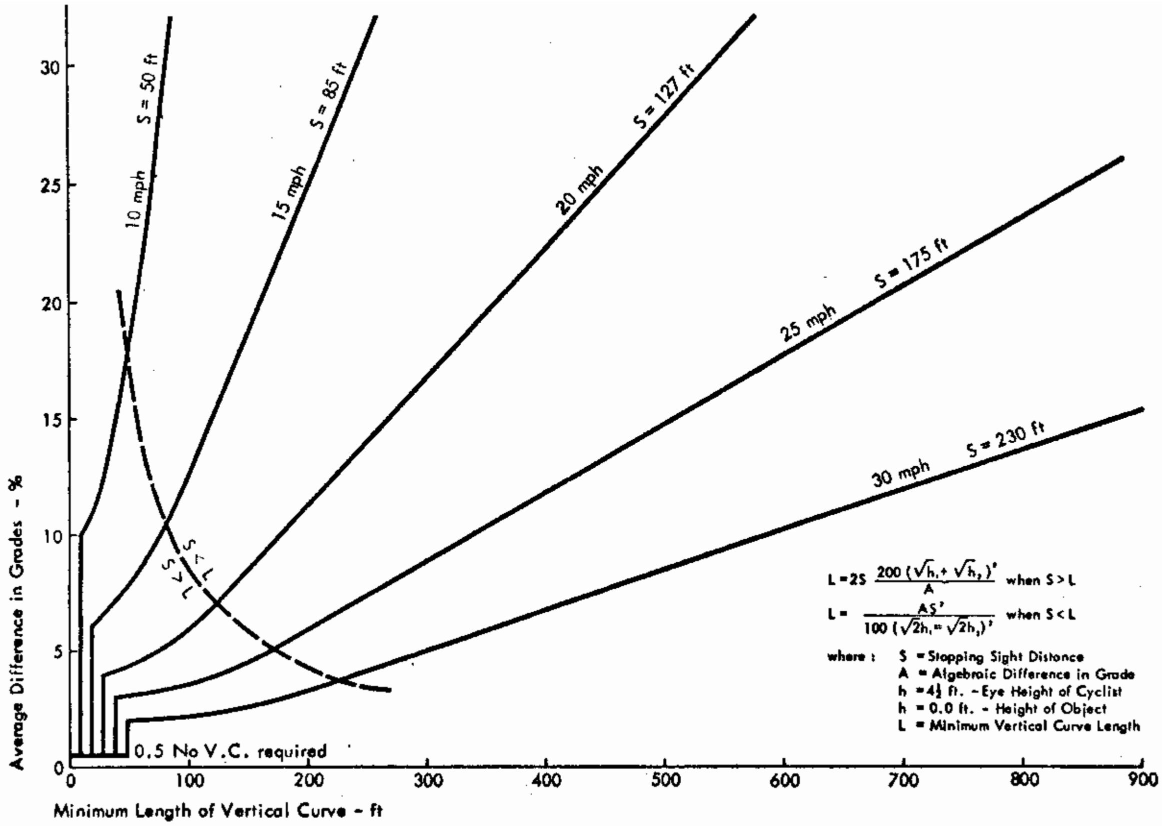
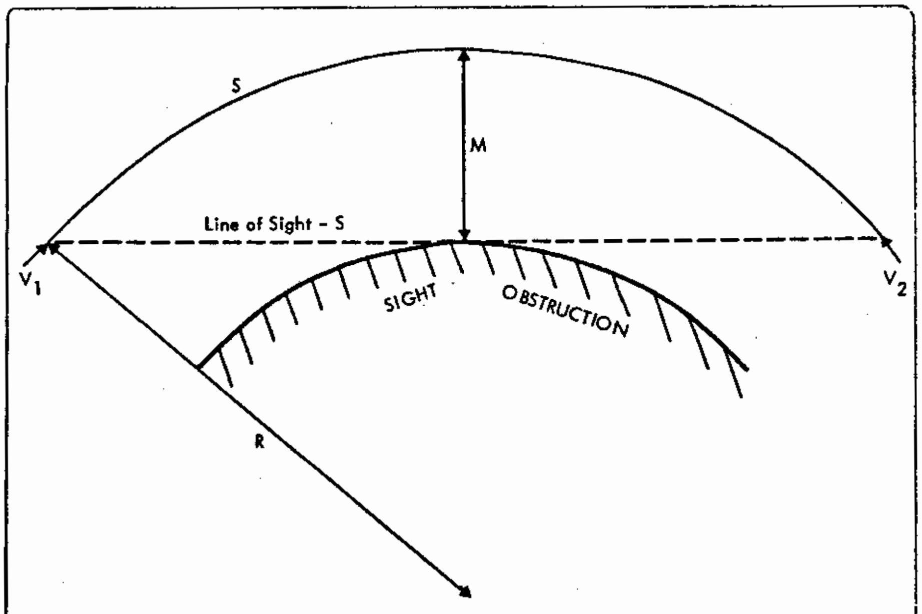


Figure 12
BIKEWAY SIGHT DISTANCE FOR CREST VERTICAL CURVES



R = radius of curvature

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

M = Obstruction offset from lane centerline

$M = R\left(\text{vers } \frac{28.65S}{R}\right)$

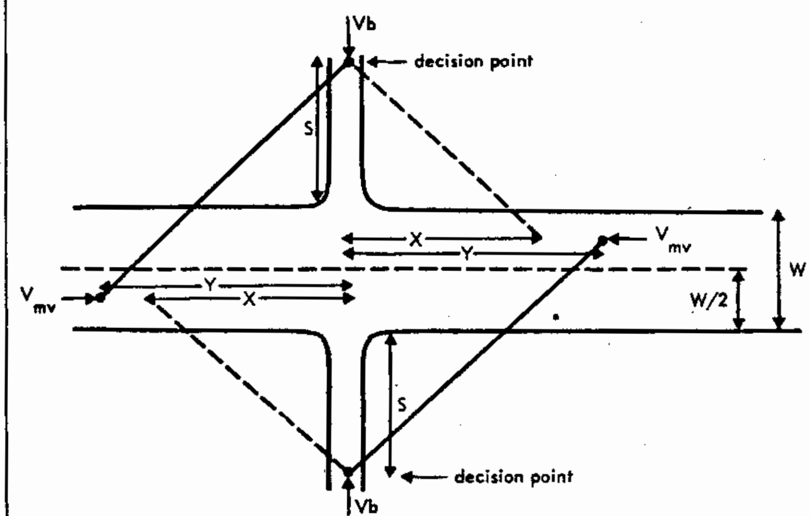
$S = Sv_1 + Sv_2$

Sv_1 = Stopping Sight Distance of Vehicle 1

Sv_2 = Stopping Sight Distance of Vehicle 2

Figure 13
HORIZONTAL SIGHT CLEARANCE

Source: Oregon State Highway Division
"Bikeway Design" Manual 1974



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 14
INTERSECTION SIGHT CLEARANCES

Figure 11 presents stopping distances as per this equation for the range of typical bicycle speeds and on various grades.

Stopping sight distances for cresting vertical curves are presented on Figure 12. The values in the figure are calculated assuming an objective height of zero. Zero object height is assumed because some of the most common obstacles which cause a bicyclist to brake or take evasive action appear at pavement surface level -- such things as potholes, unsafe drainage grates and broken glass.

Method for computation of sight distance and sight clearance area on horizonal curves is presented on Figure 13. Maintenance of adequate sight clearance around wayside obstructions is particularly critical on independent pathways used bi-directionally by bicyclists.

Figure 14 presents methodology for establishing sight clearance triangles at bikeway crossings. Sight clearance areas should be defined to provide guidance for planting policies and location of other sight obstructions. When the bicycle facility is on-street, the greater sight-distance requirements of motor vehicles will normally insure adequate sight clearance zones at intersections. However, these should be checked by field inspection to assure proper lines of sight from the bicyclists' typical position on the roadway.

9. GRADES

Volume I provides a summary of exercise physiology as applied to bicycling. This material provides a scientific basis for design of bikeway grade profiles tailored to the capabilities of an anticiapted user population. The designer is referenced to that material for overall guidance in grade design. Following is an abbreviated presentation of methodology for the typical grade-related decision faced by bikeway planners as a design rather than locational consideration: the short, relatively steep grade as on a grade separation approach. The basic criterion upon which grade acceptability is judged is the amount of work of which a cyclist is capable. For short grades, this criterion is measured by the anaerobic work capability for various design cyclists. Work durations of one-third exhaustion level durations are estimated as reasonable periods bicyclists might be expected to work in the anaerobic range. The basic calculations which follow attempt to determine the length of time over which a calculated quantity of work is performed. Comparisons between calculated and observed limits of working time are made to determine grade acceptability.

Table 5 presents a range of typical bicyclists for analysis purposes. All are presumed to be riding the same three-speed bicycle with gear ratios of 1.9, 2.5 and 3.4 in the closest to optimal gear.

Table 5
REPRESENTATIVE CYCLIST TYPES

Cyclist	Age yrs	Sex	Wheel Dia. D ft.	Tire Infl.prss. T psi	Bike Wt. W_B lb.	Rider Wt. W_R lb.	Max.aerobic work rate	Drag Area A_D ft^2	Comments
1	12	M	2.25	60	35	90	41	3.0	
2	22	M	2.25	60	35	160	41	4.0	
3	30	F	2.25	60	35	130	33	3.5	
4	40	M	2.25	60	35	175	25	4.0	Post coronary subject
5	55	M	2.25	60	35	185	30	4.0	
6	55	F	2.25	60	35	145	25	3.5	

Three speed bicycles were selected as a reasonable "design bicycle" to simplify the analysis procedure. While standard five and ten speed bicycles offer more gears, their maximum range is similar to that of three speed bicycles. In addition most cyclists riding the five and ten speed bicycles do not come any closer to selection of optimal gear ratios than it is possible being in the optimal three speed gear. And further, one speed bicycles are typically most often ridden by younger cyclists who generally are not the critical design cyclists in terms of grade climbing. Precise procedure for accounting for specific gears on each type of bicycle are detailed in the final report.

Analysis procedures for design involve a trial and error solution:

1. Select a grade profile to suit the change in elevation required.

2. Calculate deceleration distance from the base of the grade to the point at which speed drops to a steady-state climbing speed.

3. Subtract deceleration distance from total grade distance -- determine time to climb this distance based on steady-state speed. If grade length is greater than 400 feet, STEP 2 can be omitted and climb time determined for the full grade.

4. Determine aerobic work requirement for various anticipated design cyclists for the chosen grade from Figures 15 through 20. Figure 21 is used to determine aerobic work requirements on long grades.

5. Determine maximum time that each cyclist can work at the above work rate.

6. Compare calculated time for climbing to maximum allowable time each cyclist can work and evaluate for acceptability. If unacceptable, repeat the process under new grade profile assumptions.

The following example details the steps in the calculation.

Sample Design Problem

A grade separation will necessitate an elevation change of 20 feet for bicyclists. No site constraints are present but reasonably short approaches are desired to limit costs.

Solution

STEP 1 The designer assumes an approach grade of eight percent. Grade Length (L) = 20 feet/8 percent = 250 feet.

STEP 2 The distance cyclists' initial momentum will carry then up the hill (L') until a steady-state speed of six miles per hour is reached is approximately by:

$$L^1 = (V_i^2 - V^2) \frac{1}{2_g G}$$

Where

V = Steady state climb velocity (assumes six MPH)

V_i = Initial approach velocity

g = Acceleration due to gravity (32.2 ft./sec.^{2})

G = Grade (ft./ft.)

STEP 3 Assuming an initial approach speed of 15 MPH, L' = 36 feet. The distance cyclists must pedal upgrade at six miles per hour (1) is given by L-L' = 214 feet. Critical travel time (t) = distance/speed = 214 feet/6 MPH = 24.3 seconds.

STEP 4 Next, cyclist work rate on the six miles per hour steady-state segment is computed. Figures 15-20 present work-grade relationships for test cyclists identified in Table 5, each traveling at six miles per hour.

STEP 5 Figure 22 presents duration of time bicyclists can work at various percentages of maximum aerobic work capacity before reaching exhaustion. Work durations of one-third exhaustion level durations are estimated as reasonable periods bicyclists might be expected to work in the anaerobic range. These exhaustion level and reasonable work durations are summarized for each test cyclist on Table 6.

STEP 6 Assessing the results on Table 6 it can be seen that both the 12 and 22 year old males can ride the grade working in the aerobic range; it is well within the limits of their capabilities. The 30 year old female and the 50 year old male would be forced to work in their anaerobic range but the 24.3 seconds required to ride the grade would fall within their duration tolerances. Only the 40 year old post-coronary patient and the 55 year old female would be unable to ride the grade within reasonable limits of effort and duration

Table 6
SUMMARY OF AEROBIC WORK CAPACITY

Subject	Percent Maximum Aerobic Work Capability (k)	Time to Exhaustion	One-third Time to Exhaustion
12-year-old male	114	155 seconds	51 seconds
22-year-old male	95	440 seconds	146 seconds
30-year-old male	134	90 seconds	30 seconds
40-year-old male*	166	42 seconds	14 seconds
55-year-old male	138	84 seconds	27 seconds
55-year-old female	166	42 seconds	14 seconds

* Post-coronary patient.

Here the designer must exercise judgment: The conclusion may be that the grade profile is generally acceptable and that the post-coronary patient will simply have to walk part way up the grade, or more moderate grade profiles will be tested until the post-coronary patient can ride is identified.

That judgment will depend upon site and economic constraints and characteristics of the expected users. For instance, 60 year old male and female cyclists might also be included among the cyclist types tested above.

