Requested by
ASSEMBLY CONCURRENT RESOLUTION NO. 26
1971 REGULAR SESSION

STATE OF CALIFORNIA
BUSINESS AND TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

BIKEWAY PLANNING CRITERIA AND GUIDELINES

April 1972

Prepared by
INSTITUTE OF TRANSPORTATION
AND
TRAFFIC ENGINEERING

SCHOOL OF ENGINEERING AND APPLIED SCIENCE
UNIVERSITY OF CALIFORNIA, LOS ANGELES
UCLA–ENG–7224

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NOTICE

STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
1120 N STREET
SACRAMENTO, CALIFORNIA 95814

April 28, 1972

Honorable Darryl R. White
Secretary of the Senate
State Capitol

Honorable James D. Driscoll
Chief Clerk of the Assembly
State Capitol

Gentlemen:

Assembly Concurrent Resolution No. 26, Resolution Chapter No. 107, of the 1971 Regular Session, by Assemblyman John T. Knox, requested the Department of Public Works to make a study of the most feasible and least expensive methods by which existing and future public streets and thoroughfares can more safely accommodate bicycle riders.

Attached are two copies of a report on this subject prepared for the Department by the Institute of Transportation and Traffic Engineering at the University of California, Los Angeles, in accordance with the request contained in the resolution.

Respectfully,

JAMES A. MOE
Director of Public Works

Attachments

Assembly Concurrent Resolution No. 26

RESOLUTION CHAPTER 107

Assembly Concurrent Resolution No. 26—Relative to bicycle lanes and paths.

[Filed with Secretary of State July 28, 1971.]

WHEREAS, It has come to the attention of the Members of the Legislature that bicycling is becoming the principal sport and recreation of ever-increasing numbers of Californians of all ages, and serves as an important mode of basic transportation for many persons as well; and

WHEREAS, The volume of motor traffic on California streets and highways makes bicycling a sometimes hazardous pursuit; and

WHEREAS, Alternatives to bicycling on public streets and highways by sharing the traffic lanes with motor vehicles should be made available to the bicyclists of the state, since every effort should be made to encourage this healthful and pollution-free activity; now, therefore, be it

Resolved by the Assembly of the State of California, the Senate thereof concurring, That the Division of Highways shall study the most feasible and least expensive methods by which existing and future public streets and thoroughfares can more safely accommodate bicycle riders; and be it further

Resolved, That the Division of Highways report its findings and recommendations to the Legislature no later than the fifth calendar day of the 1972 Regular Session; and be it further

Resolved, That the Chief Clerk of the Assembly transmit a copy of this resolution to the Director of Public Works and the State Highway Engineer.

UCLA-ENG-7224
April 1972

BIKEWAY PLANNING CRITERIA AND GUIDELINES

FINAL REPORT

Contract No. ST CAL - Div Hwys 13945 - A13424

"A STUDY OF BICYCLE PATHWAY EFFECTIVENESS"

Principal Investigator: H. W. Case, Professor,
Associate Director, ITTE

Co-Principal Investigator: S. F. Hulbert, Research Psychologist

Project Consultant: Gary Fisher, Ph. D.

U. C. Davis Coordinator: M. R. Ramey, Professor,
Engineering, U. C. Davis

Authors: G. Fisher, S. Hulbert, M. R. Ramey, S. Fass,
D. Gonzales, A. Horowitz, J. Kefauver,
B. Kobritz, W. Lum, M. Millar, C. Nicodemus,
A. Ravindranath, D. Stenson, E. Weller

Prepared for

State of California - Business and Transportation Agency
Department of Public Works
Division of Highways

Institute of Transportation and Traffic Engineering
School of Engineering and Applied Science
University of California, Los Angeles

FACULTY ADVISERS:

Prof. K. Arulanandan	(Engr., Davis)
Prof. A. Bush	(Engr., UCLA)
Prof. J. M. English	(Engr., UCLA)
Prof. D. Lott	(Engr., Davis)
Prof. D. McAllister	(Architecture & Urban Planning, UCLA)
Prof. F. G. Mittlebach	(Housing, Real Estate & Urban Land Studies, UCLA)
Prof. R. L. Perrine	(Engr., UCLA)
Prof. C. K. Shen	(Engr., Davis)
Prof. R. Sommer	(Psych., Davis)

GRADUATE STUDENT STAFF MEMBERS:

J. Bennett	(Engr., Davis)	*M. Millar	(Urban Planning, UCLA)
R. Burgess	(Engr., UCLA)	*C. Nicodemus	(Engr., Davis)
M. English	(Engr., Davis)	K. Prakash	(Engr., UCLA)
*S. Fass	(Urban Planning, UCLA)	*A. Ravindranath	(Engr., UCLA)
*D. Gonzales	(Management, UCLA)	R. Rudden	(Engr., Davis)
B. Harrington	(Psych., Davis)	T. Steiner	(Engr., Davis)
*A. Horowitz	(Urban Planning, UCLA)	*D. Stenson	(Zoology, UCLA)
*J. Kefauver	(Management, UCLA)	J. Vrymoed	(Engr., Davis)
*B. Kobritz	(Bus. Ad., UCLA)	*E. Jud Weller	(Engr., UCLA)
B. Kroll	(Psych., Davis)	R. Willis	(Engr., UCLA)
*W. Lum	(Engr., UCLA)	T. Zanic	(Urban Planning, UCLA)

*Primary contribution to the writing of the Final Report

ABSTRACT

Design criteria, specifications and guidelines for providing Class I and Class II bikeway facilities are presented. Topics treated include: bikeway design characteristics (design speed, width and clearances, grade, radius of curvature, surface and drainage); capacity; volume criteria for separated bikeways; accident and safety considerations; alternatives for incorporating bikeways on existing streets; traffic intersections; signing; and bikeway lighting.

In addition to design information, topics relating to the more global aspects of providing bikeways and routes in a community are presented. These include: short and long range planning considerations; community participation in the planning process; assessing land use impacts; mixed mode travel; bicycle parking facilities; theft prevention; techniques for assessing demand; and the design of a special bicycle-user questionnaire.

KEY WORDS

BICYCLE, BIKEWAY DESIGN, BICYCLE FACILITIES, BIKEWAY ALTERNATIVES, CRITERIA, DEMAND, BICYCLE SAFETY, BIKEWAY COSTS, HUMAN FACTORS, BIKEWAY TRAFFIC CONTROL DEVICES.

PREFACE

The 1971 California Legislature, by passing Concurrent Resolution 26, recognized the burgeoning increase in bicycle users; and, they called for the California Department of Public Works, Division of Highways to authorize and fund this study which is an in-depth investigation of the various ways bicycles can effectively be accommodated on California streets and roads. The UCLA Institute of Transportation and Traffic Engineering was requested to carry out the study as rapidly as possible in view of the pressing need for information. The research team consisted of an inter-disciplinary team of staff, faculty, and graduate students in the fields of engineering, urban planning, psychology, and management, from the campuses of the University of California at Los Angeles and Davis.

ACKNOWLEDGMENTS

The support, and assistance of the following persons are gratefully acknowledged:

Mr. Kenneth D. Bandow, Assistant Highway Design Engineer, State of California, Division of Highways, provided administrative liaison during the course of the work.

Mr. O. E. Patterson, Administrative Analyst, provided administrative supervision on behalf of ITTE.

Mr. Richard H. Kermode, District Design Coordinator, Design B; Mr. Frank Swan, Design Staff Assistant, Design B; and Mr. Glen Hill, Design B, State of California, Division of Highways District 7, Los Angeles, provided valuable assistance in supplying cost estimates and information on highway design practices.

Mr. S. E. Rowe, Senior Traffic Engineer, Department of Traffic, City of Los Angeles, supplied the project with a tape file of Los Angeles bicycle accidents. Tabulations of these accident data that appear in the report were performed with a computer program written by Mr. Harry Knobel, ITTE, UCLA.

Access to Los Angeles bicycle registration files for a pilot study with the user-questionnaire was granted by Police Chief Edward Davis, City of Los Angeles. Commander Noel A. McQuown, Commanding Officer, Technical Services Bureau, provided liaison with the staff in obtaining a sample of approximately 1900 registrants for the questionnaire mailing.

Mr. Robert M. Cleckner, National Field Director, Bicycle Institute of America, and Mr. Keith Kingbay, Activities Chairman, League of American Wheelmen, provided valuable information and insights from their extensive personal experience with bicycles.

Language translations were provided by Mrs. Astrid Brown and Mrs. Rita Shea. Bibliographic assistance was provided by Ms. Rosalee Wright and Ms. June Armstrong, Reference Librarians, UCLA Engineering Library.

Mrs. Louise Kirkpatrick was efficient and dedicated in preparing typed copy of the manuscript during the course of the study. Final typing and report preparation was provided by Engineering Reports Group, UCLA.

The authors also gratefully acknowledge the numerous engineers and city representatives both here and abroad who provided the project with extensive information on existing and proposed bicycle facilities and documents pertinent to bikeway design.

SUMMARY

It is well documented that bicycles are being purchased by adults for their personal use at a rate that might best be described as phenomenal. Historically, in the United States, this is a resurgence of bicycle interest — the strongest in the last 70 years. In the ensuing years a great network of roads, streets and highways have been built to accommodate the private automobile with only marginal provision for bicycle use (predominately by school children who as soon as possible put aside their bikes for cars.) However, changes are taking place. Physical fitness, recreation and "protect the environment" programs all are in the ascendancy, and are reinforcing the new bicycle boom to give it even greater vitality. This is reflected in increasing public pressure for pathways and routes where bicycles can be ridden with relative safety. And while there is a growing demand for more recreational bicycle facilities in this country, there is also a growing demand for more urban bikeways. The emphasis in this report is towards providing bicycle facilities within the street rights-of-way in urban areas.

In the report the term "bikeway" is used extensively to designate all facilities that explicitly provide for bicycle travel. Three classes of bikeway are defined. Class I bikeways are completely separated rights-of-way designated for the exclusive use of bicycles. Class II bikeways are defined as restricted rights-of-way (generally on the street alignment) designated for the exclusive or semi-exclusive use of bicycles. Class III bikeways are defined as shared rights-of-way designated as such only by signs or stencilled pavement markers.

In urban redevelopment, new towns, park land, and along linear rights-of-way, it is possible to create Class I bikeways. In existing cities and along rural roads Class II bikeways can be created. Class III bikeways offer very little to the would-be cyclist and are not generally recommended.

Freeway road beds in urban areas are neither safe nor healthy places to encourage bicycle riders to travel. Other types of linear right-of-way, on the other hand, such as power lines, flood control channels, and abandoned railroad lines, present excellent opportunities for creation of Class I bikeways for both transportation and recreation use.

Design criteria, specifications, and guidelines for providing Class I and Class II bikeways are presented in detail in the report. Topics treated include: bikeway design characteristics (design speed, width and clearances, grade, radius of curvature, surface, drainage, and grate hazards); capacity; volume criteria for separated bikeways; accident and safety considerations; alternatives for incorporating bikeways on existing streets; traffic intersections; signing; and bikeway lighting. Data are also included to aid in making cost estimates for any particular bikeway under consideration.

Coping with bicycle traffic at intersections poses particularly difficult problems from the standpoint of design. Many types of intersection design are presented and using these various designs, most types of intersections can be modified to increase the safety to the bicyclist.

Safety is a primary factor in providing bikeways that will be used. It is clear that in the United States bicycle accidents are on the increase; however, if European experience is any indication, accidents can be reduced by proper design of the bikeway.

Nighttime use of bikeways will require adequate illumination but generally no more than is usual for urban streets. Traffic signs and pavement markings should be standard in compliance with the MUTCD, and placed so as clearly to inform motorists that a pathway is provided for the use of bicyclists. Other, smaller standard signs and markings are appropriate for guiding the bicyclists and warning them of various hazards. It should be emphasized that the enactment and enforcement of laws and ordinances governing bikeway operation, motor vehicle parking and intrusion on the bikeway, and, in some cases, bicycle use of sidewalks, are necessary to insure the efficient and safe operation of bikeways once they are provided.

In addition to design information, topics relating to the more global aspects of providing bikeways and routes in a community are presented. These include: short and long range planning considerations; community participation in the planning process; assessing land use impacts; mixed mode travel; bicycle parking facilities; theft prevention; techniques for assessing demand; and the design of a special bicycle-user questionnaire created by the project staff. The questionnaire provides a framework for collecting data on the socio-economic characteristics, preferences, and attitudes of bicycle users with respect to the roadways they use, the type of trips they take, their reasons for using their bicycle, their personal evaluation of safety and comfort, and their propensity for using bikeways if such were provided. As such, the questionnaire provides a valuable tool for use by communities in planning for the bicycle.

Each community will have to assay its own potential demand for bikeways. The overall demand is apparently still growing but certainly is subject to rapid change and likely to have quite different time and spatial characteristics for each urban area. More or less standard origin-destination techniques can be used together with registration, sales, and maintenance records, among others, to aid in assessing demand. Accident statistics also can be used to reflect amount and type of bicycle usage.

It would appear that especially for short trips the modern multi-speed bicycle constitutes a potentially viable alternative mode of transportation for urban adults. This study shows how bikeways can be created, but does not attempt to answer to what extent they would actually be used in any given community.

It is clear that community representation is important in considering bikeways and their locations, just as it is in the location of highways. This report can help engineers and community representatives to reach more reasoned conclusions regarding provision of bikeways than heretofore has been possible. In a similar fashion it provides a source of unbiased information for legislative debate, thereby fulfilling its initial purpose.

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CHAPTER ONE

1.1 INTRODUCTION

Bicycles are being purchased by adults for their own use in phenomenally increasing volume. Historically, in the United States this is a resurgence, the strongest, since the advent of the automobile 60 years ago. In the ensuing years a great network of roads, streets and highways have been built to accommodate the private automobile and only marginally provide for bicycle use predominately by school children who as soon as possible put aside their bikes for cars.