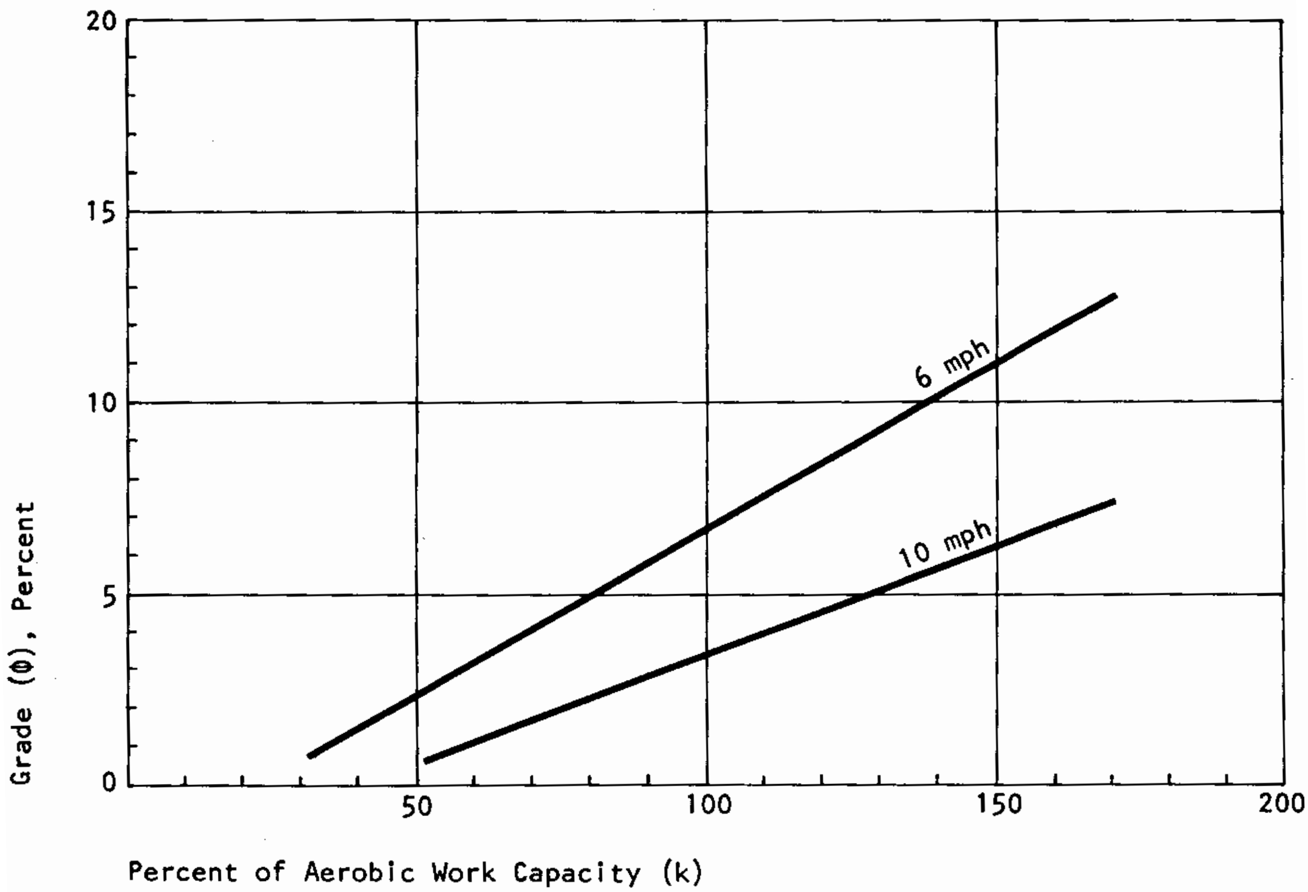


Figure 15
GRADE VS AEROBIC WORK CAPACITY -
12 YEAR OLD MALE DESIGN CYCLIST

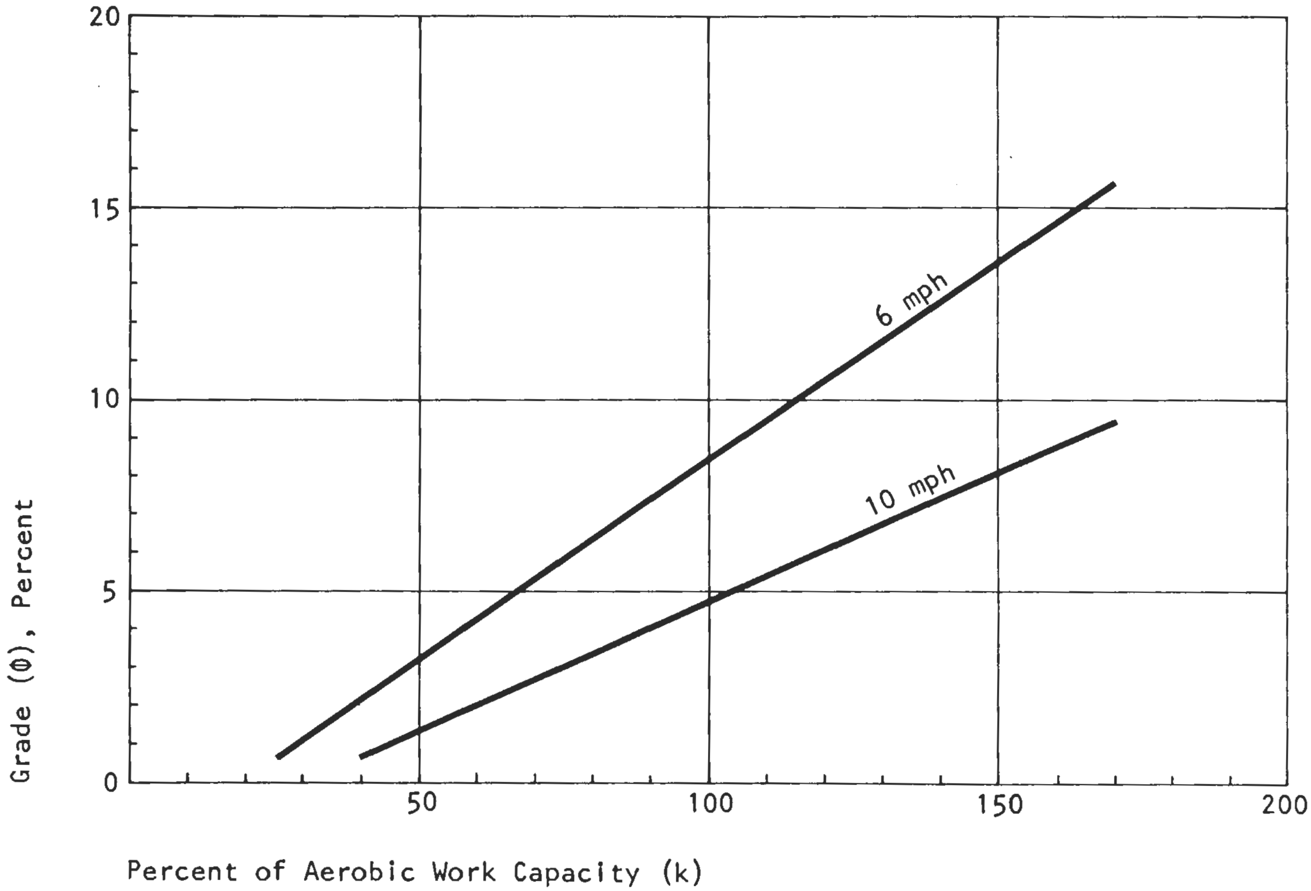


Figure 16
GRADE VS AEROBIC WORK CAPACITY
22 YEAR OLD DESIGN CYCLIST

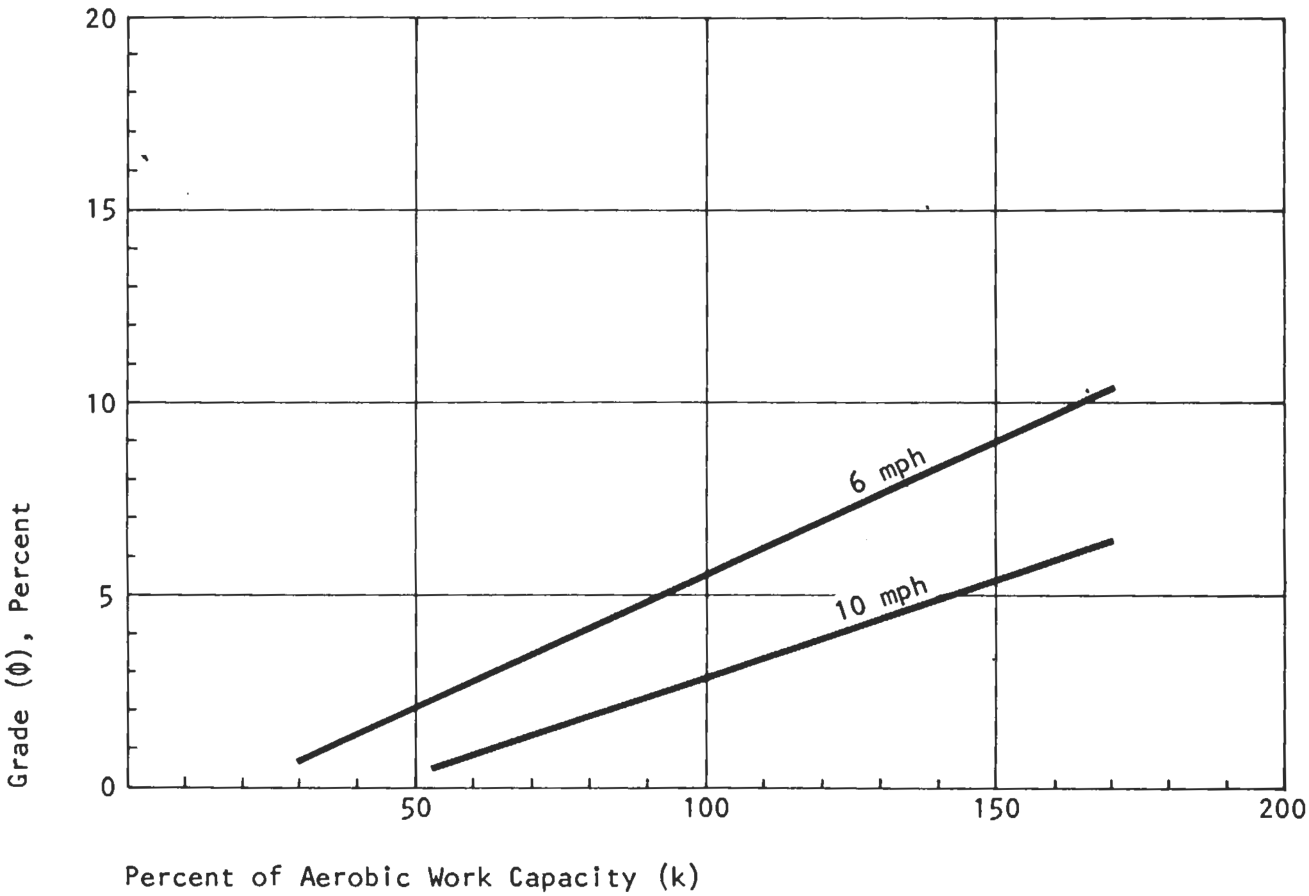


Figure 17
GRADE VS AEROBIC WORK CAPACITY -
30 YEAR OLD FEMALE DESIGN CYCLIST

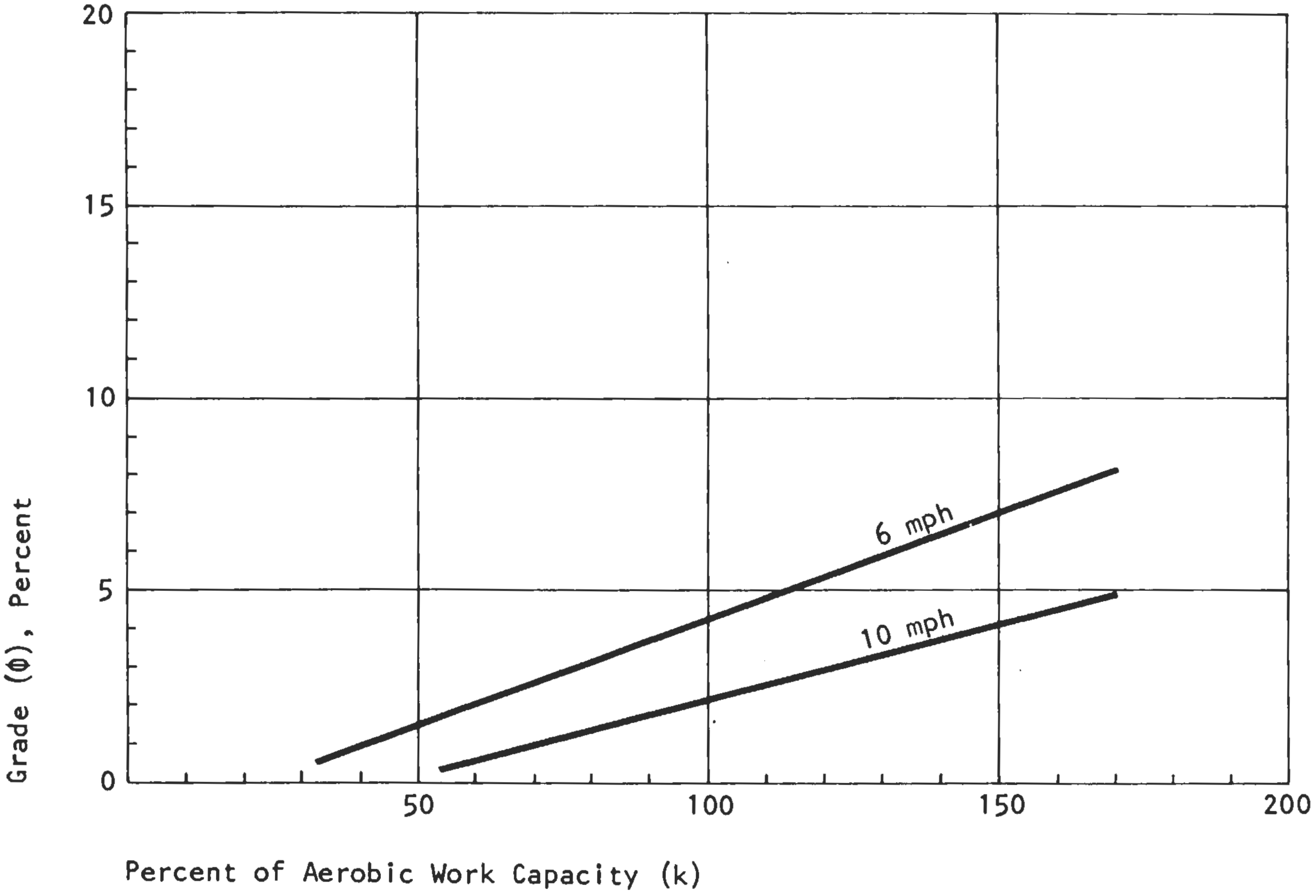


Figure 18
GRADE VS AEROBIC WORK CAPACITY -
40 YEAR OLD MALE (POST CORONARY) DESIGN CYCLIST

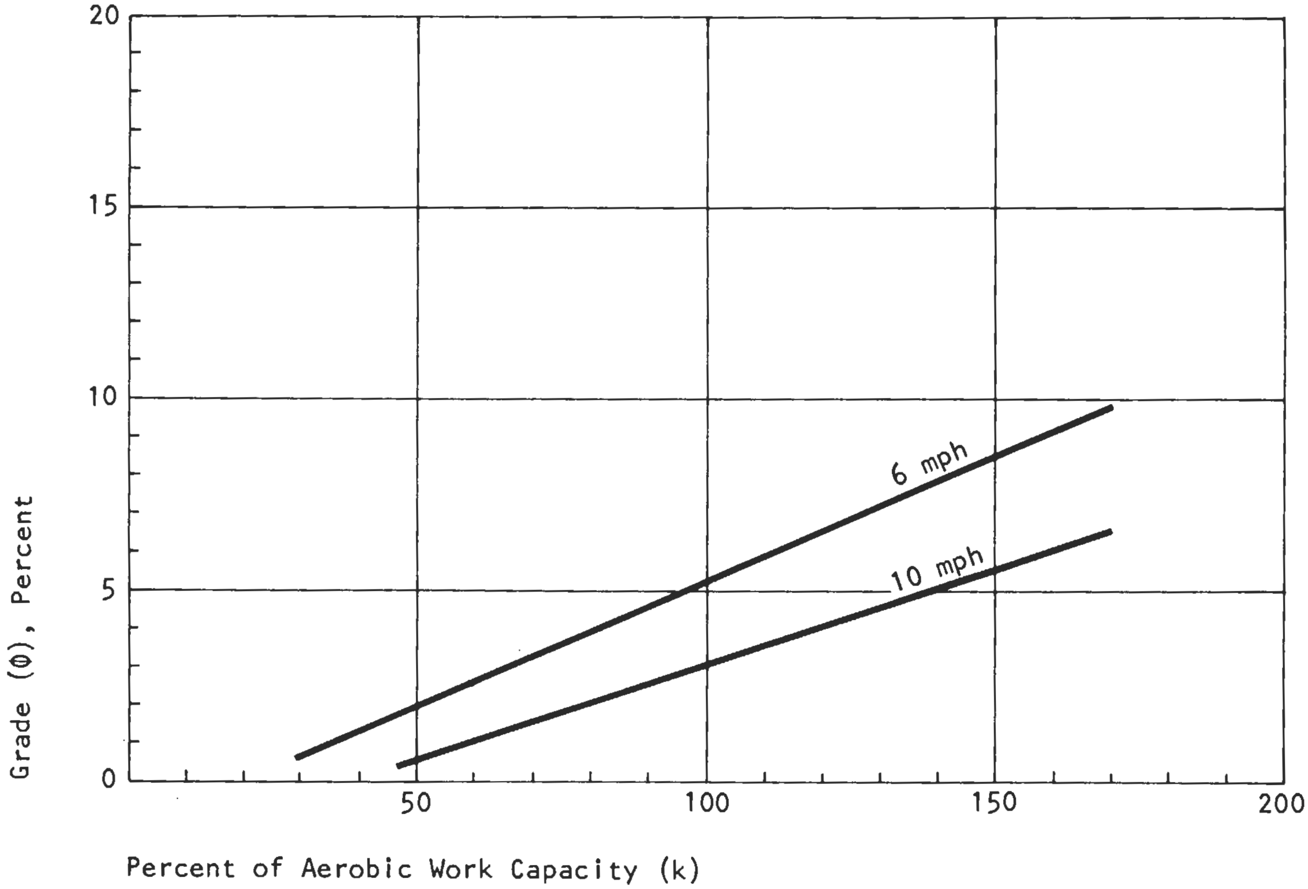


Figure 19
GRADE VS AEROBIC WORK CAPACITY -
55 YEAR OLD MALE DESIGN CYCLIST

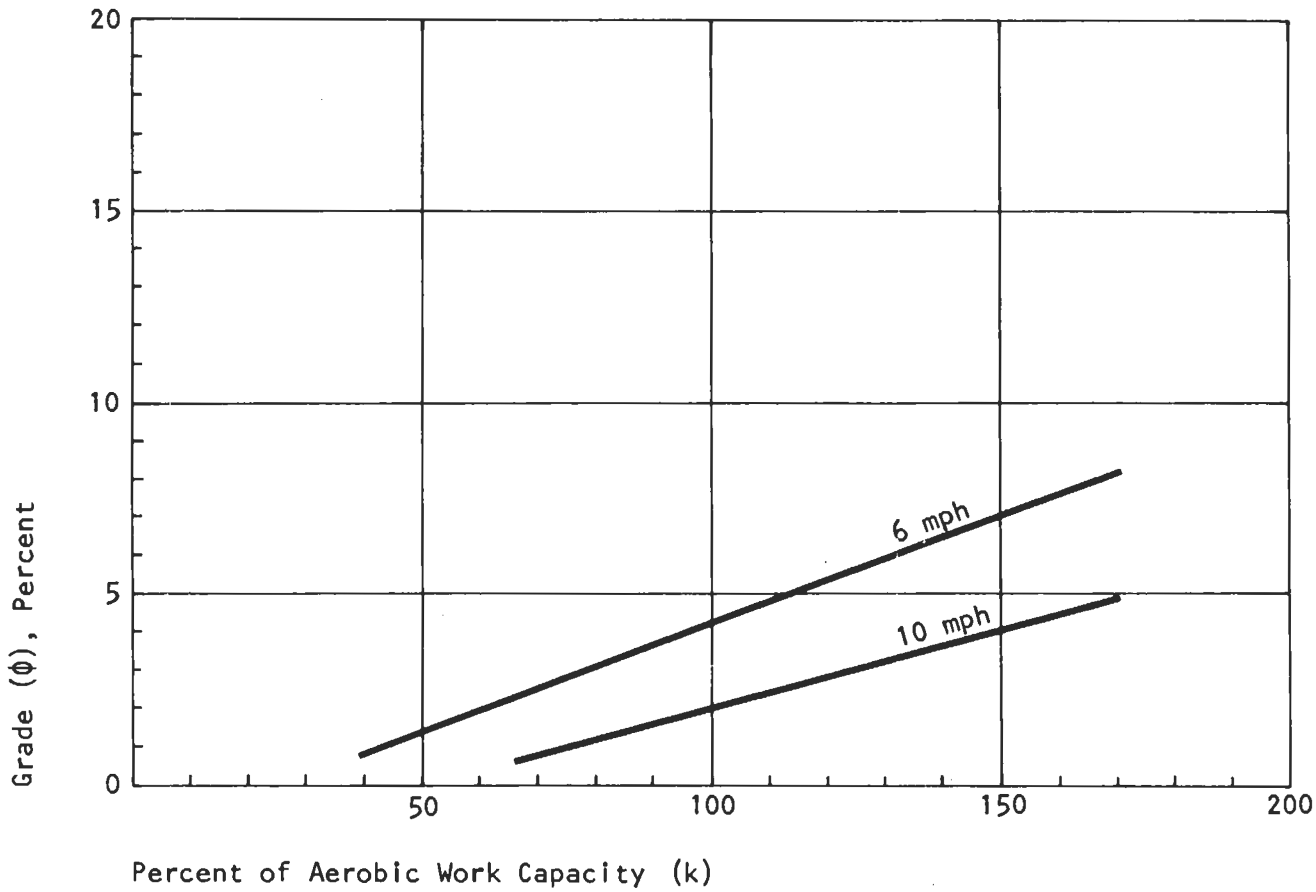


Figure 20
GRADE VS AEROBIC WORK CAPACITY -
55 YEAR OLD FEMALE DESIGN CYCLIST

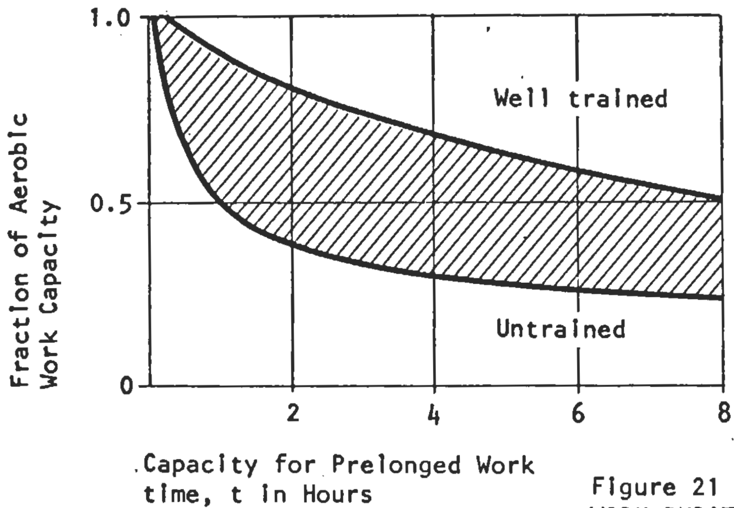


Figure 21
WORK DURATION CAPABILITY AEROBIC RANGE

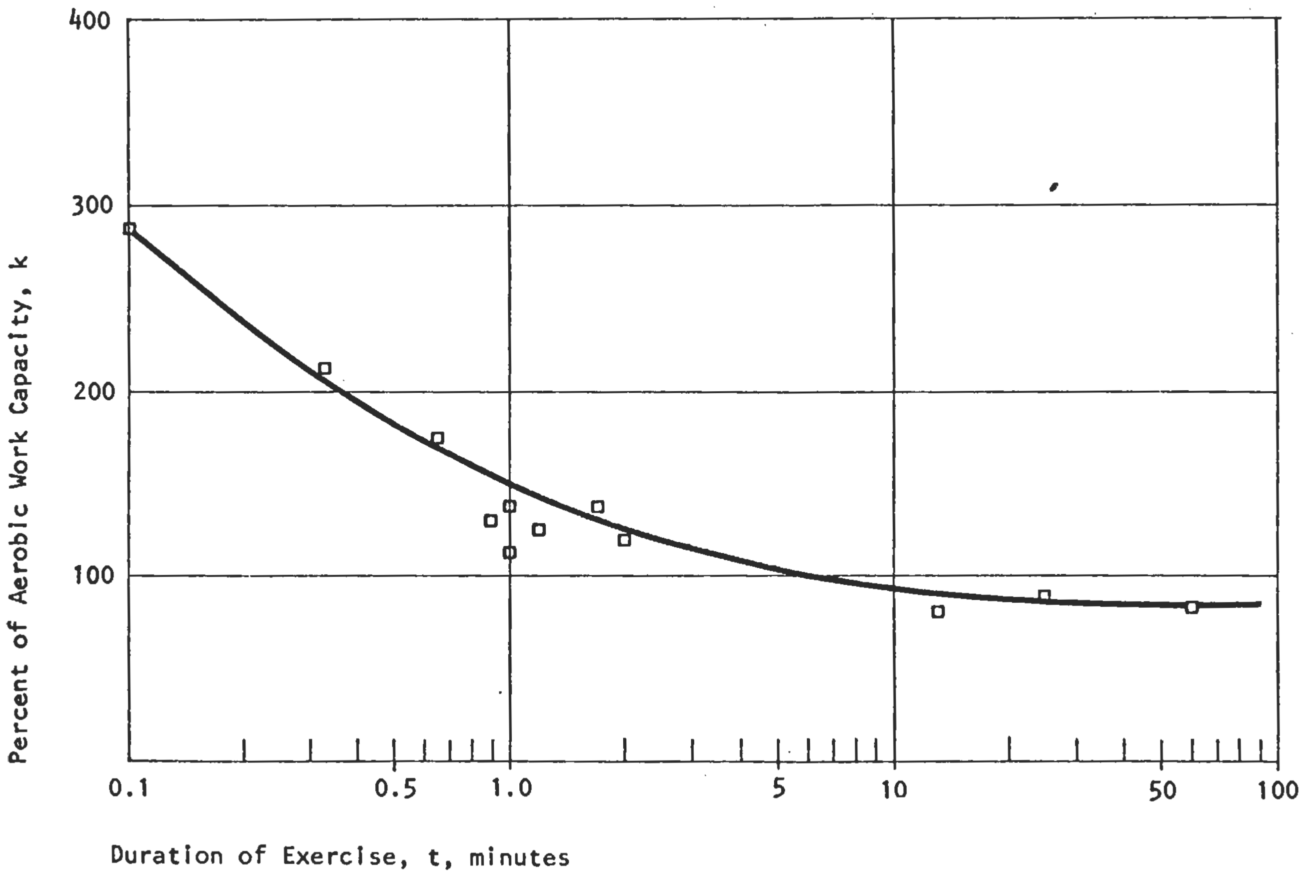


Figure 22
WORK DURATION CAPABILITY ANAEROBIC RANGE

If the site of the proposed facility was in an adult retirement community, these persons might be identified as the critical design types and desirable standards identified for them according to procedures outlined above.

10. PAVEMENT SPECIFICATIONS

Normal pavement surfaces provided for motor vehicles are generally acceptable for bicycles where bicycle facilities are placed on-street. It is essential that surface quality along the portion of the roadway where most bicyclists will normally travel be maintained at the same standards as the motor vehicle travel lanes.

Considerable latitude is possible and desirable in design of off-street bikeway pavements. Pavements should be designed in consideration of local soil conditions, drainage and materials. The following should also be taken into account:

- Pavement surfaces should be as smooth as possible. Bicycles do not have shock absorbing suspension systems and with typical high tire pressures give an extremely stiff ride. Existing pavements with uneven expansion joints should be avoided while special care should be taken in finishing joints in new pavement so they do not distract from the quality of the riding surface.

- Existing path pavements that include uneven expansion joints, chuck holes, rough patching or severely upheaved slabs should not be used without repair.

- Loose gravel or crushed aggregate surfaces which are subject to washboarding and could induce skidding should generally not be employed.

- If maintenance vehicles must travel on the bikeway to service it (typical with Class I independent path facilities), design load criteria is an 8,000 pound light maintenance vehicle making infrequent trips. If it is feasible to maintain the facility using lighter equipment such as is used in parks and on golf courses, lower design loads could be considered.

Because of the wide variation in local conditions, no specific structural sections can be generally recommended. Figure 23 illustrates typical uses of various materials and a range of structural sections* which might be considered.

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*"Guide for Bicycle Routes," American Association of State Highway and Transportation Officials, 1974.

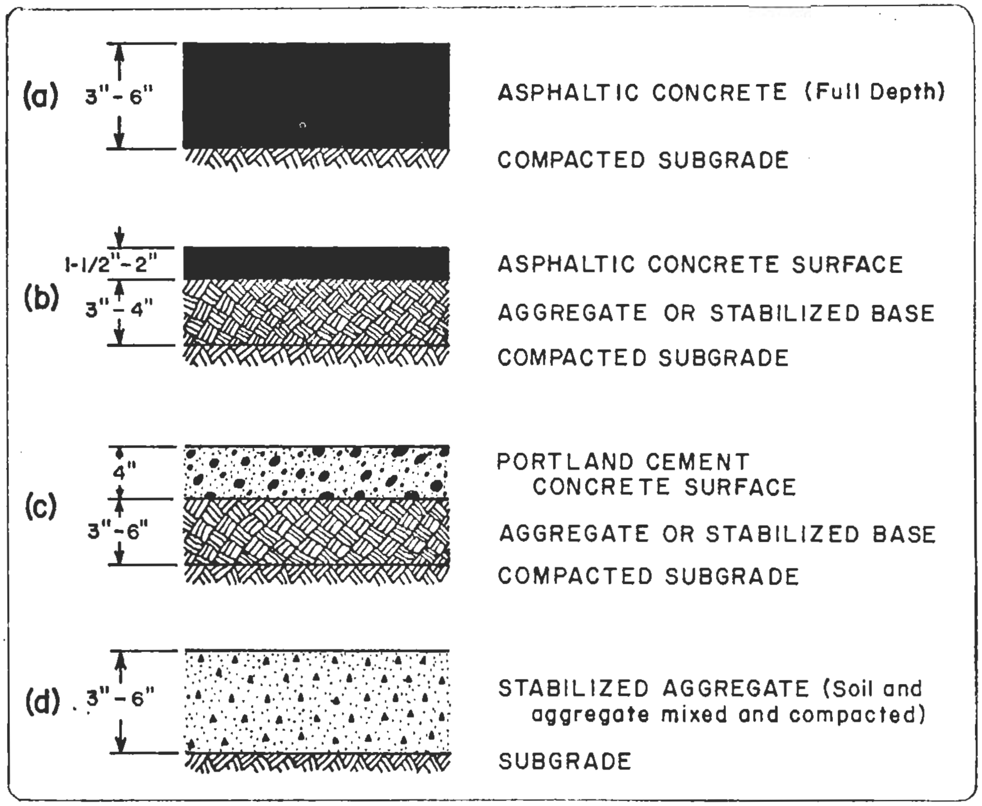


Figure 23
REPRESENTATIVE BIKEWAY PAVEMENT SECTIONS

Source: AASHTO

The area adjacent to the bikeway surface should always be backfilled to grade using topsoil, sod or other acceptable material. Backfilling not only reduces the potential hazard involved in running off the edge of pavement but also retards edge chipping. Use of exposed rock as backfill material is not acceptable because it tends to become scattered on the riding surface.

11. BICYCLE TERMINAL FACILITIES

As with other vehicles the bicycle must be parked when not in use. While the cyclist's place of residence is the major terminal facility for bicycle parking, nearly all trips away from home involve parking the bicycle one or more times before returning. Sometimes this involves merely depositing the bicycle on the neighbors' lawn, in the driveway, or up against a house or fence while playing or visiting with friends. This spontaneous act of leaving a bike where it lies is most evident among young riders using the bicycle more as a toy in their immediate neighborhoods than when used as a serious mode of transportation, although this behavior does carry over somewhat in the habits of more mature riders. The flexibility of bicycle transportation allows cyclists to ride very near their exact destination point and then look for a suitable parking site. This may be a bicycle rack, sign post, light pole, street furniture, railing, tree or just a patch of sidewalk adjacent to a store entrance where the bicycle is visible to the rider inside the building.

Until recently the only locations where bicycle parking facilities were consistently provided were associated with schools and major recreation facilities. Demand for bicycle parking facilities at other types of activity centers is beginning to increase designer awareness that additional facilities are needed now. In addition, bicycle vandalism and theft is a growing problem, especially with the prevalence of expensive ten-speed bicycles, which focuses even more attention on bicycle parking deficiencies. Various elements relating to bicycle parking are outlined in the following paragraphs.

Location

Commercial and office as well as school, residential and recreational land uses are candidates for bicycle parking facilities as is any location where bicycles congregate. Bicycle parking facilities for intermodal transfer points, such as feeder bus stops, may also be important to consider. Ferries and trains equipped with bicycle carrying facilities enable cyclists to utilize another mode to extend their mobility. In this vein, racks, carriers or trailers attached to buses or vans are a further extension of travel options applicable to selected situations.

Availability

Persons considering utilizing a bicycle to satisfy a trip purpose, particularly in an urban setting, must know or feel reasonably assured that there is a parking space close to their destination; otherwise they may choose some other mode of travel. This is especially important for long-term parking such as required for work and school trips. Consequently, at high activity locations the supply of bicycle parking facilities should always be more than peak demand if bicycle ridership is to be promoted.

Convenience

Convenience is a prerequisite for maximizing parking facility utilization. Therefore, every effort should be made to provide bicycle terminal facilities close to destination points; although care should be taken that bicycle parking does not block pedestrian facilities. Treatments to enhance the convenience of bicycle parking encompass a wide range of possibilities including provision for bike racks in parking garages, basements, and in storage areas in buildings; utilization of a motor vehicle parking space in a lot or along the curb in front of a store, and construction of bike ports or pavilions adjacent to activity center entrances. Observations have shown that peripheral bicycle parking facilities often are the last to be utilized unless there is strict enforcement or lack of alternatives.

Shelter

Weather is another factor influencing where cyclists prefer to park. Covered bicycle parking areas are very popular on rainy days while adjacent bicycle racks in the open are underutilized. Use should be made of existing or planned sheltered areas wherever it is possible to satisfy the criteria of convenience and security.

Demand

Existing bike parking deficiencies can be readily assessed by inventorying facility availability, location and utilization. Action can then be taken to satisfy need by providing additonal bike parking facilities and/or modifying the location of existing facilities which are underutilized. In the planning of new developments, bicycle parking should be one of the elements considered so that space allocation can be designated and be integral to the site plan so as to best serve the needs of cyclists as well as being compatible with pedestrian and other transportation considerations. Space allocations should remain as flexible as possible to allow for expansion or modification as users respond to availability.

Security

Level of security necessary to satisfy cyclists varies with site and user characteristics. For instance, a highly visible location served by well designed bicycle racks may provide excellent service while the same type of facility in a location where cyclists perceive a need for more security may be underutilized because of fear. Areas having proven theft and vandalism problems will discourage most cyclists from parking unless security is greatly improved.

Trip purpose and parking duration are factors of cyclist behavior which influence the acceptance of a specific degree of security. For trips in the neighborhood or to other areas where cyclists are familiar and have come to believe that there is little chance of problems, a lesser degree of security is generally acceptable. Where cyclists must park bicycles for long periods of time and, particularly if this involves nighttime parking even though there is adequate lighting, more security may be required to maximize ridership potentials. Various security techniques are listed in the following paragraphs:

- The basic tool of each cyclist is the lock and chain which is typically carried along on each trip to assure that the bicycle can be locked when parked. Quality of locks and chains varies widely from types easily opened or severed to varieties stopping all but the professionally equipped thief. However, chains and locks do not impede the vandal or prankster, who is determined to meddle with the bicycle.

- Where no special bicycle parking features are provided, cyclists must rely on ingenuity to find places to park their bikes. Bicycles may be locked or not, depending on rider preference and familiarity with security risks.

- When bicycle "racks" are provided, they facilitate orderly parking and locking of bicycles to a solid object. Racks should be designed to accommodate bicycles equipped with kick stands as well as bicycles without kick stands and to be usable with various types of locks.

- Special bicycle racks are available which are designed to hold bicycles more securely and inhibit theft and vandalism. A special keyed locking device is often incorporated in the design.

- Bicycle lockers or cabinets may be installed to enclose and lock the bicycle out of reach and out of view of passersby. Lockers are available singularly or in groups and may supplement other bicycle parking faclities to provide an option for security minded cyclists.

- Fenced or walled areas can be used to create a limited access compound in which bicycles are parked and kept generally under visual surveillance. If required, locking and unlocking the entrance could be done at special times such as arrival and departure times at an elementary school. In other situations keys are assigned to permit individual demand access as might be more practical at a large employment center.

- Video surveillance is a technique applicable to any situation although it may prove more beneficial for scanning parking areas out of sight from the normal or frequent travel patterns of pedestrians and patrol personnel. Where such a technique is employed, attendants should be available to respond quickly once a problem is spotted.

- Conspicuous presence of patrol personnel increases the potential to apprehend thieves and vandals thereby discouraging incidence of problems. Where officers are on duty for general security reasons such as at shopping and employment centers, patrolling of bicycle parking facilities is a practical task. In certain circumstances assigning surveillance duties to special attendants may be appropriate to dissuade persons from tampering with bicycles. A variation of this type of security arrangement would occur where bicycle parking is allowed in a parking garage in full view of and in close proximity to the attendant.

- Utilization of old or non-descript bicycles is a self-imposed security strategy employed by some cyclists in an effort to avoid theft and vandalism. These riders believe that while their bicycle may be mechanically sound it does not attract the same attention as a more expensive model and is therefore less apt to be a target for meddling.

- Transporting a bicycle to the exact point of final destination, such as inside an office, is another self-imposed security strategy commonly used by owners of very expensive bicycles to minimize the exposure to potential problems. However, if the practice became widespread, complications relating to storage capacity and intrusion on pedestrian space may force permissive policies to be changed and focus attention on providing secure bicycle parking facilities at less disruptive locations.

CHAPTER 5

INTERSECTION TREATMENT

INTRODUCTION

This chapter addresses the unique problems that occur for bicyclists at intersections. The problem of conflict between cyclists and motor vehicle is discussed to identify the nature of the problem and the perspectives of both participants. The chapter concludes with a number of design solutions to these problems.

Safe movement of bicyclists through intersections has been a topic of paramount concern among bikeway designers. However, satisfactory solutions to "the intersection problem" have been elusive.

It is fact that a high percentage of bicycle-motor vehicle collisions take place at intersections. Intersections are, by nature, places of more intense activity and conflict than other points on a street network; hence, a concentration of accidents at these locations is not surprising. The ratio of intersection accidents involving bicyclists to those occurring at other locations is not significantly different than the pattern of motor vehicle accidents. This is not to downplay the need for more effective treatment of bicyclists at intersections, but simply to place the concern in perspective. Even as better provisions for bicyclist movements are made intersections are likely to remain sites of high accident concentration.

THE INTERSECTION PROBLEM

There is no dominant cause of bicycle accidents at intersections. A number of elements compound the basic fact that intersections are inherently points of significant traffic conflict. Among these are human error, basic conflict between behavior and expectations, inadequate traffic engineering improvements, and the fact that measures undertaken to improve motor vehicle flows and safety may conflict with bicyclist operational convenience and safety. The implication is that short of totally removing bicyclists from intersections, <u>there is no single measure that will provide a primary "solution" to the intersection problem</u>. The treatments that are possible will respond to some but not all intersection accident causal circumstances.

Human error describes a broad range of accident causal circumstance including:

- errors in judgment interpreting the other vehicle's intended movement,

- failure to signal intent,

- errors in judgment of clearances, speeds and gaps,

- motorist failure to perceive the bicyclist due to the bikes' low target value,

- erratic or illegal traffic behavior of some bicyclists, and

- motorist determination to force the right-of-way on assumption that the bicyclist would yield to a superior vehicle.

Most of the above respond primarily to education and enforcement; some may not be correctable at all. But physical facility treatment can have impact on some of these causes. For instance, bike lanes have been shown to reduce one form of illegal bicyclist behavior, riding against traffic -- a significant cause of intersection accidents. It is likely that other physical treatments at intersections will have impact on other undesirable bicyclist behavior patterns -- i.e., designated turning lanes for bicyclists may reduce incidence of eratic left turns. The same physical treatment could have significant impact on problems related to signaling and perception of turning intent as it provides a passive indicator of turning intent. Influence of physical treatment in reducing human error is difficult to predict. But in general, provision of positive direction and control has proven effective in reducing human error.

Lack of needed conventional traffic engineering improvements as a contributor to bike accidents at intersections is readily perceptible. Conversely application of many normal types of physical treatment which are desirable simply for motor vehicle traffic purposes may significantly improve safety for bicyclists.

For instance, signalization can improve bicyclist safety and convenience in crossing the intersection as well as improving motorist safety and efficiency. Thus, if bicyclist safety is a recognized goal, bicycles might be counted as vehicles in assessing whether the intersection meets volume warrants for signalization.

Similarly, maintenance of proper sight clearance triangles at intersections -- providing proper parking setbacks from the corners, triming foliage, prohibiting erection of or removing fences and similar sight obstructions -- would specifically improve bicyclist safety as well as general traffic safety. Bikeway designers should continuously seek and take advantage of opportunities to employ normal traffic engineering measures which could improve bicyclist as well as overall traffic safety.

Conflicts between bicyclist behavior and ingrained motorist expectation relative to traffic behavior is a significant cause of accidents at intersections. And this conflict is partially the result of physical facility provisions for bicyclists and laws and ordinances relating to bicycle operation.

The "right-turning motorist vs. straight-through bicyclist" conflict is a prime example of this. When a motorist executes a right turn he has no expectation that any vehicle traveling straight through the intersection might be on his right. Yet this is exactly where bicyclists often are, particularly if traffic ordinances mandate that the bicyclist travel strictly along the right edge of the roadway or if a bike lane guides the cyclist there. Other similar types of conflict occur due to other variances between motorist expectation of traffic flow behavior and actual cyclist behavior as shaped by training, facilities, and ordinances. These include bicyclist left turn from the right lane or right edge of the road and sudden bicyclist entry to the crosswalk area from a sidewalk bikeway.

A final aspect of the intersection problem involves a basic conflict of street uses and of objectives. Measures undertaken to improve motor vehicle traffic operations and safety frequently conflict with bicyclist convenience and safety. Measures to increase bicyclist safety may conflict with motor vehicle traffic flow quality. And measures to increase bicyclist safety may conflict with cyclists' own convenience. For example, provision of exclusive or "free" right turning lanes improves traffic flow but poses significant hazard to bicyclists. Provision of a separate traffic signal phase for bicycle movements may improve bicyclist safety but it decreases motor vehicle capacity at the intersection. And forcing a bicyclist to dismount and behave like a pedestrian by leaving an unbroken curb rather than providing a ramp at an intersection on a sidewalk bikeway may increase cyclist safety but it decreases cyclist convenience.

Possible solutions to the intersection problem are of three forms:

1. Designs can be implemented which channel the bicycle into specific and more desirable locations. This approach is covered in greater detail in the following paragraphs.

2. The second approach is to improve the motorists' perception of the potential for bicycle-motor vehicle conflict. This can best be done by advance warning through signs or markings at locations where heavily cyclist conflicts are expected.

3. A third approach is to separate traffic flows either by signalization or grade separation.

While the second approach is equally desirable to bicycle channelization, its probability of success is less except for emphasis at key locations. The lower probability is due to the fact that a bicycle is an unusual and difficult object for the motorist to perceive, whereas the motor vehicle is a constant part of the cyclists' environment. Thus, it is recommended that signing directed toward motorists be limited to high activity or particularly hazardous locations where bicycle channelization treatment is not possible. Since opportunities and funding for grade separations are limited, improved signalization treatments are an area for high priority attention. Specific discussion of signalization potential is presented subsequently in this chapter.