Physical fitness, recreation, and "protect the environment" programs all are in the ascendancy, and directly tie in with the bicycle boom and give it a vitality that is causing public pressure for bikeways and routes where bicycles can be ridden with relative safety.

Of major importance for this study is forthright recognition of the dramatic improvements in bicycles that manufacturers have adopted from racing bicycles and made available for mass marketing. The modern bicycle for adults is lightweight, fast and has a variety of speeds which makes hill climbing far easier and level ground speeds far greater than on the ordinary, heavy, balloon tire, single-speed bicycle that dominated the market until a few years ago.

It has only been since about 1960 that ten-speed bicycles have been in use. By 1967 they were in widespread use and fifteen-speed bicycles had become available. The multi-speed cycles have made the bicycle a potentially viable alternative mode of transportation. To those who have not ridden these "new" bikes the concept of bicycling is purely as a recreation or exercise activity probably based on childhood memories.

With the advent of bicycles that can cope with hills and easily average 10 mph or better on level ground for long periods of time, the feasibility of the bicycle becoming a significant mode of transport has increased markedly.

In other countries, the bicycle is and has been a major mode of transportation. For example, in 1971 in the Copenhagen metropolitan area there were one million bicycle trips per day out of a total of six million person-trips by all modes.

A June 1971, 151-item annotated bibliography, (63), reflects the resurgence of interest in bicycling among adults. A great many of these references bear dates in the mid-1930's; articles in the 1950's seem to deal with recreational aspects of cycling and with children's use of bicycles. But starting about 1966 there are more and more references to the bicycle as a viable alternative mode of adult transportation.

The 1971 California Legislature by passing Assembly Concurrent Resolution 26 recognized the burgeoning increase in bicycle users and called for the California Department of Public Works, Division of Highways to authorize and fund this study of the various ways that bicycles can effectively be accommodated on California streets and highways. The UCLA Institute of Transportation and Traffic Engineering under California Standard Agreement No. 13945-A13424 was requested to carry out the study as rapidly as possible in view of the pressing need for information. Since the initiation of the study, many requests for the results have been received steadily from all parts of the country which testifies to the foresight of the California Legislature in calling for the research to be performed and completed as soon as possible.

This report covers many aspects of provision for the bicycle, from design information relevant and necessary in providing bikeways on streets, highways, and other rights-of-way to special sub-studies covering bikeway planning, community participation, mixed mode travel, parking, theft prevention, and techniques for assessing demand.

In Chapter Two, the history of the bicycle in the United States is briefly presented followed by an over-view of the international experience with the bicycle as a viable form of transportation. The current American bicycle renaissance is then presented and the current status of bikeways throughout the country is summarized.

In Chapter Three design criteria and guidelines for providing bikeways are presented in detail. Topics treated include bikeway design characteristics, capacity, volume criteria for separated bikeways, the ideal bikeway (completely separated from street right-of-way), alternatives for incorporating bikeways on existing streets, bikeways at traffic intersections and road crossings, bicycles on freeway rights-of-way, signing of bikeways, and bikeway lighting.

In Chapter Four, several special topics relating to the more global aspects of providing bikeways and routes in a community are presented. These include short and long range planning considerations, community participation in the planning process, assessing land use impacts, mixed mode travel, bicycle parking facilities, theft prevention, and techniques for assessing demand. In the final section the design of a special questionnaire is presented. This questionnaire was designed by the project to aid in providing a framework for analyzing the socio-economic characteristics; values, preferences, and attitudes of bicycle users with respect to the roadways they use; the type of trips they take; their reasons for using their bicycle; their personal evaluation of safety and comfort; and their propensity for using bikeways if such were provided. As such, the questionnaire provides a valuable tool for use by communities in planning for the bicycle.

Finally in Chapter Five recommendations and conclusions are made, and areas for further study are delineated.

CHAPTER TWO

2.1 HISTORICAL PERSPECTIVE

In the United States, the bicycle has had a long and somewhat turbulent history. A primitive bicycle, the dandy horse, or Draisine, was first introduced in 1819. A later machine, the "velocipedes" was introduced in 1869 and gained considerable popularity. This machine was somewhat supplanted by an unstable machine known as the "ordinary" or "high wheeler." By 1879 the ordinary was being manufactured in Boston.

In 1885, the British Rover "safety bicycle" was introduced and by 1893, the addition of pneumatic tires, roller chain drive, and "diamond" frame evolved the Rover into a form essentially similar to the bicycle of today. Additional sophistications introduced before the turn of the century included the suspension wheel, ballbearings for crank and hubs, weldless steel tubing for the frame, and coaster brakes. (4, 45).

By 1900, the safety bicycle had almost completely supplanted the highwheeler. While the ease of mounting the safety bicycle and its stability were important considerations in the demise of the highwheeler so was its cost. When first introduced, the highwheeler sold for $313, and dropped to $150 by the turn of the century. The safety bicycle on the other hand cost $60 when first introduced and could be purchased for as little as $18 by 1900. Since the big wheel of the ordinary had to be tailored to each individual, it did not lend well to mass-production as did the more adjustable "diamond" framed safety bicycle. By 1900 safety bicycles were being made from components from other manufacturers, and an important facet of mass production, parts-interchangeability, was attained.

As the bicycle gained in popularity in the United States, bicyclists began to demand and obtain better roads upon which to ride. In 1879, a Massachusetts court ruled that "bicycles cannot be deemed a nuisance, but are entitled to a reasonable use of highways." In 1880, bike riders organized as The League of American Wheelmen. By 1893, the L. A. W. had close to 40,000 members and was spearheading many legal battles leading to lighted streets, street name signs at intersections, and the application of "carriage laws" to the bicycle. By 1896, 16 states had appropriated money to improve their roads, since the railroads had made private turnpike operation unprofitable. [1]

Many hazards still faced the early cyclists. Children were known to poke sticks into the cycle spokes and the majority of paved roads in cities were paved with cobblestones. "Good roads for bicycles" was a political slogan helping to foster such projects as the Santa Monica Cycle Path from the Los Angeles City limits to the beach. "Cycle Path" buttons were sold for a dollar apiece to build it. An elevated bicycle path was proposed to run from Pasadena to downtown. The first section, wide enough for four bicycles abreast, was completed in 1900. The Pasadena Freeway now follows its route, (60).

The coming of the auto then ushered in the "Dark Ages" for the American bicycle. Besides giving the infant auto industry the roads its needed, experience in mass-production technology, and several inventions (differential steering, and expansion brakes), provisions made for the bicycle served many of the needs of autoists as well. Bicycle repair shops were widely distributed and lent well to auto repair as the "hostles" built for bicyclists adapted easily to the needs of auto drivers. It was in the bicycle repair shops of Charles and Frank Duryea that the first American car was made. And it was in the repair shops of Henry Ford and the Wright Brothers that the idea of a mass-produced automobile and the aeroplane, respectively, were born.

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[1] League of American Wheelmen, Inc., <u>Material Information Release</u>, Jan. 1970.

The shift of high caliber talent to the infant auto industry, the redirection of capital for development of the car, and the auto's range, convenience, carrying capacity and popularity, led to the nearly complete elimination of the bicycle as a transportation mode in America. Until the 1960's except for brief resurgences during the Depression and the two World Wars, when fuel was scarce and low cost transportation was desirable, the bicycle in the USA served primarily as transportation and recreation for children not yet old enough to drive.

Internationally, however, the bicycle has long been a viable mode of transportation. Certainly, economic factors played a major role in the popularity of the bicycle abroad. This picture, however, is changing and in many locales the bicycle is loosing its place to the automobile. Old "cycleways", as they are called in British-influenced areas, have been pretty much ignored since World War II and in some cases have been absorbed into the "carriageway" during street widening. This trend is occurring in Christchurch, New Zealand;[1] Singapore;[2] Hong Kong;[3] Newcastle, New South Wales;[4] Adelaide, South Australia;[5] and several

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[1] Ltr to Dr. Slade Hulbert, ITTE, UCLA, from P.G. Scoular, Engr., City Engineering Office, Christchurch, New Zealand, Oct. 29, 1971.

[2] Ltr to Dr. Slade Hulbert, ITTE, UCLA from Low Heck Pheng, for the Permanent Secretary, Ministry of Communications, Singapore, Nov. 23, 1971.

[3] Ltr to Dr. Slade Hulbert, ITTE, UCLA from S.A. Barden, Chief Engr., Traffic and Transport Survey, Highway Dept., Dept. of Public Works, Hong Kong, Nov. 18, 1971.

[4] Ltr to Dr. Slade Hulbert, ITTE, UCLA from E.A. Baldwin, Asst. Commissioner of Police, Sydney, Australia, Nov. 25, 1971.

[5] Ltr to Dr. Slade Hulbert, ITTE, UCLA from J. Wageesaysemi, for the Commissioner of Police, Adelaide, South Australia, Dec. 6, 1971.

parts of Great Britain.[1,2] In Adelaide[3] even the laws enacting cycleways have been repealed. Disuse and need for wider roads to meet motorized traffic demands have been cited as the major causes for this transition.

However, in other overseas areas, the bicycle is still an important mode of transportation, and as such is being considered an integral part of the transportation systems of Copenhagen, Denmark;[4] Uppsala, Sweden;[5] the Netherlands;[6] Germany (30); Tehran, Iran;[7] Japan (49-53); Bangalore, India (61); the USSR (6); and British "New Towns."[8,9] Several of the current developments in these countries are as follows:

In Uppsala, bicycles comprise 20% of the total traffic. It is planned to create special pedestrian and bicycle "paths" linking the city

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[1] Ltr to Dr. Slade Hulbert, ITTE, UCLA, from I. T. Cusbery, Chief Engr. for the Director of Transportation and Basic Services, City of Liverpool, England, Oct. 19, 1971.

[2] Ltr to Dr. Slade Hulbert, ITTE, UCLA, from R. W. Faulks, Principal Planning Officer, West Midlands Passenger Transport Executive, Birmingham, England, Oct. 18, 1971.

[3] Ltr to Dr. Slade Hulbert, ITTE, UCLA, from J. Wagcesaysemi, for the Commissioner of Police, Adelaide, South Australia, Dec. 6, 1971.

[4] Ltr to Mr. Alva Williams, Jr., Traffic Engr., Dept. of Public Works, Eugene, Oregon, from Wulf D. Wätjen, for Egnsplanrådet, Copenhagen, Denmark, July 18, 1971.

[5] Ltr to Dr. Slade Hulbert, ITTE, UCLA, from Anders Berggren, Uppsala Kommun Stadsarkitektkontoret, Uppsala, Sweden, Dec. 1971.

[6] Ltr to Dr. Slade Hulbert, ITTE, UCLA, from the Director-General of the Rijkswaterstaat, the Hague, Netherlands, Nov. 8, 1971.

[7] Ltr to Dr. Slade Hulbert, ITTE, UCLA, from Col. Ali Hatami, Chief Technical Advisor, Traffic Dept., Tehran, Iran, Oct. 23, 1971.

[8] Ltr to Dr. Slade Hulbert, ITTE, UCLA, from E. C. Claxton, Chief Engr., Stevenage Development Corp., Stevenage, England, Nov. 9, 1971.

[9] Ltr to Mr. A. Williams, Jr., Traffic Engr., Dept. of Public Works, Eugene, Oregon, from E. C. Claxton, Chief Engr., Stevenage Development Corp., Stevenage, England, Aug. 6, 1971.

center to various areas (primarily recreational, work, and residential). Some parts of this system have already been built.

Bangalore has a heavy percentage of bicycles and many of its intersections have been designed to meet this demand. At intersections with heavy bicycle turning movements, bicycles are allocated an exclusive portion of the signal cycle so as to allow bicycle platoons to clear before automobile traffic is allowed to enter the intersection, (61). There is a similar system in Budapest, Hungary.[1]

Tehran, plans to construct "pathways" with different colored asphalt ("for distinction"), slightly raised from the roadway and separated from pedestrians by a low barrier. Riders in Tehran must be licensed.

Germany, Japan and the USSR all have "cyclepaths" separated from the roadway. In Japan,[2] a huge bicycle recreational area with road race courses, sprint tracks and athletic areas of various kinds has been built.

In the Netherlands, there are 8 million bicycles in a country of 13 million people. Bicycle sales were 850,000 in 1970 and are expected to top 1.5 million by 1980. In urban areas, 70% of the movement is by pedestrians and bicycles. In the Netherlands mopeds[3] are legally defined as bicycles, however, non-motorized bicycles outnumber mopeds by about 2:1. Currently there are 2375 miles of completely separated "cyclepaths" outside urban areas.[4]

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[1] Közúti Csomopontok, Utügyi Kutato Intézet, 29. SZ. Kiadványa, Budapest, (Hungary), 1963, pp. 114-118. (Concerning Highway Junctions).

[2] Anonymous, Cycle-Sports Center, 1, Shuzenji-cho, Tagata-gun, Shizuoka Prefecture, 1971, © R2050107 AAPA.

[3] A moped is generally defined as a motor-bicycle of under 50 cc engine displacement.

[4] Woods, Sydney, Cycleways (on Cycle Mini-roads) Interim, Report on Visit to Holland, for Raleigh Limited, Nottingham, England, Aug. 1971, 10 pp mimeo.

In Stevenage, England, a "New Town" 30 miles from London, a full third of the commuting is done by non-motorized vehicles and pedestrians. Four thousand workers and children use "cyclepaths" daily; which comprises 10% of the total traffic. Intersections are grade separated with the carriageway ten feet higher than the "cyclepath." Parts of the system run along ancient country lanes which have been set aside completely for non-motorized traffic.[1,2]

Almost all of the international "cyclepath" systems provide separated lanes exclusively reserved for bicycle and, sometimes, moped use. Painted lines or stripes to demark bicycle rights-of-way are generally not recommended owing to the ease of encroachment by motorized traffic. International "cyclepaths" for the most part separate bicycles from motorized traffic by barriers, hedges, physical separation, or grade separation.

The predominant method of "separation" employed in the United States to date has amounted to symbolic separation. With several notable exceptions the majority of United States "bike routes" currently consist of little more than signs to guide bicyclists along a scenic route and at the same time warn motorists of their presence.

Presented in the following section is a description of the current resurgence of interest in the bicycle as a form of transportation and recreation in the United States. From responses to queries sent by the project, it was not always possible to ascertain the makeup and characteristics of the "pathways" reported by the individual cities. However, these characteristics when reported are noted.

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[1] LTR to Mr. Alva Williams, Jr., Traffic Engineer, from E.C. Claxton, Chief Engineer, Stevenage Development Corp., August 6, 1971.

[2] LTR to Dr. Slade Hulbert, ITTE, UCLA, from E.C. Claxton, Chief Engineer, Stevenage Development Corp., Stevenage, England, Nov. 9, 1971.

In order to accommodate the differences in definitions of bicycle facilities, the remainder of this chapter will use the following distinctions:

a) "Route" refers to any system of facilities designated in any manner for use by bicyclists.

b) "Trail" refers to any system that is separated from the roadway (usually intended for recreational use).

Due to the variety of terms used to designate bicycle facilities, a uniform set of definitions is presented in Chapter Three, and used thereafter in the report.

2.2 THE AMERICAN BICYCLE RENAISSANCE

In 1961, Homestead, Florida started the current bicycle renaissance. Their desire was to provide a safer way for their children to bicycle to school.[1,2] Between 1966 and 1971, Dade County, Florida, which includes Miami as well as Homestead completed 100 miles of bicycle routes. A bank in Miami even has a pedal-up teller window, (13). The State of Florida, Department of Outdoor Recreation, is considering itself responsible for the development of longer touring trails and coordinating trail development by local interests with those of the state.[1]

The State of Wisconsin has an extensive, 300 mile statewide system which includes the Elroy-Sparta Trail (The Old Railroad Trail). The trail is 32 miles long, passes through 3 tunnels (one over 1/2 mile long) and crosses 33 trestles. This section alone was used by 24,000 bikers and

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[1] Florida State Dept. of Natural Resources, Division of Recreation and Parks, A System of Bicycle Safety Trails as a Part of the Florida Recreation and Parks Program, 1971, 6 pp.

[2] Berstein, Carl, "Commuter Cycling Picks Up Speed", Congressional Record - Senate, June 25, 1970, p. S9838 - S9839.

hikers last year (double the volume of the year before). The entire system can be cycled in a week to ten days and traverses 13 counties.[1,2]

Milwaukee, Wisconsin has proposed 127 miles of routes on which currently there is a 64 mile tour around the outskirts of the city. They are contemplating trails in existing parks and on electric company rights-of-way[3] (42, 56, 68). Madision has planned 150 miles of routes, some outside the city limits, some separate from the roadway, and some on sidewalks and streets.[4.]

Chicago has completed 18 miles of its 34 mile Phase I bicycle route plan. This includes 15 miles on walkways and 1.5 miles along "channels." Eventually the system is to consist of approximately 250 miles of bicycle routes,[5] (19).

Washington, D.C., claims to have 1200 bicycle commuters per day during their 8 months of "fair weather." They have spent $9,000 for four miles of route and have opened a route from the Georgetown waterfront

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[1] LTR to Mr. Doug Stenson, ITTE, UCLA, from Loren M. Thorson, Chief, Recreational Programming, State of Wisconsin Dept. of Natural Resources, Nov. 15, 1971.

[2] Wisconsin State Dept. of Natural Resources, The Wisconsin Bikeway, Featuring the Elroy-Sparta Trail, Madison, Wisconsin, Publication 115-71, 1971 Brochure.

[3] Portland, (Oregon) Traffic Safety Commission, Bicycle Safety Program, 1971, Aug. 16, 1971, 40 pp.

[4] LTR to California Dept. of Public Works Transportation Library, from Duane F. Hinz, Principal Planner, Madison City Planning Dept., Madison, Wisconsin, July 16, 1971.

[5] City of Chicago, Cyclist Guide, Chicago Bicycle Route System, no date, 33 pp (Bound).

to RFK Stadium. The Smithsonian Institute reports plans for 130 miles of routes in the city, and 500 miles of routes within an afternoon's travelling distance by bicycle.[1,2,3.]

The State of Ohio has 237 miles of routes in at least seven different portions of the state, ranging from 24-50 miles each. These are specific tours designed to direct the bicyclist to various points of interest and scenic beauty.[4.]

The cities of Dallas and Austin, Texas have established park routes and additionally Dallas has two experimental commuter routes.[5] Houston has plans for routes throughout the city.[6]

Princeton, New Jersey has built a 1.3 mile route and has proposed a 38.5 mile system which has 20.3 miles planned for transportational use, (55).

Phoenix, Arizona, has bike trails along irrigation canals in the country surrounding the city, but there are no routes in the city to date.[7]

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[1] LTR to Dr. Slade Hulbert, ITTE, UCLA, from Wilcomb E. Washburn, Director of American Studies Program, Washington, D.C., Nov. 1, 1971.

[2] Washburn, Wilcomb E., _et al._, _Proposal: The Bicycle as a Means for Commuter Travel!?._, (Smithsonian Bikeways Report), Summer 1969, 15 pp., mimeo.

[3] Berstein, Carl, "Commuter Cycling Picks Up Speed", _Congressional Record - Senate_, June 25, 1970, p. S9838 - S9839.

[4] _Bicycle Journeys Around the Wonderful World of Ohio_, Publisher unknown, no date.

[5] Portland, (Oregon) Traffic Safety Commission, _Bicycle Safety Program, 1971_, Aug. 16, 1971, 40 pp.

[6] LTR to Dr. Slade Hulbert, ITTE, UCLA, from Richard P. Castleberry, Asst. Director, Parks and Recreation Dept., City of Houston, Texas, Dec. 16, 1971.

[7] Portland, (Oregon) Traffic Safety Commission, _Bicycle Safety Program, 1971_, Aug. 16, 1971, 40 pp.

In Colorado, Fort Collins has 4.5 miles of route (consisting of a lane delineated by a painted stripe) on an experimental basis;[1] Colorado Springs has also set up an experimental bicycle route system; Denver has bike trails in its parks.[2]

Seattle, Washington, has routes, joining several of the 156 parks in the city, which use the pre-existing street system. They already have a "scenic drive" with bicycle routes established "whenever possible" around the city.[3]

Wichita, Kansas, has proposed a hiking and bicycle trail beside a proposed elevated freeway, (67). A similar trail is proposed for Madison, Wisconsin, (68).

In 1971, the State of Oregon passed House Bill 1700 which "requires the State Highway Commission, cities and counties to spend at least 1% of their highway revenue on footpaths and bicycle trails." This money cannot be spent on other projects. This bill should produce about 1.5 million dollars in funds which may be matched by the Federal Government. The first highway to be constructed with a bicycle route goes to bid in March, 1972. The Oregon Highway Commission now plans for the construction of 30 miles of routes along four or five highways, (21, 29).

In California, the City of Davis, a semi-isolated academically-oriented community of 24,000 people, is probably the most spectacular

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[1] Rice, Joe A., Bicycle Lane Feasibility Study, Ft. Collins, Colorado, Submitted to the City Manager Tom Coffey by City Traffic Engr. Joe A. Rice, Sept. 1, 1970.

[2] LTR to Dr. Slade Hulbert, ITTE, UCLA, from Richard C. Thomas, Director of Transportation Services, City and County Dept. of Public Works, Denver, Colorado, Oct. 5, 1971.

[3] LTR to Dr. Slade Hulbert, ITTE, UCLA, from W. G. van Gelder, P. E., City Traffic Engr., Dept. of Engineering, City of Seattle, Washington, Oct. 22, 1971.

example of the re-birth of the bicycle in America. People in the com-minity were able to convince the city and University to recognize Davis' 18,000 bicycles as transportation vehicles. Through political pressure, the bicyclists' needs were recognized. The Campus itself is closed to all motorized traffic with the exception of University maintenance vehicles. City streets incorporate a variety of bicycle routes from painted line to physical barrier. New housing construction must provide for bicycle routes with lanes separated from motorized traffic. On one major arte-rial in Davis the rush hour traffic is 40% bicycles with 90% ridden by adults, even during the summer when there are few students. A recent survey estimated that up to 10,000 persons ride to and from the campus every day. These developments at Davis were augmented by a special law passed by the California State Assembly which enabled the City of Davis to formulate regulations for bicycles, (Ord. #442), and to create bicycle lanes. The city has plans to build 12 more miles of routes by 1974 with 5 miles of completely separate right-of-way (230).

Marin County has embarked upon an energetic effort to cure a problem: Until recently the only possible means of leaving the city of Sausalito was via motorized vehicle on freeways. By working with vari-ous authorities, Marin County now has a bike route system of 24 miles running through the county, crossing the Golden Gate Bridge, and connec-ting with the bicycle routes of San Francisco. Besides obtaining coopera-tion from all cities along the route, cooperation was required from the State Highway Department, two water companies, a railroad, the Golden Gate Bridge Authority, and the Department of the Army. The route varies from simple signed sections (18 miles completed) to several entirely separated trails (6 miles completed), including one along Richardson Bay on an old railroad right-of-way.[1,2]

San Francisco, even with its problem of steep grades, has dedicated itself to bicycle route systems for recreation (14-1/2 miles completed) and transportation (7-1/2 miles completed). Golden Gate Park is open to bicyclists on Sundays. The park connects with the rest of the route system which goes to Lake Merced, the Wharf, and the Presidio, where it joins the Marin County bicycle route system.[3]

Sacramento is planning for a regional system using river levee roads, existing rights-of-way, abandoned railroad right-of-way, and open space. It already has built the "American River Bikeway" trail. The planned pilot project is 9.1 miles long.[4]

Berkeley plans include the use of existing roads, railroad rights-of-way, and sidewalks. The Berkeley Master Plan proposes to integrate auto, bike, pedestrian and local transit and "reduce dependence on the private automobile as the dominant mode of transportation." (9)

San Luis Obispo has signed a 16.3 mile route throughout the city on two-way streets ranging from 34' - 80' curb-to-curb.[5,6]

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[1] Joske, Pierre, Marin County Parks and Recreation Dept., Re: Bike Path Progress Report, Memoranda dates: Sept. 29, 1970, Oct. 21, 1970, Dec. 4, 1970, and Apr. 30, 1971, 11pp.

[2] LTR. to UCLA-(ITTE), from Don Rolph, Park Planner, Marin County Parks and Recreation Dept., Feb. 4, 1972, and verbal communication.

[3] Division of Traffic Engineering, Bureau of Engineering, San Francisco Bikeways, Dec. 6, 1971, 4 pp., mimeo.

[4] Bikeway Action Committee: Sacramento Region, Bikeways Sacramento Region, no date, 10 pp., bound.

[5] Newhart, Robert L., II, Investigation into the Feasibility of Bicycle Paths, as Chairman of the Citizens' Advisory Committee to the Mayor and City Council of San Luis Obispo (California), June 1, 1971, 5pp.

[6] LTR to Mr. Doug Stenson, ITTE, UCLA, from David F. Romero, City Engr., City of San Luis Obispo (California), Public Works Dept., Jan. 24, 1972.

While Riverside County [1] has, "not progressed in this field," because their unincorporated areas are rural and undeveloped, the City of Riverside [2] has a trial bicycle route paralleling major streets with some street widening and striping of lanes.

The City of Santa Barbara has 3-1/2 miles of route on the beach and the County has signed routes. [3] The County is "not happy" with bicycles being mixed with auto traffic, and is experimenting with removing parking lanes and painting stripes to separate the modes. [4]

In San Diego, there are four routes between recreational areas, and a new subdivision has incorporated routes consisting of separate lanes (Tiera Santa). [5]

Orange County has issued a proposed Master Bikeways Plan (46) which asks the County to be responsible for development of routes and trails in unincorporated areas as well as coordinating the local systems. There are 25 cities in Orange County, of which sixteen are developing

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[1] Keith, A. C., Re: Bicycle Trails, for the County of Riverside Board of Supervisors and Road Commissioner, Sept. 2, 1971, 6pp. mimeo.

[2] LTR to Dr. Slade Hulbert, ITTE, UCLA, from Aaron D. Darnell, Traffic Engr., City of Riverside, California, Oct. 15, 1971.

[3] Hogle, R. D., and C. L. Lefler, City of Santa Barbara Bikeway Program 1971, for the Dept. of Public Works, Traffic Division, City of Santa Barbara, California, Sept. 1971, 9 pp., mimeo.

[4] LTR to Dr. Slade Hulbert, ITTE, UCLA, from Maynard Keith Franklin, County Traffic Engr., County of Santa Barbara, Road Dept., for Leland R. Steward, Road Commissioner, Sept. 28, 1971.

[5] Portland (Oregon) Traffic Safety Commission, Bicycle Safety Program, 1971, Aug. 16, 1971, 40 pp.

master plans of bicycle facilities and two are studying routes. The City of Fullerton has proposed a bicycle route system as "... expandable into a viable, safe transportation mode when required" (27). Newport Beach and Costa Mesa have signed streets, while Newport Beach also has a route along the beach. Of the 700 miles of routes proposed in the Orange County Master Plan for Bicycles, 315 miles were approved and recommended by the Planning Department to the Orange County Board (27, 46).

At the federal level, a government spokesman, Edward C. Crofts, then director of the Bureau of Outdoor Recreation in the U.S. Department of Interior, announced plans in 1966 for 150,000 miles of urban and suburban bicycle routes to be provided over a ten year period. He noted that a government report concluded that ideally, there should be 25 miles of trails (foot and bicycle) provided for every 50,000 persons. [1] In a recent address, the Assistant Secretary of Transportation, Herbert F. DeSimone stated that "I'm determined to lend the assistance of my office to make it (bicycling) a more viable mode of transportation." (25). Indications are that the Department of Transportation is willing to cooperate with the Department of the Interior to achieve the goal of providing more extensive bicycle facilities in this country for both transportational and recreational use.