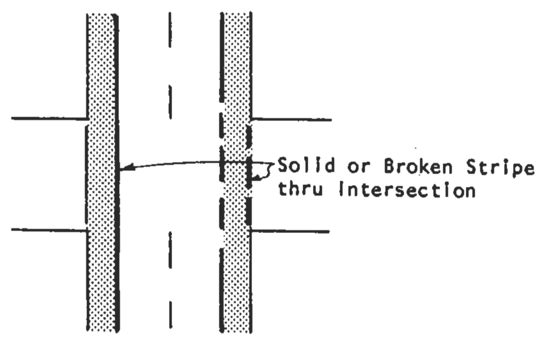
The sections which follow present physical treatments for intersections which respond primarily to the problems of conflict between motorist expectation and bicyclist behavior and conflict between flow quality improvements and safety.

BIKE LANES AT INTERSECTIONS

The following bike lane treatments are appropriate at intersections under varying circumstances. No single treatment is universally recommended.

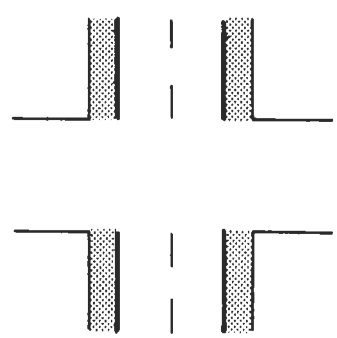
Lane Continuation

The "lane continuation" treatment where the bike lane is marked through the intersection may be appropriate only at intersections where bike lanes on major streets cross minor streets, particularly at "T" intersections and only where right turns from the major street to the minor street are minimal. The purpose is to provide continuity flow for the bicyclist by reinforcing bicyclist right-of-way over traffic emerging from the minor street and to alert right turning motorists on the major street of the possibility of bicyclists on their right.



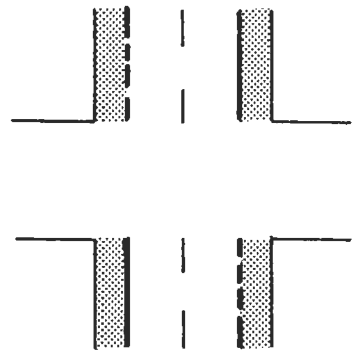
Lane to Intersection

Bike lanes carried to the intersection is the recommended treatment when right turning motor vehicle traffic is extremely light or when traffic conditions make bicyclist weaving to establish normal positional relationships with motor vehicles for through and left-turn movements more potentially hazardous than crossing conflict with right turning motor vehicles. When this treatment is provided, left turning bicyclists should make two-stage turns.



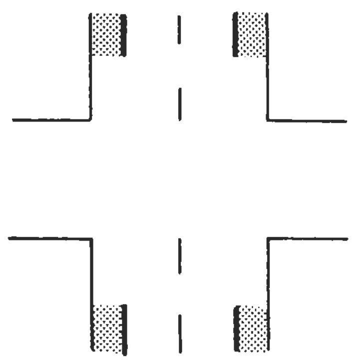
Broken Stripe on Approach

Broken stripe provided on the intersection approach is recommended when traffic conditions are such that it is desirable that cyclists weave with motor vehicle traffic to establish normal positional relationships with motor vehicles for through and left-turn movements. The broken stripe has the advantage over lane termination (discussed below) in that it delineates linear space from which weaving movements can be initiated when safe gaps appear rather than an abrupt point at which weaving must be initiated. It also provides a protected area for bicyclists executing right turns.



Lane Termination

"Lane termination" treatment is normally employed under the same conditions as the broken stripe except that space is unavailable to maintain a bike lane to the intersection. Whether "broken stripe" or "lane termination" treatment is employed, arbitrary setback distances from the intersection should not be specified as standard points for initiation of treatment. Each intersection should be individually assessed as to appropriate weaving distance required and lane termination or broken stripe initiation should be located accordingly.



Designated Directional Lanes

This treatment employed with either the broken stripe or lane termination treatments when substantial through or left turning bicycle traffic is present and allocation of designated storage space for directional movement queues appears appropriate. Designated queuing space for bike left turn and through movements may be provided for both or only one movement depending on traffic conditions and roadway width availability.

Use of the solid and broken lane lines in the treatments above is consistent with the "Manual on Uniform Traffic Control Devices" recommendations for use of broken and solid white lane lines. Broken white lane lines permit lane changing with care. Solid lines are used in critical areas where it is advisable to discourage lane changing.

LANE TREATMENTS FOR SPECIAL INTERSECTION FEATURES

Certain geometric designs and other measures pose special problems for on-street lane treatments as well as in instances when no bicycle facilities are provided. Among these are designated and "free" right turning lanes, traffic circles and legal "right turns on red."

Mandatory Right Turning Lane

A mandatory right turning lane for motor vehicles normally makes use of the treatment in which the bike lane is continued uninterrupted to the intersection inappropriate. If separate signal phasing for bicyclist movements (discussed subsequently in this chapter) is feasible, the "lane to intersection" treatment would be acceptable. Application of either the "broken stripe" or "lane termination" treatment is advisable, preferably coupled with provision of a designated through-bike queue storage pocket. When such treatments appear inadvisable due to traffic conditions, the treatment in which the bike lane is "marked through" the intersection may be considered.

Double Right Turning Lanes

Where "double-right" turning lanes (mandatory plus optional) are present, the following alternatives should be considered. They are listed in order of desirability from bicyclists' point of view.

- Eliminate the "optional" motor vehicle right turning lane and provide one of the treatments discussed above for the "mandatory" right turning lane.
- Provide separate signal phasing for bicyclist movements in conjunction with the "lane continuation" or "lane to intersection" treatment.
- Provide a bicycle grade separation in the vicinity of the intersection.
- Channel the bike lane onto the sidewalk area and encourage bicyclists to behave as pedestrians at this intersection.
- Do not provide an on-street bike lane on this street.

Channelized Free Turning Lanes

Channelized "Free" turning lanes pose problems similar to the designated turning lanes. Recommended treatment at single free turning lanes is indicated on Figure 24. This involves the broken stripe treatment to encourage bicyclist weaving to the proper position relative to turning traffic, and a marked right-angle crossing to encourage bicyclists to

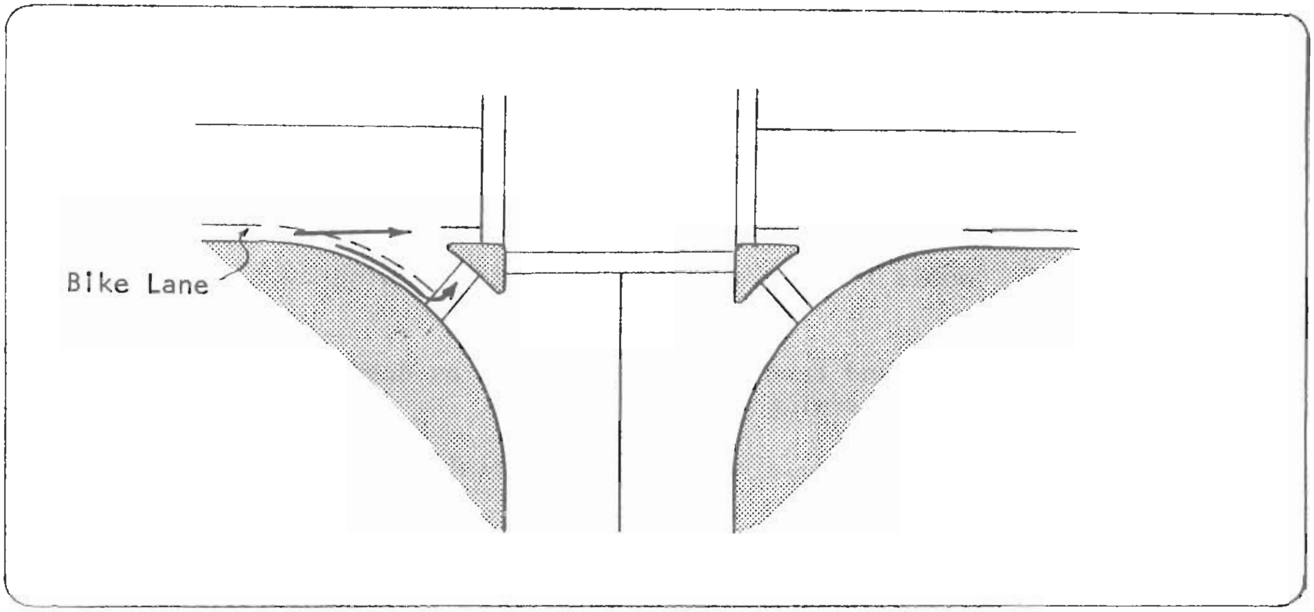


Figure 24
LOW SPEED RIGHT TURN LANES
BIKE LANE TREATMENT

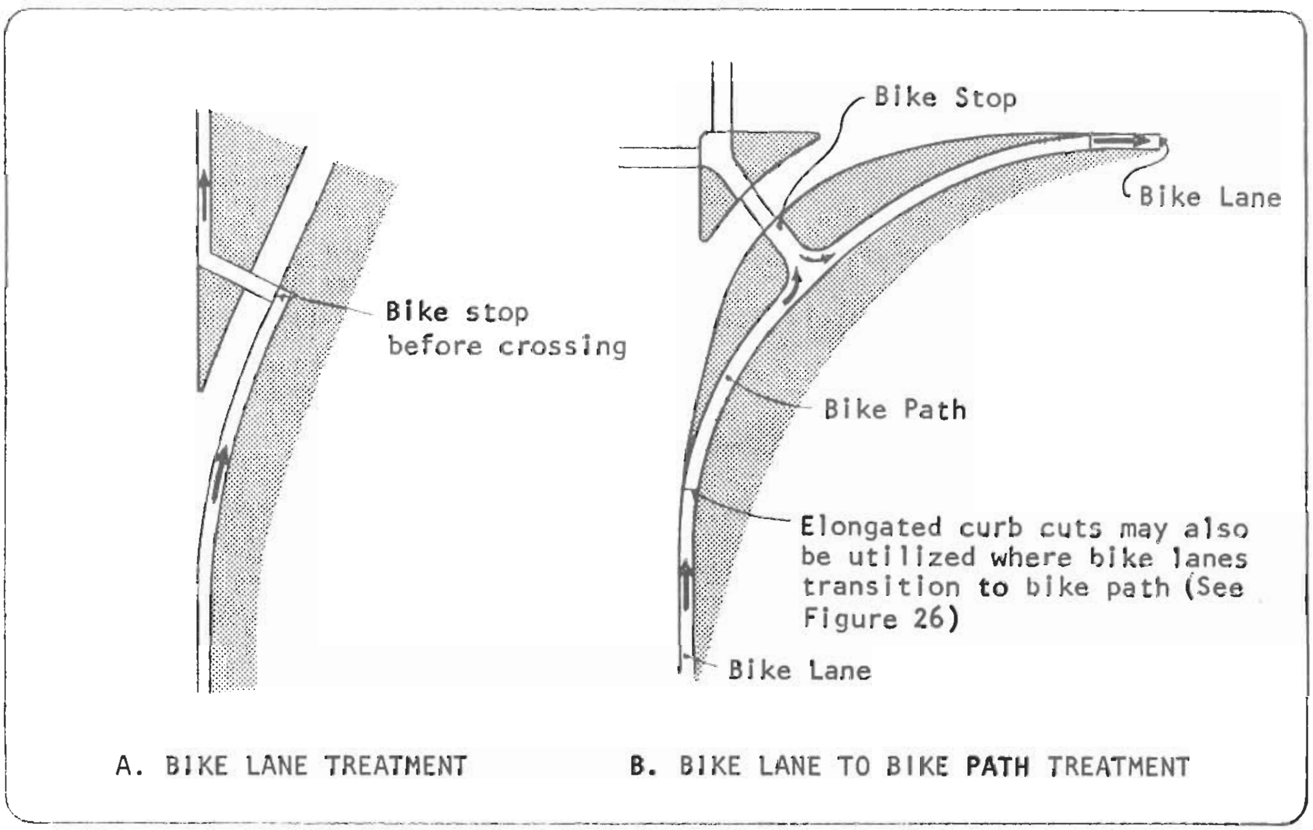


Figure 25
HIGH SPEED RIGHT TURN LANES

make a pedestrian-like crossing if they are unable or unwilling to execute the weaving maneuver. For high speed turning lanes, the right angle crossing indicated on Figure 25 is recommended.

Double Free Turning Lanes

In the case of "double free" turning lanes, the following options are open:

- Eliminate the second turning lane and treat as described above for the single "free" turning lane;
- Provide a bike grade separation in the vicinity; and
- Do not provide bike lanes on this street.

Only in cases where the second free turning lane is marginally used should treatments indicated on Figures 24 and 25 be applied to a "double-free" turning lane configuration.

Traffic Circles

Traffic circles are employed relatively infrequently except in a few U.S. cities. Where they exist, bike lanes should be terminated on the approaches to the intersection. Preferably routes for bike lane application should be located so as not to pass through traffic circle intersections.

Right Turn on Red

Where "right turn on red" is permitted, the focus of right turning motorist toward cross traffic approaching from the left is intensified; therefore the "lane to intersection" treatment should not be used with right turn on red.

SIDEWALK BIKEWAYS AT INTERSECTIONS

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. There is an inherent conflict between intersection safety on a sidewalk bikeway and bicyclist convenience -- the ability to maintain continuous momentum on through and left-turn movements.

The most obvious way to reduce the safety hazard is to prevent bicyclist high-speed entry to the intersection from the sidewalk. The straightforward way to do this is by maintaining existing unbroken curbs rather than providing new curb ramps at intersections where pedestrian usage does not require it. 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 all but the most unsure cyclists avoiding the sidewalk completely.

A more sophisticated attempt at the same objective is by providing curb ramps which by their positioning and configuration retard bicyclist entry to the street. Such contrivances are not recommended. Experience has been that the inconvenience involved in entry-retardant curb ramps is sufficient to cause many cyclists to ignore the facility. And some such ramps have been so difficult to negotiate that cyclists concentrating on riding them have been oblivious to conflicting traffic.

When sidewalk bikeways are to be employed, good curb ramps should be provided. Safety here is dependent upon bicyclists adopting a more pedestrian-like yielding posture to motor vehicles when using sidewalk bikeways (bicyclist education and training should be directed to this point). This fact should be taken into consideration when selecting a sidewalk treatment over other options.