While the present trend in the United States appears to be towards response in quantity to the renewed interest in the bicycle, it behooves planners to design routes and trails that insure tangible levels of safety and service to users of the system. The remainder of the report is addressed to these aspects of the problem.

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[1] Bicycles and Motorcycles, "Here Comes the Federal Bikeway Boom," Apr. 1966.

CHAPTER THREE
BIKEWAY DESIGN CRITERIA

3.1 DEFINITIONS

The current literature on the subject of bicycles and bikeways contains many different terms describing the same, or shaded variations of the same concept. The list of terms includes:

- Bicycle way (Bikeway)
- Bicycle Route (Bikeroute, Bicycle Safety Route)
- Bicycle Path (Bikepath)
- Bicycle Trail (Biketrail)
- Bicycle Lane (Bikelane)
- Bicycle Track (Biketrack, Cycleway)

Since most of the above terms vary only marginally in describing different characteristics of bicycle travel facilities, it is appropriate at this point to set out some general definitions that systematically categorize the various types of bicycle facilities.

In this report the term "Bikeway" is used to define all facilities that explicitly provide for bicycle travel. Bikeways, then, can be anything from fully grade-separated facilities to simple signed streets. The following three classes of bikeway are defined:

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

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

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

Class I bikeways typically may be found in parks, recreation areas, rural areas, and new developments where the routes are so laid out as to be completely separate from both roadways and pedestrian paths. In existing built-up urban areas provision of Class I bikeways might be infeasible when considered in light of the available right-of-way, the associated land use, and cost. In such cases it is appropriate to consider feasibility in terms of a set of Class II bikeway alternatives. Class III bikeways, as often found in this country, achieve only symbolic separation of the travel modes; as such they may be feasible only under the most ideal situations.

A term that will be used extensively in the remainder of the report is "bikeway route." This phrase is meant to denote the routing, in urban and rural areas, of either Class I, II, or III bikeways. The term "bikeroute" will be restricted to routes consisting solely of signs (Class III).

3.2 BIKEWAY DESIGN CHARACTERISTICS

Several characteristics of the bikeway must be specified if it is to be rationally designed. These include the design speed of the facility, the space required by the bicycle and cyclist, minimum widths and clearances, grade, radius of curvature, bikeway surface, and drainage. In the following portions of this section each of these characteristics shall be discussed and, where appropriate, design recommendations shall be given.

3.2.1 BIKEWAY DESIGN SPEED

The speed that a cyclist travels is dependent upon several factors which include the type of bicycle and gearing, grade, surface, the direction and magnitude of the wind, air resistance, and the physical condition of the bicyclist. Although bike riders have been clocked at speeds in excess of 30 mph, most persons ride at less than half this rate. To cite two examples: Speeds of unconstrained bicyclists in Germany have averaged between 10.5 and 11.2 mph, with a range of approximately 3 to 19 mph (26). Recent measurements in Davis, California have shown speeds to vary between 7 and 15 mph, with the average between 10 - 11 mph. For bikeway design purposes a speed of 10 mph is a conservative value to use in setting criteria for minimum widths and radii of curvature on level bikeways. A quite liberal standard of 15 mph, however, has been specified in the USSR (6). It should be noted that design speeds on up and down grades should reflect in the first case energy expenditure as a function of desired speed, gear ratio and grade, and in the second case the increased speed of the average cyclist over level ground conditions.

3.2.2 BICYCLE AND CYCLIST DIMENSIONS

The average dimensions of a bicycle and cyclist pertinent to minimum bikeway width specifications and employed in European design are:

Handle bar width: 1.96 ft. (0.6m)

Cycle length: 5.75 ft. (1.75m)

Pedal clearance: 0.5 ft. (0.15m)

Vertical space occupied by cycle/cyclist: 7.4 ft. (2.5m)

3.2.3 BIKEWAY WIDTH AND CLEARANCES

The width required for a bikeway is one of the primary considerations in bikeway design. Since the cost and feasibility of providing the bikeway varies with its width, it is necessary to determine minimum specifications subject to the space required for the cyclist, allowance for lateral movement between cyclists, allowance for lateral clearance to obstructions, and allowance for clearance to other hazards.

Virtually all countries in which bikeways are provided specify suggested minimum specifications. Most of these are identical to or slightly vary from specifications used in German bikeway design (26). For example, identical specifications are used in Germany, Japan (53), Sweden (23), and India (61). In the Netherlands (35), and the USSR (6), slightly lower minimum lane widths are suggested, however greater allowance is given for lateral clearance to obstructions.

Owing to the wide acceptance of the German standards it is suggested that at the present they be used to set <u>minimums</u> for the widths of Class I and Class II bikeways in the United States. However, it is recommended that more liberal standards based upon a "comfortable" maneuvering allowance, as determined experimentally by this project, be employed wherever the available space and costs allow. Both the German specifications and those developed in this work shall now be presented:

3.2.3.1 GERMAN SPECIFICATIONS

The width requirements and horizontal and vertical clearances for a single-lane bikeway are shown schematically in Figure 3.2.1. Minimum width consists of a 1.96 foot lateral cyclist space and a 0.66 foot maneuvering allowance on each side of the cyclist. Minimum recommended horizontal clearance to obstructions is 0.25 meters (0.82 feet). Curbing on a bikeway in excess of two inches in height is considered a vertical obstruction.

A vertical clearance allowance to overhead obstruction of 0.8 feet is recommended. In terms of the static vertical space requirement (7.4 feet), overhead obstructions should be no less than 8.2 feet from the surface of the bikeway.

Minimum width recommendations for multiple lane bikeways, are shown in Figure 3.2.2. These minimums for multiple lane bikeways are based on provision of a maneuvering allowance <u>only</u> between pairs of cyclists; no maneuvering allowance is provided between the cyclist and the edge of the bikeway as in the one-lane case.

3.2.3.2 COMFORTABLE MANEUVERING ALLOWANCE FOR PAIRS OF CYCLISTS ON MULTI-LANE BIKEWAYS

Observations have shown that given available space, bicycle riders when riding abreast will adjust their lateral separation to provide a comfortable maneuvering zone. The size of this zone is a function of their perceived danger of collision, their common velocity, and the dynamic stability of their bicycles. Thus a preliminary test was performed to estimate cyclist separation (handle-bar edge to handle-bar edge) as a function of velocity. In the test, pairs of cyclists were instructed to ride abreast at various speeds within the range 6-18 mph while adjusting their separation to suit their own feeling of comfort. At each given speed each pair approached a camera, which had a predetermined scale fixed in the field of view, and were photographed at the end of a predetermined distance which was unknown to the cyclists. All tests were done on a level asphalt surface. As anticipated, the mean distance

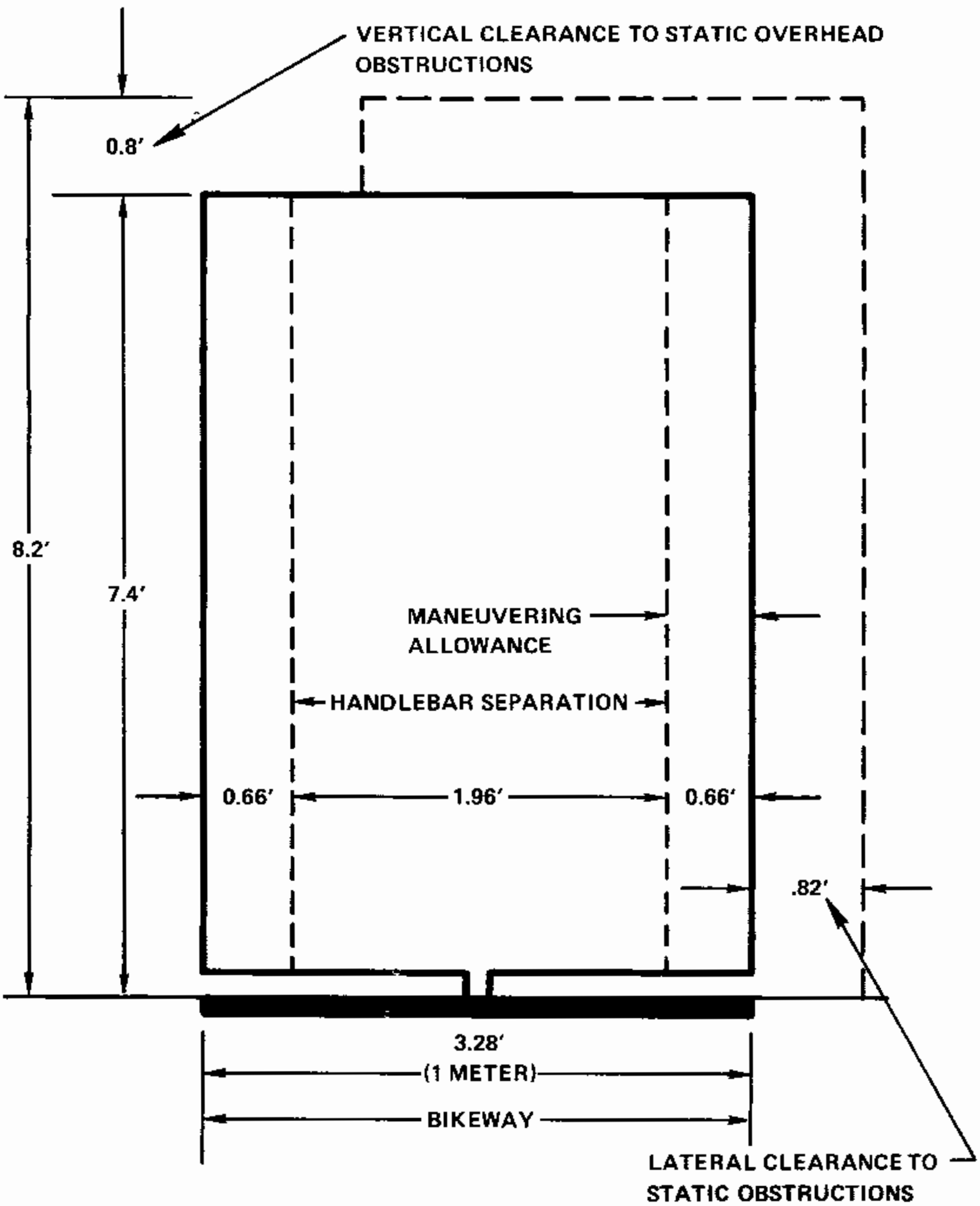

Figure 3.2.1. Single Lane Bikeway: Minimum Effective Width, Horizontal and Vertical Clearance to Static Obstructions. (Based on German Specification)

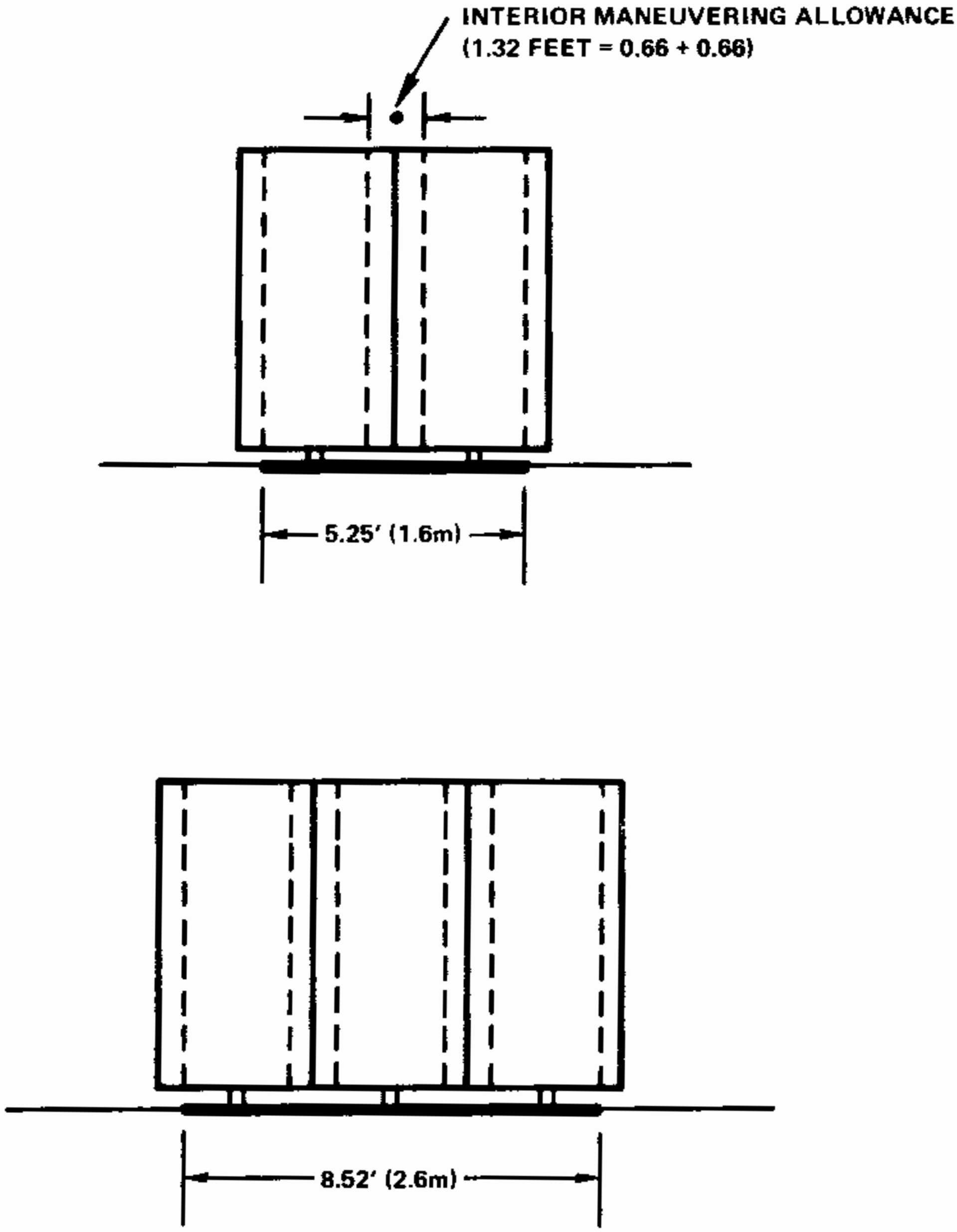

Figure 3.2.2. Minimum Effective Width for Two and Three Lane Bikeways Based on German Specifications. (Clearances not Shown)

between the handle bars increased with velocity; for a 10 mph bikeway design speed the mean measured separation was 2.5 feet.