Curb ramps for sidewalk bikeways should as a minimum:

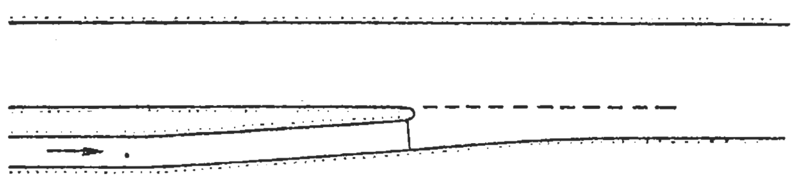
- be wide enough to provide basic operating width (42 inches for one lane facility);
- have slopes less than 12:1 (8.33 percent); and
- have a gutter lip no higher than one-half inch and preferably no lip at all.

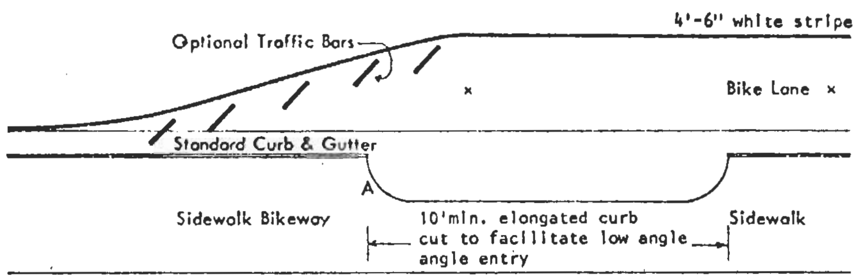
These criteria are similar to typical wheelchair ramp specifications although it should be stressed that they are minimum criteria.

In some cases where long stretch of uninterrupted sidewalk bikeway has been provided it is possible to transition to an on-street facility on the intersection approach as shown on Figure 26. This is preferred treatment but is only possible when space is available and parking is or can be prohibited for a significant distance on the intersection approach. Such a transition must be made sufficiently in advance of the intersection for bicyclists position to be established on the street and permit weaving space required for appropriate intersection maneuvers.

ISOLATED INDEPENDENT-PATH CROSSINGS

Independent path crossings of motor vehicle roadways merit particular attention to design detail. Problems at these sites appear to stem from:





(× Bike Lane Stencil)

NOTE: 1) Use zero lip cut
2) Avoid Profile hump at point A
3) Study adequacy of residual sidewalk
for pedestrian use

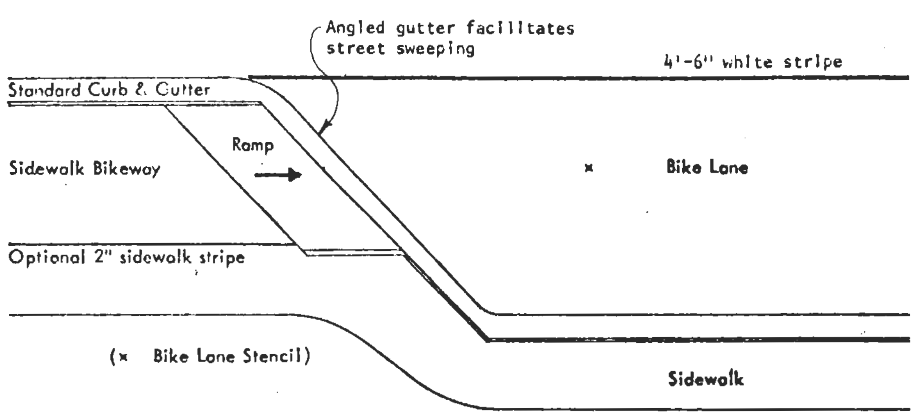


Figure 26
SIDEWALK BIKEWAY TRANSITION TO STREET

- Failure to provide proper sight clearance;

- Location of the crossing at points where such a facility would be unexpected by motorists and poor motorist perception of or reaction to crossing signs and markings;

- Motorist expectation of entries to the crossing at typical pedestrian rather than bicyclist speeds;

- Bicyclist disobedience of STOP or YIELD controls; and

- Insufficient traffic gaps for safe bicyclist crossing.

Measures to alleviate these problems where isolated independent paths cross roadways include the following:

- Provide proper sight clearances according to procedures indicated on Figure 14. Sight clearance assessment must consider obstructions due to roadway cross-section profile (steep cuts or fills) as well as common obstructions such as foliage.

- Locate the crossing a minimum of 250 feet from any roadway intersection. If such separation is impossible, the crossing should be brought into the intersection and treated as a sidewalk bikeway.

- Align the crossing to intersect the motor vehicle roadway at right angles.

- Mark the crossing with "zebra" or "panda" pavement marking. "BIKE XING" signs should be placed on the motor vehicle approaches 250 to 1,500 feet in advance, with specific location depending upon roadway speed limit and proximity to adjacent intersections. Employment of reduced speed zones should be considered.

- Place "STOP AHEAD" signs on the bikeway approach approximately 150 feet in advance of the crossing; further if downgrades make bicyclist speed in excess of 20 MPH likely.

- Consider deceleration curves or mild undulations to enforce bicyclist speed reduction.

- Consider bollards or posts placed near the curb line to further constrain bicyclist speed and prevent motor vehicle entry to the bikeway. However, adequate space for bicyclist maneuver must be provided. Cyclists preoccupied with squeezing between bollards may become less conscious of traffic. The possibility of collision with a bollard is of itself a problem.

- Install traffic control devices appropriate to traffic conditions at the crossing (see sections which follow).

TRAFFIC CONTROL DEVICES

Traffic control devices installed at intersections are intended to facilitate orderly and safe flow of traffic. Control devices now in use, their technology and manner of application have been evolved with the object of serving the motor vehicle and (possibly as a lesser priority) the pedestrian.

The bicycle has generally not been considered in the evolution of intersection control technology and applications. As a result the bicycle, which differs operationally in significant ways from both the motor vehicle and the pedestrian, is at times not well served by current traffic control provisions. Hence, there are great opportunities for improving bicyclist operations and safety at intersections through further evolution of traffic control techniques and hardware as well as some difficult problems to be addressed.

The sections which follow describe some of the problems current traffic controls pose for bicyclists, some adjustments which hold promise for improvement and discuss the relation of bicycle traffic to warrants for control devices.

Traffic Signals

Traffic signals are employed at sites of highest traffic conflict. Hence, current problems with their design and the possibilities for change are of greatest concern in attempting to provide for improved bicyclist convenience and safety. Topics of interest relate to actuation, timing, pedestrian controls and special phasing provisions for bicyclists.

Bicyclist problems are perhaps most acute at some of the most advanced installations -- traffic actuated signals. The problem stems from the fact that bicycles are not detected by most commonly employed magnetic inductance loop detectors (nor by the obsolescent pressure plate detectors). Hence the bicyclist is dependent on motor vehicles to "call" the green to his approach.

This may be quite satisfactory when traveling along the mainstream traffic. But a bicyclist attempting to execute a left turn from a turn pocket which has a separate detector for a "minor movement" phase or a bicyclist on a minor street approach may be considerably delayed before a motor vehicle executing a similar movement arrives. In such situations the bicyclist has no good options; he can get off his bicycle and use the pedestrian actuation button if there is one, violate the signal or just wait.

The simplest remedy, now employed frequently is to install a pedestrian actuation button by curbside where cyclists can reach it without dismounting. This is satisfactory for cyclists at curbside but no use to through and left turning cyclists who leave curbside to execute these movements. Some intersections have channelized left turn lanes with signals standards, including pedestrian actuation buttons, located in a median; however, median pedestrian actuation is only useful to cyclists who wish to cross in the crosswalk.

Fortunately, inductance detectors which do detect bicycles are becoming available. Use of such detectors appears desirable at traffic actuated signal installations on bikeway streets, particularly if the bike lane treatment on the intersection approach encourages cyclists to move away from curbside.

One problem experienced by bicyclists crossing multi-lane streets at signalized intersections is that a yellow intersection clearance interval, if set to close tolerances for motor vehicle clearance, may not provide sufficient clearance time for slower moving bicyclists. A bicyclist who entered the intersection at the tail-end of a green phase may still be in the intersection when cross traffic gets the green. On bikeway streets or on any street carrying measurable bicycle traffic, yellow or a combination of yellow and all-red phasing should be evaluated and modified if necessary to provide a sufficient interval for bicyclists to clear the intersection. While this detracts slightly from intersection traffic carrying capacity, it tends to increase overall (not just bike) traffic safety and is more realistic than the possible alternative: providing a separate signal head for bikes with an advanced yellow setting. Clearance time required for bicycles should be evaluated as standard practice for each signalized intersection along a bikeway. A bicyclist speed of 10 MPH (14.7 ft./sec. should be utilized in the calculations. The number of seconds required to ride cross a street can then be determined. To this figure is added the amount of time necessary for the bicyclist to perceive, react and brake to a stop without entering the intersection. Considering that the cyclist is in an "alerted" condition (as described in the 1965 edition of the AASHO Policy on Geometric Design of Rural Highways) a combined perception/reaction time of one second is reasonable. The braking time is calculated by the formula:

$$\frac{V^2}{30\,(f \pm G)}$$

<u>Where:</u> V = Speed in MPH
f = Coefficient of Friction (0.25)
G = Grade ft./ft.

Evaluation for a zero grade, 40 foot wide street being crossed by a bicyclist travelling at 10 MPH is as follows:

Crossing 40 foot wide street at 10 MPH		2.7 seconds
Altered Perception/Reaction Time		1.0 seconds
Braking Time		0.8 seconds
		4.5 seconds
Bicycle Clearance Time Required	Say	5.0 seconds

Timing modifications to improve overall traffic service are possible if separate detection of bicyclists is employed at traffic-actuated signal installations. Normally when a curbside mounted pedestrian-type button is provided for bicyclist use, actuations are simply treated as a pedestrian "call." Phase length allocated for pedestrian actuations are significantly longer than those provided for motor vehicles or the actual crossing time required by bicyclists.

It is well within existing hardware technology capabilities to record bicyclist actuations, whether detected by curbside mounted buttons or inductance loops discussed above as a separate type of "call." One city (Davis, California) has used this capability to provide a "minor movement" phase timing for bicyclists slightly longer than the normal green time allocation for motor vehicle "calls" but far more brief than the allocation for a pedestrian call, thereby minimizing potential delay to all intersection users.

Provision of extensive separate signalization treatment for bicyclists with separate signal heads and separate phasing is definitely feasible in terms of existing technology. Although such installations have not been attempted in the United States, this is a commonly employed treatment in Europe. Possibilities range from simple provision of a bike "scramble cycle," where bicycles are allowed to cross from any corner of an intersection to another during an all red phase for motor vehicles, to advanced forms of detection and minor movement phasing.

The problem with this approach is that locations at which such treatment might be most needed are busy intersections where intersection delay and capacity may already be a concern. Allocation of signal time for a separate bicyclist phase would detract from the green time available for motor vehicle movement phases, hence, constraining motor vehicle capacity. Whether or not this would be a significant concern would depend upon analysis of the particular intersection involved.

Separate bicyclist phasing would also probably require attitude adjustment for acceptance by current bicyclists (and probably a heavy dose of enforcement to achieve this). Current bicyclists would be likely to attempt to travel on the motor vehicle green phases as well as on the designated bicyclist movement phase thereby defeating the purpose of the installation. While such a behavioral adjustment is possible -- bicyclists respect the separate phasing in Europe -- it must be recognized that while this approach may increase safety, it does so at the expense of bicyclist (as well as pedestrian and motorist) delay and inconvenience, another example of trade-off of transportation utility for increased safety. Another problem may occur if pedestrians try to cross on special bike phasing which is shorter duration than required for pedestrians.

At current levels of bicycle use, application of such extensive special signalization treatment does not appear generally warranted; although experimental application at locations of extremely high bicycle traffic such as in the vicinity of college campuses seems appropriate.

Another traffic control-related problem occurs when bicyclists on sidewalk bikeways are forced to key on pedestrian crossing indicators. Cyclists know that they can easily cross during the pedestrian clearance interval and are typically unhesitant about entering the intersection against a "flashing WAIT" or "flashing DON'T WALK." But if they misgauge the clearance time remaining, they may be caught in the intersection. Separate indicators for bicyclists may be appropriate where such occurrences are common such as on heavily used sidewalk bikeways.

STOP and YIELD Controls

STOP and YIELD controls pose other sorts of problems for bicyclists. At minor intersections motorists often travel through YIELD controlled intersections at a brisk pace, giving only a cursory glance for cross traffic. Due to bicyclists' low target value, they are frequently overlooked by motorists and accidents result. It is preferable that STOP rather than YIELD signs be set against cross traffic when bike routes or lanes are located along minor streets.

At some minor street intersections where sight obstructions exist, YIELD signs have been deployed because the obstruction cannot be removed or as a more palatable measure than forcing a property owner to cut back shrubbery or remove fencing or than prohibiting parking for a few more feet on the intersection approach. This is an inappropriate use of the control device. Sight obstructions should be removed where possible. Where they cannot be removed (i.e., if the obstruction is a building), STOP rather than YIELD control should be deployed. This is good traffic engineering practice in general and it should be particularly emphasized at intersections involving bikeways.

Motivated by a natural desire to maintain momentum, bicyclists frequently are in technical violation of STOP controls. Because of their speed and maneuverability characteristics bicyclists can usually do this without conflicting with traffic. But bicyclist violation of STOP controls is a significant causal factor in bike-motor vehicle collisions. Due to this bicyclist behavior, STOP control set against the bicyclist does not protect the bicyclist from right-of-way conflict; it simply places the bicyclist at fault where such conflict occurs.

STOP sign notation is primarily a problem to be resolved by enforcement, education and training but physical design can at times be a factor. For instance, at minor street intersections involving bikeways, where specific traffic engineering study indicates the feasibility, STOP control could be set against cross-street traffic rather than against the bikeway street.

CONTROL DEVICE WARRANTS

At any intersection involving measurable bicycle traffic, it appears reasonable that bicycles be taken into account in determining an appropriate control device for the intersection. However, such procedures are not frequently utilized in current traffic engineering practice although one city (Davis, California) counts bicycles as motor vehicles when justifying traffic signals. (This procedure has not been questioned by state and federal agencies in applications for signal construction funding.)

In light of the need to clarify the relationship of bicycles to traffic control devices, a literature search and original research on this topic was undertaken as a part of this project. The following sections present significant findings of that research, while the supportive documentation is presented in the Final Project Report.

Street Intersections

Warrants for signalization as presented in the "Manual on Uniform Traffic Control Devices" should continue to be applied.

- Bicyclists on the major street or on both streets of relatively equal importance should be counted as the equivalent of one-half a motor vehicle.

- Bicycles on minor streets should:

  - <u>not be counted</u> if they queue at the right side of the traveled way; and

  - be counted as the equivalent of one-half a motor vehicle if they mix with motor vehicle traffic as provided in some treatments indicated previously.