Using this separation (2.5'), rather than the 1.3 foot German maneuvering allowance, will increase the minimum width of a bikeway when it has greater than one lane. The resultant minimum bikeway widths based on the measured comfortable maneuvering allowance at a 10 mph design speed, together with German specifications are given in Table 3.2.1.

Choice of which of the width specifications to be used depends upon many factors. To cite two: if level of service of the bikeway is a prime consideration it is recommended that the liberal standards be adopted as minima. If the bikeway is to be "squeezed" into the least space and anticipated volumes are not excessive the conservative standards should be used. Pragmatically speaking other factors such as the width of construction equipment and maintenance vehicles may, when overall cost is considered, set more liberal widths than those indicated in Table 3.2.1 suggest (at least for fewer than 3 bikeway lanes).

In terms of the minimum desirable number of lanes, a single lane on a Class I bikeway is not particularly effective since it doesn't allow passing without leaving the bikeway. As a recommended minimum on Class I bikeways, two lanes should thus be provided to allow a passing lane capability. The two lane minimum is also recommended in Germany (26) and the Netherlands (35), as well as in other countries, in instances where much passing is anticipated or where mixed modes (moped and bicycle) share the bikeway.

On Class II bikeways the minimum number of lanes that should be provided depends upon where on the street the bikeway is incorporated. Recommendations in these cases will be presented after the Class II bikeway alternatives have been discussed (Section 3.7).

TABLE 3.2.1 MINIMUM EFFECTIVE WIDTH FOR CLASS I AND CLASS II BIKEWAYS AS A FUNCTION OF NUMBER OF BIKEWAY LANES

Number of Lanes (One Way)	MINIMUM EFFECTIVE WIDTH (FT)	
	German Specifications	Modified German Specifications Based upon a Comfortable Maneuvering Allowance at a 10 mph Design Speed
1	3.3 (1m)	3.3
2	5.3 (1.6m)	6.4
3	8.5 (2.6m)	10.9
4	11.8 (3.6m)	15.3

3.2.3.3 HORIZONTAL CLEARANCES TO VERTICAL OBSTRUCTIONS AND OTHER STATIC HAZARDS

The minimum recommended horizontal clearance to vertical obstructions, together with minimal lateral clearances to other hazards (i.e. curb drop-offs) are given in Table 3.2.2. These recommendations vary with the country reporting them, the situation encountered, and the class of the bikeway.

In Class II bikeways additional clearance should be allowed for "dynamic" obstructions. The most obvious example of this is when the bikeway is located adjacent to a parking lane. Since opening doors constitute a dynamic hazard to cyclists, an additional clearance for the car door should be allowed if adequate clearance is not provided in the parking lane and high parking density and turnover exist. Similarly the proximity of the bikeway to traffic lanes (and the speed, volume and mix of passing traffic) may require additional clearance if barriers are not provided and if the traffic lane is not wide enough to provide the necessary spatial separation. Clearances for Class II bikeway alternatives are treated in depth in Section 3.7.4.

TABLE 3.2.2: MINIMUM RECOMMENDED LATERAL CLEARANCE FROM EDGE OF BIKEWAY TO OBSTRUCTIONS AND OTHER HAZARDS

DESCRIPTION	MINIMUM CLEARANCE (FT)	REMARKS
Horizontal clearance to obstructions	0.8 0.8 1.0 1.3 1.6	Germany (26) India (61) Canada [1] USSR (6) Netherlands (35)
Class II bikeway at grade of sidewalk: Clearance to curb drop-off	1.5 1.6 2.3	Canada [1] Netherlands (35) Germany (26)
Class II Bikeway at grade of roadway: Clearance to raised curb	1.6	Netherlands (35)
Shoulder clearance to edge of sloped drop-off (i.e., bikeway on an embankment, with less than 2:1 slope)	0.8 1.0	Finland [2] Canada [1]
Soft shoulder: increase minimum width of bikeway by	1.6	Netherlands (35)

1 National Capital Commission, Typical Signing Plan for Bicycle at Street Crossing, Standard Drawing 3459-E26, Project Design Agency, Ottawa, Canada, June 1971.

2 TVL (National Board of Public Roads and Waterways), Poikkileikkauksen suunnittelu (Section Planning), Normaalipoikkileikkaus (Standard Section), N-2jk+2pp and N-yhd. 2jk+2pp, III 1.3-Liite 16-17, Finland, Dec. 3, 1968

3.2.4 GRADE

Cyclist characteristics (age, weight, conditioning, oxygen uptake, etc.), bicycle characteristics (gear ratios, type of cycle, tires, weight, etc.), wind velocity, air resistance, and road surface are major determinants of maximum acceptable bikeway grades and the length such grades should be in effect. The available literature, while proposing grade criteria for bikeways, provides little explanantion of how such criteria have been determined. Some of the suggested grade and grade-length criteria are indicated in Table 3.2.3. Another source (26) not represented in the table suggests a 3% maximum grade with 5% allowable for "short" sections. An American source (1) recommends a 4-5% grade for one-speed cycles with a 9-10% maximum on "short" runs.

It is apparent that considerable study is warranted in order to determine bikeway grade design criteria that relates to the energy requirements of the cyclist. Since cyclists may be deterred from using a facility in direct proportion to the amount of energy and work rate necessary to overcome a given length grade on the facility, the importance of developing criteria based upon physiological requirements cannot be over emphasized. A preliminary study along these lines is reported in Appendix B.

The reveiwed literature nevertheless provides some interesting considerations for bikeway grade planning. The Netherlands source (35) suggests that if maximum lengths are inconsistent with prevailing grades, horizontal sections should be introduced (330 ft minimum) before or at the maximum distance at which the bikeway ascending grade is resumed. An American source (1) suggests rest stops along difficult grades. It is also possible to envisage lower grade "switchbacks." These suggestions appear quite useful when considering Class I bikeways in rural or urban open-space areas. They are not particularly applicable to Class II or Class III bikeways that are to be routed on existing urban street rights-of-way. For example, it is possible to suggest that to overcome topographical grades,

TABLE 3.2.3 GRADE AND GRADE LENGTH CRITERIA

Bikeway Gradient	Netherlands (35) Desirable Length[1]	Netherlands (35) Normal Length[2]	Netherlands (35) Maximum Length[3]	Denmark[4] Maximum Length[3]	India (61) Maximum Length[3]
10%	Not Recommended	33' (10 m)	66' (20 m)	--	--
5%	Not Recommended	131' (40 m)	262' (80 m)	164' (50 m)	66' (20 m)
4.5%	82' (25 m)	167' (51 m)	334' (102 m)	328' (100 m)	--
4%	102' (31 m)	203' (62 m)	410' (125 m)	656' (200 m)	164' (50 m)
3.5%	148' (45 m)	295' (90 m)	590' (180 m)	984' (300 m)	--
3.3%	148' (45 m)	295' (90 m)	590' (180 m)	--	Unrestricted
2.9%	200' (61 m)	400' (122 m)	800' (244 m)	1640' (500 m)	--
2.5%	262' (80 m)	525' (160 m)	1050' (320 m)	--	--
2%	410' (125 m)	820' (250 m)	1640' (500 m)	--	--
1.7%	590' (180 m)	1180' (360 m)	--	--	--
1.4%	--	1610' (490 m)	--	--	--
1.3%	--	2100' (640 m)	--	--	--

1 "Desirable" lengths include consideration of possible high wind conditions.

2 "Normal" lengths represent judged acceptable gradient lengths.

3 "Maximum" recommended lengths of grade should not be exceeded.

4 Ernst Renstrup, Assistant Chief Engineer, Vejdirektoratet, Copenhagen, Denmark.

the bikeway be routed in "switchback" fashion over the existing street network. The drawback with this approach, however, is that down-grade users may avoid the route designed with the up-grade user in mind.

In any event, the questions of grade and maximum grade lengths are a most important aspect of route planning, and should be actively considered when the feasibility of Class II and Class III bikeway proposals are evaluated.

3.2.5 RADIUS OF CURVATURE

In planning a Class I bikeway one must establish radii of curvature consistent with the design speed of the facility. Radii of curvature for existing bikeways in the United States range from 6 to 50 feet (1). In Germany, (26), the recommended radius is 16.4 ft (5m). In India, (61), the recommended radius is 32.8 ft (10m) on level ground and 49.3 ft (15m) on grades in excess of 2.5%. In none of these sources was the relationship between the recommended radius of curvature and design speed indicated.

Thus to obtain an empirical relationship between radius of curvature and velocity a simple experiment was conducted wherein the minimum comfortable unbraked turning radius was measured as a function of the cyclist's velocity. In the experiment bicyclists were instructed to ride at various velocities while negotiating a 180 degree turn in the smallest "comfortable" arc without applying their brakes. All tests were done on level, dry, paved asphalt.

As anticipated, the size of the arc increased with velocity. Data for the equivalent radius of curvature of the turn as a function of velocity yielded the following linear relationship:

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

where,

R = the unbraked radius of curvature (ft.)
V = the velocity in mph.

From the equation, for a Class I bikeway design speed of 10 mph, the "comfortable" unbraked radius of curvature is 13.9 feet.

It should be noted that Class II bikeways in urban areas that follow the existing road alignment will generally have curvatures dictated by the existing system. Since these curvatures are designed to accommodate the motor vehicle, they should be more than adequate for cyclists. However, whenever the expected or actual speed of cyclists exceeds the available radius of curvature, traffic control devices should be employed to warn cyclists or regulate bicycle speeds in the interests of safety. Such situations may occur on down-grades where bicycle speeds easily and frequently exceed 10 mph.

3.2.6 BIKEWAY SURFACE, BASE, AND SUB-GRADE

A basic bikeway structural section criterion is that the section be adequate to support the wheel loads of bicycles and cyclists as well as maintenance vehicles that may (infrequently) use the facility. "Bike trails and facilities: A Guide to their Design, Construction and Operation", (1), contains an excellent synopsis of the advantages and disadvantages of alternate bikeway surfaces and bases. Candidate surface and base materials include: stabilized earth, stone chip, soil cement, asphalt cement, hot-mix asphalt concrete, colored hot-mix, cold-mix asphalt concrete, soil asphalt, concrete, and movable (e.g. wood plank) walks. All of the materials, to one extent or another are applicable for bicycle use, however asphalt surfacing appears to be superior in overall feasibility.

As asphaltic material is relatively inexpensive in both construction and maintenance costs, and is commonly used for many other purposes throughout the state, it is recommended that Class I bikeways be constructed of asphalt.

In "Effective Design for Bicycle Paths", (43), the use of full depth hot-mix asphalt pavement laid directly on the sub-grade is recommended.[1] The total thickness to be used depends upon the quality of the of the sub-grade, and is summarized in Table 3.2.4. It is suggested that regular highway mixes can be used provided they are dense graded (≦ 10% air voids). The surface course should be a fine mix (100% passing the 1/2 screen or finer) to provide a smooth texture. Asphalt content should be 1/2% higher than used for roads since the bikeway will be subject to lighter loadings than would a typical motor-vehicle roadway. (Also see reference 5.)

Another acceptable bikeway structural section when good drainage exists along the whole length of the bikeway consists of placing a 3" to 4" aggregrate base of gravel, crushed stone or slag on the sub-grade and laying a 1-1/2" to 2" asphalt surface course over the base. This method is more typical practice than the full depth hot-mix method and offers cost savings, particularly when the bikeway is placed on a "poor" quality sub-grade.

With respect to the width allocated for a Class I bikeway the following remarks are quite relevant:

> "Most asphalt pavement is placed with spreaders and mixing plants are geared to the high rates of production that can be achieved with spreaders. Conventional spreaders can place widths ranging from 8' to 12'. If narrow widths are used that preclude the use of conventional spreaders, the cost of hand laying may boost the price per ton of the mix to the point where the narrow hand spread walk will approach the cost of a wider machine laid walk." (43, pg. 7)

It should be emphasized that land acquisition costs must be considered in evaluating the above trade-off.

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1 These recommendations for bicycle paths are consistent with the definition of Class I bikeways used in this report.

TABLE 3.2.4 RECOMMENDED BIKEWAY THICKNESS FOR FULL-DEPTH HOT-MIX A.C. ON VARIOUS SUB-GRADES; (FROM "EFFECTIVE DESIGN FOR BICYCLE PATHS", PAVING FORUM, APRIL 1966, P. 7: NATIONAL ASPHALT PAVING ASSOCIATION).

QUALITY OF EXISTING SUB-GRADE	MATERIAL (AASHO SYSTEM)	TOTAL THICKNESS (INCHES)
Very good	Gravels and sandy gravels: A-1, A-2-4, A-2-5, A-2-6	3
Good	Slits and clays: A-4, A-5, A-6, A-7-5, A-7-6	4
Poor*	Slits and clays: A-4, A-5, A-6, A-7-5, A-7-6	6

*Slits and clays rate poor only under the following conditions:

1. when they occur in low lying areas with poor natural drainage.
2. where conditions of the water table and climate are such that severe frost heave can be expected.
3. where high percentages of mica-like fragements or diatamaceous particles produce a highly elastic condition.
4. where it is desired to "bury" highly expansive soils deeper in the section to limit the effects of seasonal variations in moisture.

Class II bikeways that can be located on the street right-of-way without necessitating pavement removal and/or re-surfacing will typically have use of the existing asphalt and/or concrete surfaces that have been provided for motor-vehicles and pedestrians. These surfaces more than adequately meet bicycle and maintenance vehicle requirements. Otherwise, it is recommended that for Class II bikeways, asphalt be laid according to standard street practice.

By their very nature Class III bikeways must use whatever existing surface is available.

3.2.7 DRAINAGE AND GRATE HAZARDS

Paved Class I bikeways require proper drainage facilities along the bikeway to ensure that surface water will not accumulate. A 1/4" to 3/8" per foot slope along the surface course will normally insure water run-off (either to one-side or crowned). Where the bikeway is cut into a hillside, a drainage ditch should be placed on the high side, and where necessary, catch basins with drains should be provided along the ditches underneath the path. Ditches should also be provided in flat areas with poor soil drainage properties. In especially wet areas underdrains are recommended. In general a 1 ft. wide drainage ditch parallel to and on a slope of 2:1 below the bikeway pavement edge will suffice (1).

For Class II and Class III bikeways along existing road rights-of-way, existing drainage systems will usually suffice. However, care must be exercised in ameliorating hazards from exposed drainage grates and storm drains along the proposed bikeway.

The problem with drainage grates is not as simply handled as would be expected. Normally, grates consist of separated slats running parallel to the curb. Even with 3/8" wide slats and 3/4" slat separations the parallel slat configuration can entrap the narrow profile wheel of the modern light-weight bicycle. Since the design of grates, storm drains, and catch basins are based upon hydrodynamic calculations, solutions such as welding cross strips on the grate, or replacing the existing grate with zig-zag or horizontal configurations may not be feasible in many cases, since they may defeat the primary purpose for which the drain is intended. Under these circumstances, and as a last resort, clearance around the grate with warning stripes should be considered, and where such hazards are infrequent, warning signs may be considered along with appropriate striping in an attempt to reduce the danger of the obstruction to the cyclists using the bikeway.[1] However, when feasible from a hydrodynamic standpoint, the practice of welding cross strips on the grate is recommended as it provides positive safety to the cyclist at existing installations. For a longer range solution it may be feasible to develop (and mass produce) a zig-zag design grating for new construction (or replacement programs) along bikeways. In any event, drainage gratings do constitute a recognized hazard and therefore represent a possible source of civil action in the event of bicycle mishaps. This potential liability may or may not be reduced by the use of traffic control devices to warn and/or guide the cyclists around them. Only law suit experiences and court rulings can provide the answers to these questions.

3.3 BIKEWAY CAPACITY

A review of the available international literature has disclosed several somewhat conflicting estimates for the capacities of single and multiple lane bikeways. These estimates are summarized in Table 3.3.1. Most of the reported estimates are for level bikeways with mean bicycle speeds in the range of 8 - 12 mph. Since the capacity of a bikeway is highly sensitive to climatic conditions, grades, proximity of barriers, and downstream bottlenecks (for example, intersections), the capacity estimates should be viewed as approximate ideal upper limits, and should not be used for design purposes. As the ideal capacity of even a one-lane bikeway is sufficient to handle all but the most extreme future demands, level of service considerations rather than capacity should predominate in deciding whether or not to provide a multiple lane bikeway.

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1 Cities should evaluate the liability problems associated with stripes and signs to warn cyclists of grate hazards.

TABLE 3.3.1 REPORTED ONE AND TWO-WAY CAPACITY OF BIKEWAYS AS A FUNCTION OF NUMBER OF LANES

TRAFFIC DIRECTION	NUMBER OF LANES	ESTIMATED CAPACITY (CYCLES/HR)	SOURCE OF DATA
One-way	1	2530	United Kingdom (20)
One-way	1	1700-2000	Netherlands (35)
One-way	2	3400-4000	Netherlands (35)
One-way	2	2000	Germany (26)
One-way	2	2000-5000	India (61)
One-way	3	5000+	India (61)
One-way	3	3500	Germany (26)
Two-way	1	850-1000	Netherlands (35)
Two-way	2	500-2000	India (61)
Two-way	2	1500	Germany (26)
Two-way	3	2500	Germany (26)
Two-way	3	1700-2000	Netherlands (35)
Two-way	3	2000-5000	India (61)
Two-way	4	5000+	India (61)
Two-way	4	4000	Germany (26)
Two-way	4	10,000	United Kingdom (20)

3.4 VOLUME CRITERIA FOR SEPARATED BIKEWAYS

Internationally, separated bikeways (Class I, II) have generally been recommended where:

1) Significant regular bicycle traffic exists, and/or
2) Significant future bicycle traffic is forecast, and/or
3) Significant motor vehicle traffic is present on the roadway.

Recommendations based upon motor vehicle and bicycle (sometimes including moped) volumes are not, however, consistent from country to country; and when reported do not explicitly relate the recommendations to safety, congestion, delay, and the like, nor are the characteristics of the recommended bikeway other than the suggested number of lanes specified.

Class III, shared rights-of-way bikeways have been guardedly recommended where motor vehicle traffic volumes are "light." However, in practice, many other circumstances may militate against a Class III bikeway recommendation.

Table 3.4.1 summarizes the international volume criteria reported in the literature. Similar warrants in the U.S. do not currently exist nor can they be generated from data available to this study. Experience data and demonstration projects will be required in order to develop such warrants for the United States.

Volume criteria should be viewed in relationship to the conditions on the existing roadway, its hazards, and the differential safety that provision of the bikeway would afford. Thus current or projected bicycle volume and car volume, while important in the decision making process, do not constitute all the factors that should be considered.

TABLE 3.4.1 REPORTED VOLUME CRITERIA FOR A SEPARATED BIKEWAY

SOURCE	MOTOR-VEHICLE VOLUME	BICYCLE VOLUME	RECOMMENDATIONS	REMARKS
Germany (26)	> 2000 M.V./day	> 500 cycles/day	Separate bikeway	Urban Areas
	> 3000	> 200 cycles/day	Separate bikeway	Urban Areas
	> 2500	< 200 cycles/day	(Class III) Use Shoulder	Rural Areas
	> 2800	< 30 cycles/hr.	(Class III) Use Shoulder	Rural Areas
	> 2500	> 200 cycles/day	Separate bikeway	Rural Areas
	> 2500	> 30 cycles/hr.	Separate bikeway	Rural Areas
	> 2500	> 100 cycles/day	Separate bikeway when no shoulder exists	Rural Areas
Netherlands (35)	-	≦ 5000 cycles/day	2-lane separate bikeway	one-way bike flow
	-	≧ 5000	3-lane separate bikeway	one-way bike flow
	-	≦ 5000	3-lane separate bikeway	two-way bike flow
	-	≧ 5000	4-lane separate bikeway	two-way bike flow
India (61)	100-200 M.V./hr.	> 400 cycles/hr.	"bikeway"	type undefined
U.S.S.R. (6)	> 250	> 100 cycles/hr.	"bikeway"	type undefined
Switzerland (66)	> 700	"Few" bicycles	Separate bikeway	
	400-700	> 50 cycles/hr.	Separate bikeway	
	"Few" M.V.	> 500 cycles/hr.	Separate bikeway	

3.5 ACCIDENTS AND SAFETY CONSIDERATIONS

3.5.1 INTRODUCTION

In 1970, the National Safety Council reported 820 fatilities resulting from bicycle/motor vehicle accidents in this country.[1] Although representing only 1.5% of the total traffic deaths for that year, this figure indicates a 78% increase for the ten year period 1960-70, an increase substantially higher than that occurring in any other single accident category or in the total combined fatility statistics for all traffic modalities. (44).

In Los Angeles County during the period 7/1/69 to 11/30/71 there were 2817 reported accidents involving motor vehicles and bicycles.[2,3] Of these, 11.4% resulted in no injury, 17.4% resulted in no visible injury (complaint), 60.5% resulted in minor visible injury, 9.7% resulted in severe injury, and 1% resulted in death to the bicyclist. 80.8% of the reported accidents for which age was coded and fully 66% of the bicyclist fatalities involved a bicyclist under the age of 16.

Table 3.5.1 gives the total number of injuries by type sustained by the bicyclist versus the injury sustained by the motorist in accidents in Los Angeles County involving a single motor vehicle and a single bicycle. From the matrix it is clear that the cyclist came off a definite "second best" in single motor vehicle involvement accidents as would be expected. In accidents for which no injury was sustained by the motorists, the bicyclist sustained the highest percentages of injuries and all of the reported fatalities.

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1 These include fatalities of bicyclists and motor-vehicle occupants from collision between bicycles and motor vehicles.

2 Los Angeles accident data were supplied in a tape file by Mr. S. E. Rowe, Senior Traffic Engineer, Department of Traffic, City of Los Angeles. The tabulations of these data were performed with the aid of a computer program written by Mr. Harry Knobel, ITTE, U.C.L.A.

3 These accidents involved two or more parties.

TABLE 3.5.1 INJURY TO BICYCLIST VERSUS INJURY TO MOTORIST IN TWO-PARTY ACCIDENTS (MOTOR VEHICLE / BICYCLE). LOS ANGELES ACCIDENTS IN PERIOD 7/1/69 THROUGH 11/30/71.

		INJURY TO BICYCLIST				
		NONE	TYPE C	TYPE B	TYPE A	FATALITY
INJURY TO MOTORIST	NONE	265	480	1664	264	27
	TYPE C	7	4	8	1	0
	TYPE B	35	2	10	4	0
	TYPE A	4	0	2	1	0
	FATALITY	0	0	0	0	0

Type A: Severe injury

Type B: Minor injury

Type C: No visible injury, however complaint

In terms of locality 42.4% of the Los Angeles bicycle motor-vehicle accidents in the period occurred in business districts, 55.3% occurred in residential areas, 1.4% occurred in open areas, and 0.9% occurred in other areas. Further, 26.3% of the total reported accidents occurred within intersections.

Table 3.5.2 gives the breakdown of total bicycle/motor-vehicle involvement accidents by contributing circumstances. Breakdowns are shown for both the bicyclist and the motorist for accidents occurring within intersections and accidents occurring outside of the immediate region of intersections. Several interesting observations can be drawn from the Table.[1] Failure of the bicyclist to yield contributed to 18.1% of the reported intersection accidents and 30.3% of the reported non-intersection

1 Tests of significance were not performed on the data in Table 3.5.2.

TABLE 3.5.2 CONTRIBUTING CIRCUMSTANCES OF ACCIDENTS INVOLVING MOTORISTS AND BICYCLISTS: LOS ANGELES BICYCLE/ MOTOR VEHICLE ACCIDENTS IN PERIOD 7/1/69 THROUGH 11/30/71.

Contributing Circumstance	BICYCLIST[1] Total Accidents[3] Within Inter-section	BICYCLIST[1] Total Accidents[3] Non-inter-section	MOTORIST[2] Total Accidents Within Inter-section	MOTORIST[2] Total Accidents Non-inter-section
No Violation	227 (30.6%)	514 (24.8%)	393 (53.9%)	1243 (60.7%)
Speed	3 (0.4%)	12 (0.6%)	15 (2.1%)	70 (3.4%)
Failure to Yield	134 (18.1%)	628 (30.3%)	203 (27.9%)	230 (11.2%)
Wrong Side	133 (17.9%)	264 (12.7%)	5 (0.7%)	32 (1.6%)
Ran Stop Sign	101 (13.6%)	30 (1.5%)	16 (1.4%)	4 (0.2%)
Ran Signal	24 (3.2%)	16 (0.8%)	17 (2.3%)	21 (1.0%)
Improper Passing	1 (0.1%)	9 (0.4%)	4 (0.6%)	35 (1.7%)
Following too Close	0 (0.0%)	9 (0.4%)	0 (0.0%)	15 (0.7%)
Improper Turn	20 (2.7%)	86 (4.1%)	17 (2.3%)	25 (1.2%)
Other improper Driving	46 (6.2%)	233 (11.2%)	40 (5.5%)	231 (11.3%)
Other Violations	49 (6.6%)	257 (12.4%)	19 (2.6%)	138 (6.7%)
Unsafe lane Change	4 (0.5%)	17 (0.8%)	0 (0.0%)	5 (0.2%)

1 Accidents involving two or more parties.
2 Accidents involving only two parties. (One bicycle, one motor vehicle).
3 Percentages given are over all-circumstances for a given category (i.e. within-intersection, bicyclist).

accidents; similarly, failure to yield on the part of the motorist contributed to 27.9% and 11.2% of the intersection and non-intersection accidents respectively. The bicyclist riding on the wrong side of the street was given as a contributing circumstance for 17.9% of the intersection accidents and 12.7% of the non-intersection accidents. Respective percentages for the motorist were substantially lower (0.7%, 0.2%). The bicyclist running a stop sign was cited as a contributing circumstance in 13.6% of the intersection accidents involving a motorist and a bicyclist; the corresponding figure for motorists running a stop sign was only 1.4%.

While no inferences were drawn from the data, it should be clear that bicycling in urban areas where no specific provision is made for the cyclist can be hazardous. Judgmental errors on the part of the bicyclist and motor vehicle operator, vehicle code violations, differences in merging speeds, limited sight distances at intersections, presence of dynamic obstructions (i.e. opening car doors), weaving on the part of the cyclist, and improper angles of interception at road crossings and intersections all contribute to the generation of motor vehicle/bicycle accident involvements. And owing to the limited protection of the bicyclist and the low mass of the bicycle, the cyclist tends to sustain injuries in such collisions far greater and more frequently than does his motor vehicle counterpart. [1]

The basic question that the above discussions do not answer is what effect does provision of Class II bikeways on street rights-of-way have upon accidents and safety. For indications in this direction it is necessary to resort to several European studies which addressed themselves to this problem.

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1 Use of accident data to estimate bicycle useage is presented in section 4.6.2.

3.5.2 EFFECT OF BIKEWAYS ON ACCIDENTS AND SAFETY

A review of European literature disclosed several limited studies that provide empirical evidence that provision of Class II bikeways on street rights-of-way affects the rate of bicycle accidents and their type. In none of these studies however were the comparisons subjected to statistical test. Thus rather than allowing firm inferences to be drawn on provision of bikeways in general or in specific cases, the studies summarized in this section together with the recommendations given by the investigators should be viewed in the context of the study sections themselves and strictly speaking cannot be generalized.