If large numbers of bicyclists (greater than motor vehicle volume) use a minor street approach, control warrants relevant to an independent path crossing (presented subsequently) can be applied.

- Bicyclists using sidewalk bikeways may be counted with pedestrians in application of standard minimum pedestrian volume warrants.

- Reported intersection accidents involving bicyclists of types susceptible to correction by traffic control should be counted toward meeting standard accident experience warrants.

The MUTCD specifies that in exceptional cases, signals occasionally may be justified where no single warrant is satisfied but where two or more warrants relating to minimum vehicular volume; minimum pedestrian volume and interruption of continuous flow are satisfied to the extent of 80 percent or more of stated values. Applying this concept to bikeways the following combination warrant should be considered:

> Where bicycle and motor vehicle traffic considered as at an independent path crossing meet 80 percent of the independent path crossing signalization warrant (see below) and where 80 percent of a warrant based upon vehicle volume or pedestrian volume (both including bicycles as per above) are met, signal installation may be justified.

Independent Path Crossings

Figure 27 presents volume warrants for STOP control on the bikeway or the roadway and for signalization at independent path crossings of two-lane motor vehicle roadways. The figure gives threshold levels of motor vehicle and crossing bicycle traffic mix at which various types of control should be utilized. Where good sight distance relationships cannot be achieved or 85th percentile motor vehicle speed exceeds 35 MPH, signalization or grade separation should also be considered. Where signalization is indicated, a semi-actuated controller typically used at pedestrian crossings would normally be deployed.

Independent path crossings of multi-lane roadways pose more significant problems for cyclists than at two-lane roadways. For such crossings warrants for signalization or grade separation are indicated on Table 7.

Table 7
MULTI-LANE CROSSING SIGNALIZATION WARRANTS

Number of Lanes	Peak Hour Vehicle Volume
4 lanes	800
6 lanes	600

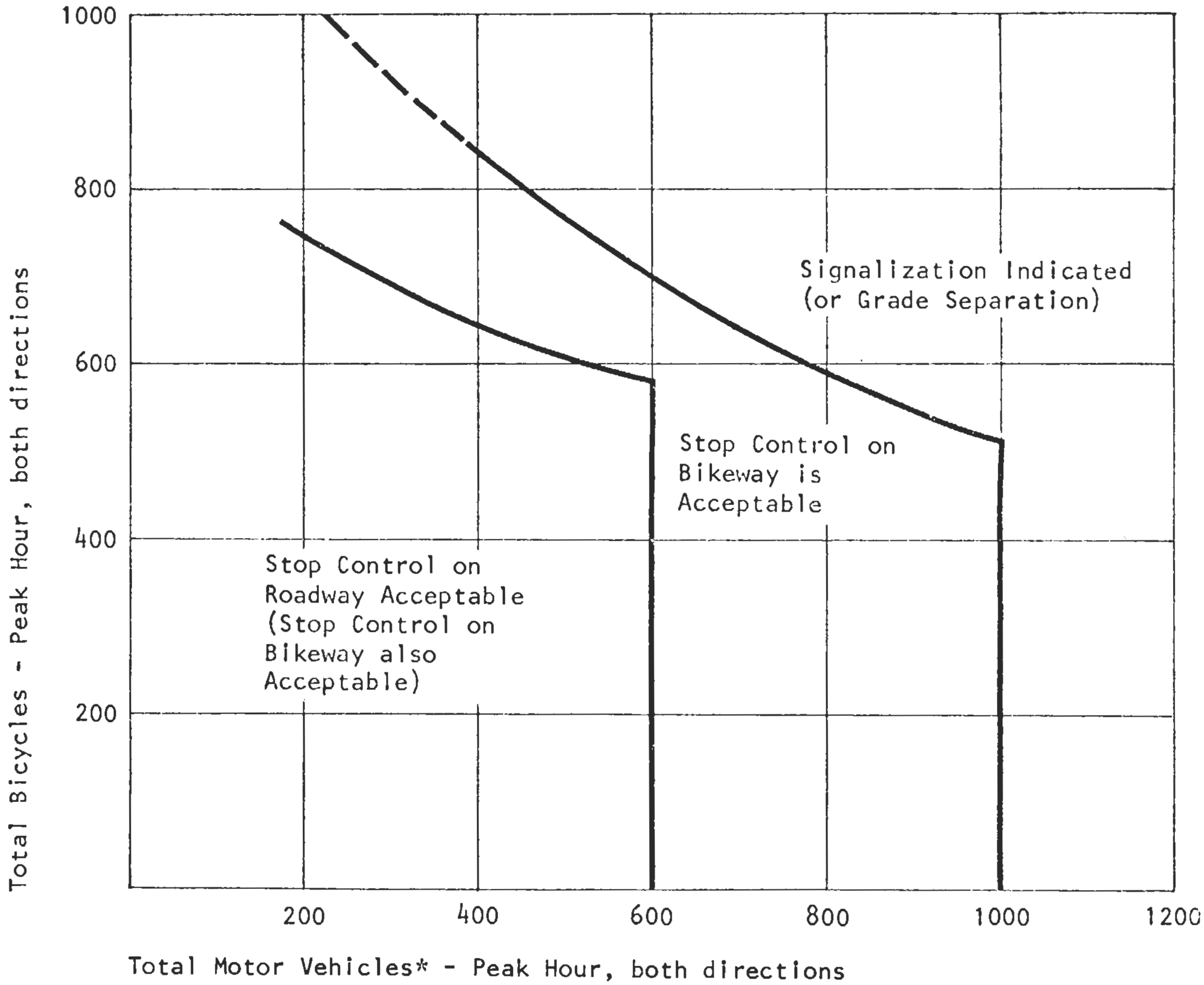


Figure 27
TRAFFIC CONTROL WARRANTS
Independent Bike Path Crossing Two-Lane Roadway

* For Stop on bikeway, motor vehicle volume is total in both directions. For stop on roadway motor vehicle volume is total in peak direction.

GRADE SEPARATIONS AND OTHER STRUCTURES

Bikeway grade separations are an effective means of eliminating bicycle-motor vehicle conflicts and often the only way of providing bikeway linkage across barriers to bicycle travel such as freeways, rivers and the like. Design of grade separations is predominantely determined by user needs, site conditions and constraints. Hence, the discussion which follows presents only general guidance.

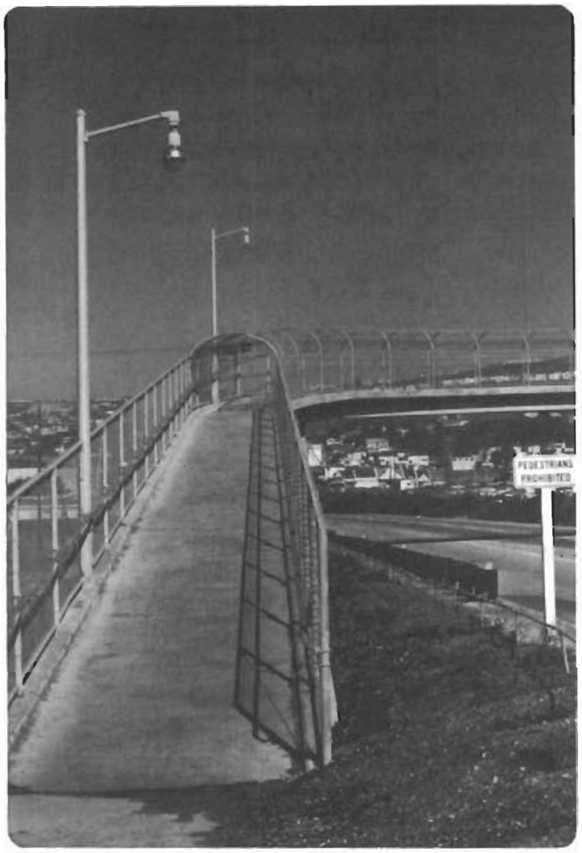
No specific warrants for grade separation are indicated. Where signalization is warranted at independent path crossings, grade separation may be substituted. Where severe conflicts between bicycles and motor vehicles at intersections cannot be mitigated by other treatments, grade separation may also be appropriate. In new developments where grade separations can be effectively provided in initial construction, this is desirable. And in the case of barriers, the need for grade separation is obvious.

Figure 28 presents several examples of bikeway grade separations. These include exclusive bikeway structures, bikeways appended to roadway structures, and bikeways making use of structures provided for other purposes.

Grade separations should be designed to provide as convenient service to bicyclists as possible, particularly where the option to continue at grade is open. In such cases, perceived safety and other advantages of the grade separation must outweigh any inconveniences involved in use of the structure or bicyclists (and pedestrians) will avoid it. Designs which force cyclists to ride overly long and steep grades, up stairs where they must carry their bikes, up sharply curving ramps which force cyclists to walk their bikes, or which take cyclists significantly out of their way should not be employed unless necessitated by site constraints.

Choice of an overpass or underpass is generally dictated by site conditions such as topography, roadway geometrics, soil conditions, utility locations, right-of-way and adjacent development constraint. Underpasses offer the advantage of lower grades (because less vertical clearance is required for a bikeway than a roadway) and a momentum building downgrade entry which helps carry cyclists on the upgrade exit. Overpasses offer advantages of natural lighting and lesser security concern.

Whether an overpass or underpass treatment is selected, approach grades should be carefully designed taking into account both upgrade effort and downgrade speed. At times, particularly in new development, it is possible to provide an underpass requiring very little bicyclist grade change by slightly elevating the roadway and slightly depressing the bikeway.



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.

Figure 28
TYPICAL BIKEWAY GRADE SEPARATIONS

On elevated bikeway structures, safety rails should be a minimum of four feet high as cyclists may tumble over a lower railing (as recommended in the Caltrans Highway Design Manual). Structures should be designed to provide acceptable operating width (as defined in Chapter 4); added width provision is desirable when feasible. It is inevitable and generally desirable that pedestrians will use bikeway structures. Hence, minimum width provisions must take into account joint bicyclist-pedestrian use.

Where bikeway structures in street corridors are to be used bi-directionally, careful consideration must be given to transition treatments which channel cyclists onto the grade separation and return them to the right side of the street at the other end.

It is usually difficult to design effective bikeway grade separations in the vicinity of street intersections. Where it is possible to achieve the same objectives by location of the grade separation away from the immediate vicinity of an intersection, this is desirable. However, a location which imposes significant out-of-direction travel may defeat the purpose of the grade separation.

Costs for bikeway structures vary substantially with site specifics such as span as well as with materials and construction methods. No truly low cost structures suitable for employment in roadway corridors have been identified. Light structures are employed on independent paths for crossing small streams and the like.

At times, existing structures can be modified or utilized directly to provide bikeway grade separations. The tremendous cost savings involved and the value of the opportunity to provide continuous bikeway linkages are usually sufficient trade-off for the compromises from ideal design which may be involved in using an existing structure. Even structures which may not be usable at all times (for such reasons as susceptibility to seasonal flooding) may be acceptable, particularly on recreational facilities. But the trade-off involved in each compromise must be carefully weighted; opportunities should not be taken simply because they exist.

CHAPTER 6

SIGNS AND MARKINGS

INTRODUCTION

Signing and marking are two primary elements in communications directed toward roadusers. Nearly all treatments placed on public streets and highways for the benefit of the motorist are also applicable to bicyclists. Many communications regarding bicycling can be solved by using standard treatments.

Basic principles governing design and usage of traffic control devices are set forth in the "Manual on Uniform Traffic Control Devices" (MUCTD). The manual identifies five basic requirements that a traffic control device should possess to be effective:

- Fulfill a need,
- Command attention,
- Convey a clear, simple meaning,
- Command respect for road users, and
- Give adequate time for response.

Standards of design, placement, operation, maintenance, and uniformity specified in the manual have been carefully developed to assure that the five basic requirements are met. While most needs along roadways can be met with standards specified in the manual, there may be other applications which are desirable under special conditions or to aid in the enforcement of other laws and regulations. However, care should be taken not to employ a special treatment when a standard treatment will serve the purpose. Finally, one of the fundamental premises of successful traffic control is that identical conditions should always be treated in the same way. This greatly simplifies the task of the user in recognizing, understanding and interpreting meaning.

SIGNS

Signs are categorized into three groups -- namely, regulatory, warning, and guide -- with each group having specific application and importance. Installation of too many signs tends to diminish their effectivenes. This is particularly true for regulatory and warning signs. All signs should be kept in proper position, clean, legible, and visible. A suitable maintenance schedule should be established.

Regulatory Signs

Regulatory signs inform users of traffic laws and regulations governing movements, parking, speeds, etc., and indicate applicability of legal requirements that would not otherwise be apparent. A regulatory sign is normally placed where its mandate or prohibition applies or begins and is visible directly to the appropriate users without being misinterpreted by others.

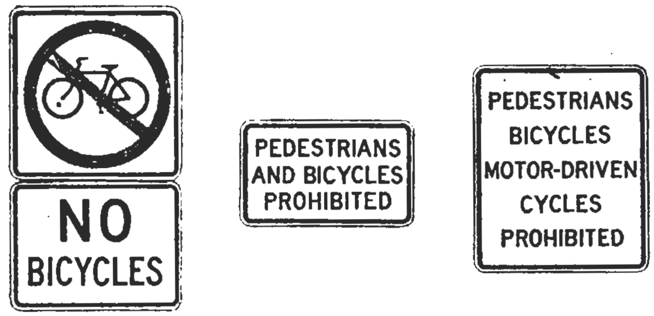
The MUTCD standards specify three regulatory signs specifically pertaining to bicycle operations: NO BICYCLES; PEDESTRIAN AND BICYCLIES PROHIBITED; and PEDESTRIANS, BICYCLES, MOTOR-DRIVEN CYCLES PROHIBITED (see Figure 29). As can be readily seen each of these signs is restrictive to bicyclists and their access to the roadway. On the other hand, supplementary regulatory bikeway signs adopted by various jurisdictions tend to largely be directed toward emphasizing the exclusiveness of the bikeway by restricting motor vehicle usage. Whether developed to clarify responsibilities for the unwary driver or to mandate compliance by the unwilling driver, there does appear to be a valid need for additional regulatory signing of this type to be considered and developed as standard practice for inclusion in the MUTCD. One example would be a regulatory bike lane sign for use to assure bike lane exclusiveness.

Signs specified in the MUTCD are directed toward application on public streets and highways although signs along Class 1 bikeways are often necessary also. However, it does seem prudent to adopt standard concepts of design, placement, operation, maintenance and uniformity for off-street usage similar to those expressed in the Manual. Examples of supplemental cyclist-directed regulatory signing for Class 1 facilities are also shown on Figure 29.