In 1952 a survey was conducted in the Netherlands to determine the number of accidents on two-lane roads with and without bikeways (35). In the survey accidents on 680 km of two-lane roads with bike traffic but without bike lanes were compared with accidents on 1230 km of two-lane roads where cycles were prohibited on the road and regular bike lanes were provided. Accidents occurring at intersections were not compiled. The number of accidents per 10 km of roadway on both sections as a function of density of traffic over the day were then compared graphically. Results showed a substantial decrease in accidents per 10 km on the roadway where compulsory bicycle lanes were provided, as compared to the roadway without bike lanes.

A more recent Dutch survey by Provinciale Waterstaat of Graininge,[1] studied accident histories on several country roads over the period 1955-1962; using accidents and traffic densities in 1955 as a base, the investigator plotted: 1) the increase in the number of motor vehicles and 2) the ratio of accidents to traffic density normalized to the 1955 base period, over the interval 1955-1962. Plots were made for: a) road section where bicycle lanes were completed in 1958, b) road sections with no bike lanes,

1 Article in Verkeerstechniek, 1964, #5, by I.M. Aarnoudse.

c) road sections where the bicycle lanes were completed in 1961, and d) road sections where the bike lanes were completed in 1963. In sections b and d the accident ratio followed the same course as the increase in traffic density. In sections a, and c, the ratio was substantially lower after the bicycle lanes were completed.

A Danish study (54) reported in 1969 investigated the benefits of bicycle tracks, (these are defined as lanes constructed along a street or road exclusively for bicycle use and generally separated from the roadway by a curb). Class I bikeways, and Class II bikeways separated by lane markings were not considered. The main results of the study were based upon accident data in 1965-1967 from four arterial streets in Copenhagen. Two of the streets had bicycle tracks (total length 5.4 km, 85 side streets), and two of the streets had no bicycle tracks (3.9 km length, 83 side streets). Heavy bicycle and motorized traffic was extant on both of the study sections. Personal injury bicycle accident rates over 1965-1967 computed on the basis of accidents per 10^4 bicycle-km were approximately 60% lower on streets with bicycle tracks than on streets without bicycle tracks. Accidents, where bicycles hit parked cars, had some importance where no tracks were provided, but were rare where tracks were provided.

The personal injury bicycle accident rate at intersections (accidents per intersection per 10^5 bicycles), was negligbly higher, (0.9%), on streets with bicycle tracks than on streets without bicycle tracks.[1] The percentage of accidents at intersections with bicycle tracks involving left turn motorists was lower than the corresponding percentage at intersections without bicycle tracks (10% versus 26%). The percentage of intersection accidents involving right turn motorists, however, was higher on streets with tracks than on streets without tracks (35% versus 23%). This later result for the arterial bike tracks could have been partially alleviated if more favorable angles of interception between right turning motor vehicles and straight

1 Note: The bicycle tracks ended at the intersection and no channelization was employed in the intersection proper.

through bicyclists were provided in the design of the intersections. Several designs along these lines are presented in Section 3. 8.

A French study (28), reported in 1962 evaluated the effect of cycle tracks on road safety. Accident and exposure data was collected in 1960 on 171 stretches of national roads in France with cycle tracks (480 km) and 126 other stretches (355 km) adjoining the former without cycle tracks. The cycle tracks were allocated for the dual use of bicycles and mopeds (motor bicycles under 50 cc displacement), and many of the discussions of results concerned comparisions of accidents involving bicycle and mopeds, and mopeds and pedestrians.

The presence of cycle tracks reduced the number of accidents involving bicycles and mopeds from 20-40%. The largest reduction (45%) occurred between two-wheeled vehicles (bicycles and mopeds) and automobiles.

Outside of intersections the rate of injuries (injury accidents per 10^6 vehicle-km) involving bicycles and mopeds was 25% higher on roads with cycle tracks than on roads without. The death rate, however, was 25% lower. The investigators state that the increase in injuries on roads with tracks was mainly caused by the concentration of mopeds, which led to an increase in collisions between mopeds, between mopeds and pedestrians, and for two-way cycle tracks, between bicycles and mopeds.

At intersections, the investigators reported that fewer accidents occurred to bicyclists and moped drivers when there were cycle tracks; and for one-way tracks the decrease approximated 30%. In these cases physical barriers between the road and the track prevented cyclists from carelessly moving towards the left before they reached the intersection so as to make a left hand turn. On the other hand, and consistent with later Danish findings, chances of a vehicle colliding with a cycle while making a right hand turn onto the minor road, slightly increased when a track was provided. The investigators however, concluded that the net result of providing cycle tracks was beneficial.

The main conclusions of the study were as follows:

- construction of two-way tracks should be avoided. When they exist, they should be supplemented by a second track on the opposite side of the road, both tracks being then used as one-way facilities. [1]
- a physical barrier between the road and the track seems more desirable than a painted line separating the road from an extra lane designated for cyclists.
- at intersections, it seems better to shift the cycle track away from the road rather than to have it merge onto that road. If the latter device is contemplated, the cycle track should merge well before the intersection to facilitate weaving maneuvers.
- when a track does not end at an intersection, its end should be designed at a small angle with the main road, in a way somewhat similar to merging lanes on expressways.

In conclusion, much remains to be done in quantitatively assessing the safety implications of bikeways. A well designed, controlled and executed series of statistical experiments appear highly in order, not strictly to determine the effects of bikeways on accidents in general, but to specifically evaluate and compare alternative Class II designs on urban streets and at traffic intersections.

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1 This conclusion is primarily based on moped/bicycle conflicts on two-way tracks. A similar recommendation is made in a Dutch report (35), however based upon bicycle/bicycle conflicts and problems in interfacing two-way bicycles and motor vehicles safely at intersections.

3.6 THE CLASS I BIKEWAY

An "ideal" bikeway in urban and rural areas is one that is completely separated from motor vehicle and pedestrian traffic, thus having a minimum number of interactions and conflicts with other travel modes. This is true whether the intent of the bikeway is primarily transportational or recreational.

Likely locations for both urban and rural Class I bikeways are continuous linear spaces such as railroad and electrical transmission line rights-of-way, river banks, dry beds, beach fronts, flood control channel levees, and irrigation canal embankments. These and other similar types of infrequently interrupted spaces are to be found throughout the urban and rural areas of the state and provide, in theory, the initial framework for the large-scale development of Class I bikeway systems.

Precedents in the use of such spaces are found in many instances in the United States. The Elroy-Sparta Trail of the Wisconsin Bikeway System is located on an abandoned railroad right-of-way. About 4000 feet of the Sausalito-Mill Valley (Calif.) Bikeway is situated along a railroad right-of-way. Railroad beds, in addition to their linear, uninterrupted spatial characteristics, have the desirable feature of rarely exhibiting gradients in excess of 3%.

Culver City, California, has recently completed a section of an urban bikeway along La Ballona Creek, a flood control channel. Although relatively short at present, it may at some future time join with other urban bikeways in the Los Angeles area. Other examples include Chicago which has provided urban bikeways along Lake Michigan, and Milwaukee which has planned bikeways along local waterways.

The cost of leasing these types of rights-of-way may be minimal. The California Highway Park Act of 1969 (36), for example, provides that unused space within freeway rights-of-way can be used for recreational purposes at a nominal cost. The hundred dollar fee required by the act is designed to cover administrative costs. The railroad right-of-way of the Wisconsin bikeway was purchased outright for $12,000. Insofar as appropriate agreements can be negotiated, use of power transmission lines and other types of right-of-way should not be overlooked as candidates for Class I transportational and recreational facilities.

Private companies and public agencies that own the rights-of-way are often particularly cautious with respect to cyclist safety. Several finalized agreements[1], for example, have specified that the leasee purchase adequate insurance and accept the liability for accidents. Further, the contracts specify that permanent facilities, such as fencing, be provided to protect both the leasor's facilities and the cyclists using the bikeway. Decisions to use certain rights-of-way for Class I bikeways should be made guardedly where fencing without breaks is required on both sides for extended distances.

In addition to the various linear rights-of-way, Class I bikeways in urban areas may be located in public parks, recreation areas, or other open spaces - which afford feasible opportunities to install Class I bikeways in already built-up areas. It is of course possible to conceive of grade-separated bikeways stretching for miles across already built-up urban areas - a system completely separated from all other forms of traffic and activity - and thus a perfect urban Class I bikeway. This type of futuristic design solution is unwarranted at this time and has therefore not been investigated in this report. Many alternate solutions are considerably more cost-feasible. For example, proposed residential developments on the fringes of urban areas, special large scale projects such as "New Towns in Town", community development programs, and major

1 Marin County (California) and Northwestern Pacific Railroad Company, Commercial Lease (RAF-VI-24121/312-1 - 6/13/70), Nov. 19, 1970.

proposed construction programs provide excellent opportunities to construct a Class I portion of an urban or suburban bikeway system integrated with the developing transportation system. In these special cases, should a Class I bikeway be warranted and advisable, private and/or public sector developers should be encouraged to provide the bikeway or at least reserve sufficient right-of-way when planning so that a bikeway may be incorporated in the future.

The cost of new Class I bikeways, where they are considered feasible, vary greatly with the topographical, soil and climatic characteristics of the particular areas. As a guide, Table 3.6.1 indicates minimum estimated construction costs for providing a typical bikeway structural section consisting of a 2" thick asphalt concrete blanket over a 4" thick aggregate base. The estimates for asphalt construction provided in Table 3.6.1 are considerably less than for providing concrete sidewalks.

TABLE 3.6.1 MINIMUM COST PER MILE FOR PROVIDING A CLASS I BIKEWAY (SEE TEXT)

ITEM	UNIT COST	BIKEWAY WIDTH		
		2 Lanes 8 ft.	3 Lanes 12 ft.	4 Lanes 16 ft.
2" A.C. Surface	$ 8.00/TON	$ 0.82/LF	$ 1.23/LF	$ 1.64/LF
4" Aggregate Base	$ 4.00/CY	$ 0.39/LF	$ 0.59/LF	$ 0.78/LF
Excavation	$ 2.00/CY	$ 0.30/LF	$ 0.45/LF	$ 0.60/LF
Sub-total	-	$ 1.51/LF	$ 2.27/LF	$ 3.02/LF
10% Contingencies	-	$ 0.15/LF	$ 0.23/LF	$ 0.30/LF
TOTAL	-	$ 1.66/LF	$ 2.50/LF	$ 3.32/LF
Minimum Cost per Mile	-	$ 8,800	$ 13,200	$ 17,600

Even so, the estimates in the table should be considered bare minima. Additional items that should be considered in estimating the cost of a Class I bikeway are:

- Drainage:	this varies considerably from place to place and depends greatly on soil, topographical, climatic and bikeway cross-sectional characteristics.
- Grading, Excavation, and Embankment:	the Table assumes a 6" excavation with no fill or borrow, on flat terrain. This item cost will vary extensively depending on the topography and location. Embankment material or imported borrow may be required.
- Barriers, Fences and Curbs:	if required, should be included (see Section 3. 7. 3). Cost estimates are given in Appendix A.
- Signs, Stencilled Messages, and Striping:	(See Section 3. 10, Bikeway Signing). Cost estimates for signs, stencilled messages, and striping are given in Appendix A.
- Lighting:	if night time use of the bikeway is anticipated, adequate lighting facilities should be provided. (See Section 3. 11)
- Landscaping:	if required as a barrier, or if desired for aesthetic reasons, landscaping should be included.

- Bridges and Retaining Walls: overcrossings, undercrossings, and retaining walls may be necessary along portions of the bikeway route; cost estimates for selected facilities are given in Appendix A.

- Signals or Signal Modifications: may be required to interface a Class I bikeway with the existing street system.

- Land Acquisition Costs: where the proposed Class I bikeway right-of-way is not in public ownership, the cost of acquiring land may be the most significant cost item. The square foot value of right-of-way needed is only one element of the total cost of acquiring right-of-way. Severance damages, value of improvements, cost to cure items, and the necessity to often acquire more land than actually needed, are substantial items that must also be taken into account. If the acquisitions necessitate any purchasing of occupied improvements, relocation costs will be additionally incurred.

From the above considerations it is evident that, in many cases provision of extended Class I bikeways in urban areas may involve large expenditures.[1] Exceptions would be where Class I bikeways are planned in public open-spaces or where linear rights-of-way can be allocated for a transportational or recreational bikeway.

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1 In some instances these expenditures may be economically justifiable.

In cases where provision of Class I facilities is infeasible it is appropriate to consider the feasibility of providing Class II and Class III bikeway configurations. In the next section several Class II and Class III alternatives will be presented, discussed and specified in terms of land use, minimum width requirements, space allocated, and unit costs.

3.7 CLASS II AND CLASS III BIKEWAYS ON EXISTING STREETS

In this section several alternative schemes for incorporating a Class II and Class III one-way bikeway on an existing street shall be presented. Since there are serious problems in interfacing a two-way Class II bikeway with motorized and pedestrian traffic at intersections along an urban bikeway route, the analysis here is limited to one-way alignment alternatives. It is recommended that in general two-way designs be limited to isolated Class I bikeways.

One-way Class II alternatives can be symmetrically employed on both sides of the street, or if conditions warrant, two different alternatives can be used for a given street section. The alternatives to be presented are thus only shown for one side of the street.