Warning Signs

Warning signs are used when necessary to call users attention to potentially hazardous conditions on or adjacent to the traveled way. Warning signs should be placed sufficiently in advance of the conditions to which they direct attention for bicyclists to take appropriate action.

The BIKE XING warning is recognized nationally and included in the MUTCD. It is used where a bikeway crosses a street and is most effective at independent path crossings and other points where a bikeway crosses an uncontrolled major street. Placement in advance of signalized intersections where bikeways cross is of little value. Although practice in many jurisdictions is to place this sign in advance of any bikeway crossing, it appears advisable to reserve its use for locations where effectiveness can be expected.



Standard (MUTCD) Regulatory Signs

Other Regulatory Signs (Non-Standard)

Cyclist-Directed Regulatory Signs (Non-Standard)

Figure 29
BIKE RELATED REGULATORY SIGNS

Other warning signs (WATCH FOR BIKES, BIKES ON ROADWAY, BIKES ON SHOULDER) are in use in some jurisdictions and may have application in some areas. These signs along with the standard warning sign are shown on Figure 30. Cyclist directed warning signs are typically reserved for Class 1 bikeways where there are no automobile-oriented signs to warn of the same condition. Examples are shown on Figure 31.

Guide Signs

Guide signs provide directional, route, recreational, destination and roadside service information to orient and assist users. Guide signs are placed where needed to keep users well informed as to their route's destination and continuity. Typically, guide signs are of most value to the unfamiliar bicyclist who does not use the route regularly. Standard guide signs included in the MUTCD include the BIKE ROUTE sign, supplementary message places BEGIN, END and TO, and directional places with a variety of arrow designations. These are shown on Figure 32.

While overuse of guide signs is not deleterious to bicyclist behavior, money so spent could be used for other bikeway priorities. BIKE ROUTE guide signs and supplemental plates should always be placed where a route beings, ends, changes direction or intersects with other bikeways. Guide signs are also useful on major non-bikeway cross streets to inform tributary cyclists of the bikeway's presence. If distances are large between major decision points where guide signs are necessary, some intermediate guide signs are appropriate to reassure cyclists. But placement of bikeway guide signs on each block, as a matter of routine, is a wasteful practice.

Construction Signs

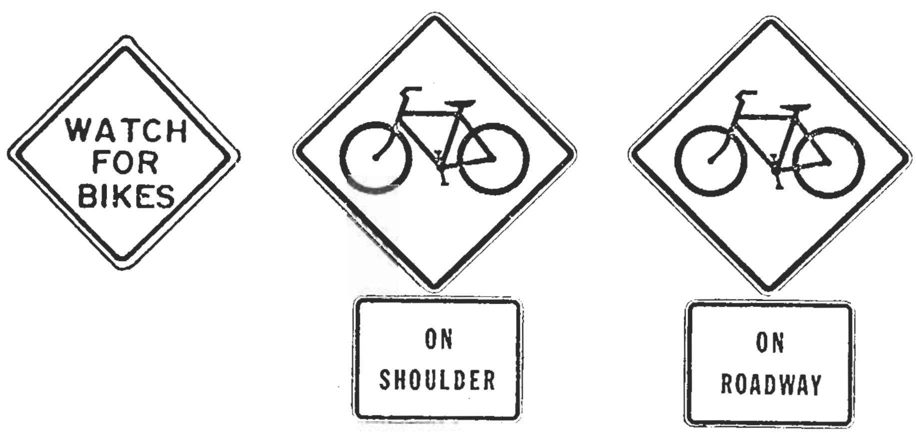
Construction signs fall into the same three categories as do other signs -- namely regulatory, warning, and guide signs. No special construction signs have been developed for bikeways and those used for motor vehicles are generally satisfactory. The critical need is that these be used to warn of conditions and provide detours when construction equipment, materials, debris and excavations obstruct a bikeway. Too often the bicyclist is simply not considered when construction activity poses hazard or inconvenience.

Sign Placement

The "Manual on Uniform Traffic Control Devices" 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:

- five feet on rural roadways;
- seven feet in business, commercial and residential districts; and

Standard (MUTCD) Warning Sign



Warning Bikeway Signs (Non-Standard)

Figure 30
MOTORIST DIRECTED WARNING SIGNS

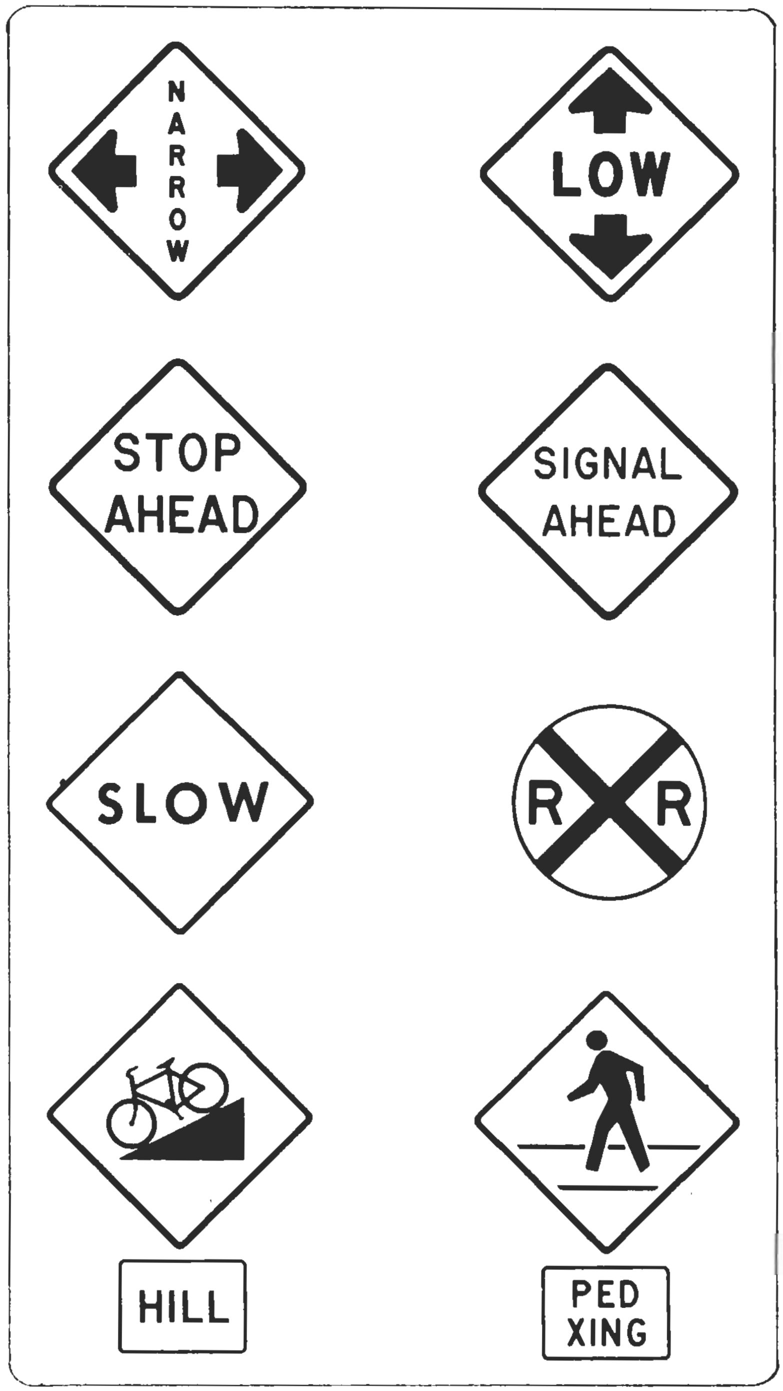
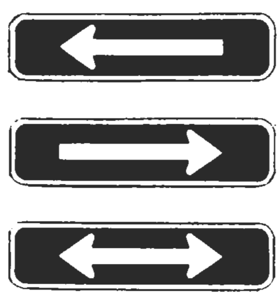


Figure 31
BICYCLIST DIRECTED WARNING SIGNS

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 32
BIKEWAY GUIDE SIGNS

- seven feet on expressways.

These specifications reflect normal driver field of vision characteristics. However, there is reason to assume that because of bicyclist head inclination, bicyclist field of vision is focused lower than a motor vehicle operator's.

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 four and five 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 previously. Lateral placement of signs should be such that full horizontal shy distance is maintained between the bikeway and nearest projection of the sign.

Along streets, bikeway as well as other traffic directed signs are often carelessly or necessarily placed in the middle of the sidewalk area, decreasing the quality of that facility for pedestrians. Where such placement is the only alternative, bikeway and all roadway signs should be kept to a necessary minimum.

MARKINGS

Pavement markings are employed both to reinforce signing and to, of themselves, provide a communication. Pavement markings are particularly useful in dealing with bicyclists since they are more directly in the cyclists' normal cone of vision than are signs. Following are some markings of specific relevance to bikeways.

Lane Lines

Bike lane lines identify a specific lane for bicyclist travel. Normally a single line provides delineation between the bike lane and motor vehicle travel lanes. Occasionally a second lane line is employed to separate the bike lane from a parking shoulder. A number of non-standard treatments with respect to striping patterns and color have been employed in various jurisdictions.

Lane line widths up to 12 inches have been employed. This gives added visibility and recognition but gains do not appear to warrant costs of extra-wide striping. Four to six inch stripes have appropriate visibility, being commonly used for lane and edge markings. Stripes of this width should normally be used to delineate bike lanes. Solid lane lines should be used except on intersection approaches where broken lines may be employed to indicate mixed traffic is desirable.

The standard color for bike lane-related pavement markings is WHITE. Numerous jurisdictions have experimented with a wide variety of line colors hoping to increase bike lane recognition. Many of these had poor visibility characteristics and have proven inappropriate. Recently, the National Advisory Committee on Uniform Traffic Control Devices denied requests to designate an approved visibility color ("strong yellow-green") as a specific use color for bike lane markings.

Edge Line

Edge line striping on bikeways may be employed on Class I facilities to delineate special features such as an area of restricted horizontal clearance or along a route to improve nighttime visibility. Edge lines are typically solid white lines although broken lines may be used to indicate mixed traffic situations such as where a driveway crosses the pathway.

Centerline Striping

Centerline striping may be useful on Class I facilities. There is little requirement for continuous treatment but delineation is appropriate at curves and sight distance obstructions.

Use Priority Lanes

Use priority lanes are sometimes placed on off-street facilities to separate bicyclist and pedestrian flows. Here unique colors may be employed if desired. Signs and pavement graphics are normally necessary to identify and reinforce meaning of such treatments.

Stenciled Message Markings

Stenciled pavement message markings for bicycle facilities include the legend BIKE LANE supplemented by an arrow indicating direction of travel. A symbolic representation of a bike may be used to supplement the legend but not used alone.

The legend BIKE ONLY may be substituted for BIKE LANE if this message is consistent with local ordinance. Pavement legends are painted white and should have minimum letter height of four feet. This height is also a minimum for directional arrows; longer arrows are desirable to increase visibility and emphasize the need for proper directional travel by bicyclists.

BIKE LANE and BIKE ONLY legends are best placed as the lane leaves an intersection. Midblock placements may be also indicated on long blocks (intersections over 600 feet apart) or downstream of major driveways.

Legends BEGIN and END are permissible additions to the BIKE LANE marking. They should be reserved for points of real termination and discontinuity; not placed at every intersection as a matter of routine.

The legend BIKES together with an appropriate directional arrow is used for marking special directional bike turning lanes described in Chapter 5.

Other pavement message markings which may be appropriate along bicycle facilities include legends STOP, YIELD, PED XING, SLOW and RR XING. Other types of legends with cryptic meanings or which are difficult to maintain should be avoided.

Vertical barriers and obstructions such as abutments, piers, and other features causing bikeway narrowing or shy distance constriction should be clearly marked to call attention of the approaching cyclist. This treatment is specified for unavoidable circumstances; not to justify acceptance of substandard bikeway design.

Paint on the street surface reduces the coefficient of friction of the pavement making stopping more difficult and increasing the possibilities of side-slip on narrow bicycle tires. This is particularly a problem on new (not roughened) paint or wet pavement. Care should be taken to avoid placing pavement markings on critical stopping surfaces and to limit markings to those which are realistically needed.

Some jurisdictions have supplemented lane delineation lines with raised pavement markers. This provides increased visibility and audio-tactile delineation of the lane. However, bicyclists dislike raised pavement markings as they cause discomfort, spills and tire and rim damage. Raised pavement markings should not be employed as bikeway delineators as a general practice.

POSTSCRIPT

The science of bikeway design and planning is continuing to advance as increased activity in the field leads to better understanding of the principles of good design. This manual presents design recommendations based upon recent research and practical experience with existing facilities. At some points it is at variance with, expands upon, and/or supercedes findings in other widely-distributed bikeway design guides.

This manual's contents should not be regarded as the definitive and final statement of design criteria. It is essential that bikeway planners take advantage of findings of subsequent technical research and practical experience. To make this possible, bikeway designers must:

- Critically evaluate the in-use performance of bikeways they build;
- Document their findings so that others may draw upon their experience;
- Continue to monitor findings emerging from experience in other areas and from new research; and
- Incorporate those findings within the criteria presented herein.

SELECTED REFERENCES

The following documents are identified as representative current references in bikeway planning and design.

MANUALS AND PLANNING GUIDES

Bikeway Design, Oregon State Highway Division, Salem, January, 1974.

Bikeways -- State-of-the-Art -- 1974, FHWA-RD-74-56, July, 1974.

Guide for Bicycle Routes, American Association of State Highway and Transportation Officials, Washington, D.C., 1974.

Bikeway System Planning and Design Manual, City of Seattle Engineering Department, Seattle, August, 1975.

APPLIED PLANNING AND DESIGN STUDIES

Ann Arbor Bicycle Path Study, Haldon L. Smith, Ann Arbor, Michigan, 1972.

Arizona Bikeways, Bivens & Associates, Inc., Phoenix, Arizona, July, 1973.

Eugene Bikeways Master Plan, De Leuw, Cather & Company, San Francisco, November, 1974.

BICYCLE ACCIDENT STUDIES

Factors in the Initiation of Bicycle -- Motor Vehicle Collisions, Williams, Alan F., Insurance Institute for Highway Safety, Washington, D.C., December, 1974.

Identifying Critical Behavior Leading to Collisions Between Bicycles and Motor Vehicles, Cross, Kenneth, D., Santa Barbara, California.

The Nature of Bicyclist Accidents and Injuries, Chlapecha, Tom, Third International Congress on Automotive Safety, San Francisco, 1974.

The above references are identified as exemplary of state-of-the-art activities in bikeway planning and design. It must be noted that a number of research findings resultant from this project extend upon or supercede statements in the referenced documents.

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