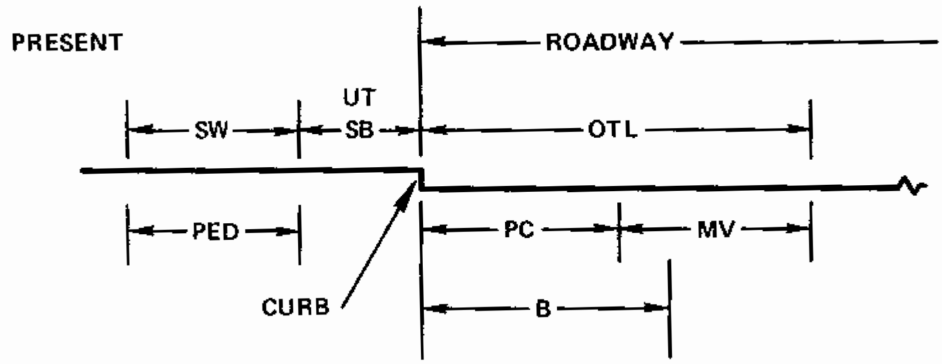
To aid in enumerating the various alternatives the following symbols are used:

- BW = bikeway (Class II, III)
- B = bicycle
- PC = parked car (static)
- OTL = outside traffic lane, (parking may or may not be allowed next to curb)
- MV = motor vehicle (moving)
- SW = sidewalk (paved)
- SB = setback from curb to sidewalk edge
- UT = utility right-of-way

PED = pedestrian

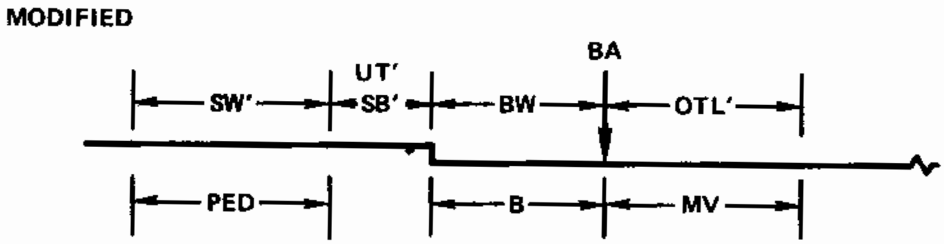
BA = barrier

Each alternative is depicted symbolically in terms of the present condition of the street and the modified street incorporating the bikeway. A typical "present" street is illustrated below in half cross-section.



In the above example the street and right-of-way consists of a paved sidewalk with either a utility right-of-way or setback, an outside traffic lane (OTL), and one or more additional one-way traffic lanes on the half cross-section. Below the cross-section, the normal rights-of-way are indicated, in this case for pedestrians (PED), parked cars (PC), moving motor vehicles (MV), and bicycles (B). The bicycle right-of-way on the roadway is shown under the "present" alignment. According to the 1970 California Vehicle Code, (18), (CVC 21203) "every person operating a bicycle upon a roadway shall ride as near to the right side of the roadway as practicable, exercising due care when passing a standing vehicle or one proceeding in the same direction." Thus the present alignment contains the "null" or status-quo bikeway alternative.

An example of a bikeway alternative on the street is shown below:



In this example the bikeway is located on the roadway between the curb and the new outside traffic lane; parking has been removed. The "prime" notation, (i.e., OTL'), denotes that the width of a lane, walkway, or right-of-way may necessitate modification to enable a given width bikeway to be located on the existing street. Width requirements to incorporate the alternatives are discussed later in the report. The symbol "BA" denotes a barrier between the bikeway (BW) and the traffic lane (OTL'). The barrier may range from purely symbolic (e.g., striping), to (for this alternative), a grade separated island partitioning the bikeway from the motorized traffic lane(s).

Two sets of Class II and III bikeway alternatives shall be presented. The first set consists of bikeways incorporated at the grade of the sidewalk thus achieving grade separation with respect to the roadway; the second set consists of alternatives where the bikeway is on the roadway at grade. A limited set of eight alternatives were chosen for discussion. Each of these have their own advantages and disadvantages, however, all fulfill the initial requirement of being realizable at relatively low cost under ideal conditions.

Discussions of the problem involved at traffic intersections along the bikeway are deferred to section 3.8.

3.7.1 SIDEWALK ALTERNATIVES

The California Vehicle Code, (18), defines the "sidewalk" as "that portion of the highway, other than the roadway, set apart by curbs, barriers, markings, or other delineation for pedestrian travel." (CVC Section 555). Section (21663) states that "no person shall operate or move a motor vehicle upon a sidewalk except as may be necessary to enter or leave adjacent property." Further, Section (21952) states that "the driver of any motor vehicle, prior to driving over or upon any sidewalk, shall yield the right-of-way to any pedestrian approaching thereon." Thus while motor vehicle travel on sidewalks is prohibited, no such provision in the vehicle code exists for bicycles.

Bicycle use of sidewalks may, however, be restricted by local ordinance. For example, the City of Santa Barbara prohibits the use of sidewalks unless designated as a bikeway.[1] The City of Torrance prohibits the use of the sidewalk in business districts, adjacent to public school buildings, churches, recreation centers, and playgrounds; in other areas the bicyclist must yield right-of-way to the pedestrian while on the sidewalk.[2] In Davis, there are rights and obligations for bicyclists when they use the sidewalks (24). Amarillo, Texas prohibits bicyclists from riding on the sidewalk in business districts; persons over the age of 15 are prohibited from riding on any sidewalk in any district; when on the sidewalk, bicyclists must yield to pedestrians and give an audible signal when overtaking a pedestrian.[3]

Thus, the provision of Class II and Class III bikeways on the sidewalk will generally necessitate local ordinances to either restrict cyclists to the bikeway if Class II, or to define the obligations of cyclists in Class

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1 Santa Barbara (California), City of, Ordinance No. 3350, Ch. 10.40 of the Santa Barbara Municipal Code, Jan. 21, 1969.

2 Torrance (California), City of, Ordinance No. 1440 adding Ch. 5, "bicycles" to "the code of the City of Torrance". Sect. 5.21A and B, Dec. 3, 1963.

3 Amarillo (Texas), City of, Amarillo Code, Traffic, Article X, Bicycles, Sect. 23-220 a), b), and c), May 6, 1958.

III shared facilities. It should be emphasized that the passage and enforcement of laws and ordinances for the cyclists, motorists, and pedestrians is a necessary step in insuring the efficacy of the bikeway.

A distinction should be made between allowing cyclists to use sidewalks by local ordinance, and designating a sidewalk as a bikeway. In the latter case, the designation implies a recommendation to use a particular sidewalk - which in itself may generate demand; in the former case, use of sidewalks by cyclists is considered in this report as a null or status-quo alternative. Thus even if the sidewalk is to be designated a Class III bikeway, it should conform to minimum width requirements.

The minimum paved width required for a single cyclist is 3.3 feet. If the parkway is paved, then additional clearance must be allocated for obstacles on the parkway (0.8-1 foot) if they are frequent. If the parkway is unpaved (i.e. grass, dirt), and frequent obstacles exist, then a clearance from the edge of paved sidewalk to the obstacles must be allocated.

Thus the total required minimum width to accommodate the cyclist (neglecting space for the pedestrian) will be between 3.3' and 5.5', depending upon the presence and frequency of obstructions.

In terms of capacity, pedestrians have been observed to move at a rate of 33 persons per 22" lane per minute (crowds moving away from sporting events), (7, pg. 120). European sources[1] (23) specify a minimum lane width of 2.46' (.75m) for pedestrians where bicycles are present in a parallel lane. This width shall be taken as the minimum pedestrian allowance for Class II and Class III sidewalk alternatives. A more liberal allowance of 3' to allow for carrying packages, and pushing strollers and shopping carts, is however, recommended. Thus the conservative and liberal minimum width of paved sidewalk is 5.8' and 6.3' respectively to simultaneously accommodate one effective lane each for pedestrians and

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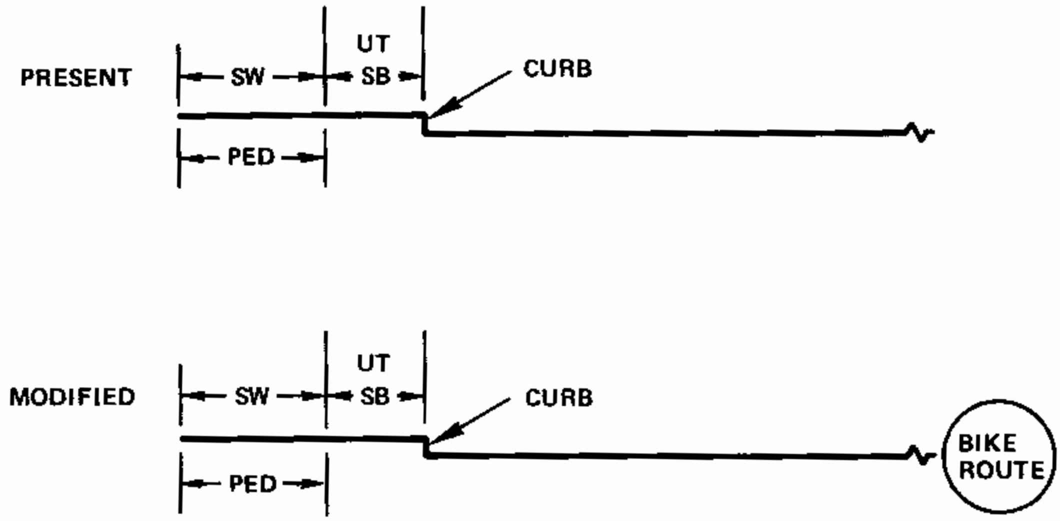
1 TVL (National Board of Public Roads and Waterways), Poikkileikkauksen suunnittelu (Section Planning), Normaalipoikkileikkaus (Standard Section), N-2jk+2pp and N-yhd. 2jk+2pp, III 1.3-Liite 16-17, Finland, Dec. 3, 1968.

cyclists on a Class II or Class III sidewalk bikeway. Additional clearance to obstacles within the border must be provided if they are frequent or constitute a hazard.

Sidewalk Alternative 1.1. One-Way Class III Bikeway on Sidewalk (Bicycles Share Right of Way With Pedestrians)



(Unchanged Except for Provision of Signs and Curb-Cuts)[1]

SAFETY CONSIDERATIONS:

Given adequate sidewalk width, this alternative minimizes motor vehicle-bicycle interactions at the expense of increasing pedestrian-bicyclist conflicts.

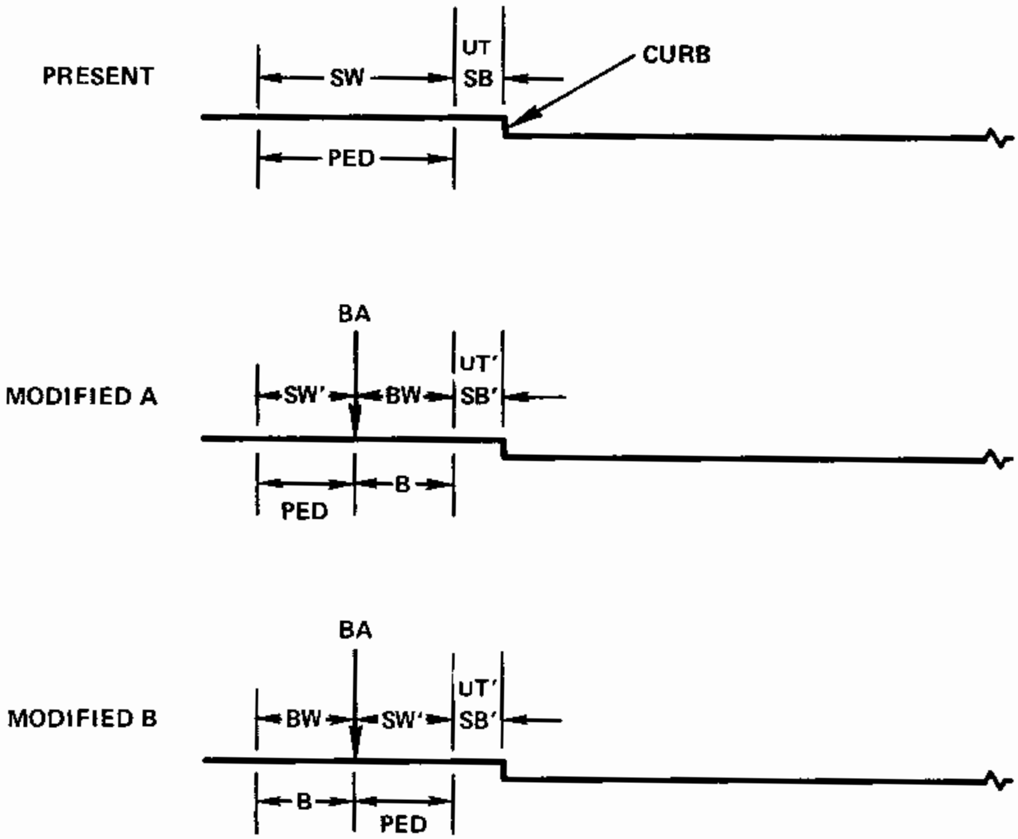
OTHER CONSIDERATIONS:

The feasibility of sharing the paved sidewalk varies inversely with the volume of bicycles and pedestrians, and directly with the width of the paved sidewalk. These factors in combination with the associated land use may seriously limit the feasibility of this alternative except on sufficiently wide sidewalks in residential areas bordering single family dwellings.

1 Curb cut is defined as a bicycle ramp at the curb line.

In commercial areas with heavy pedestrian flow it is recommended that this alternative not be applied; even with light pedestrian flow the impact of a bikeway on the abutting business establishments should be ascertained by impact studies before the alternative is further considered.

Sidewalk Alternative 1.2. One-Way Class II Bikeway on Sidewalk (Bicycles have Semi-Exclusive Right-of-Way)



SAFETY CONSIDERATIONS:

This alternative minimizes motor vehicle-bicycle interactions, and parallel pedestrian-cyclist conflicts. If located where significant pedestrian cross flow will occur, the alternative can disrupt flow on the bikeway and increase the likelihood of pedestrian-bicyclist accidents.

OTHER CONSIDERATIONS:

As a contrast to the previous alternative, in alternative 1.2 there are separate lanes on the sidewalk allocated for cyclists and pedestrians. While a painted stripe is the most feasible method of separation for areas where unchanneled crossflow must occur, separation by bushes or linear landscaping may be appropriate where the adjacent land use is either undeveloped or fenced, or pedestrian flow can be channeled through occasional gaps in the barrier.

RESIDENTIAL LAND USE

In residential areas characterized by infrequent pedestrians, modification (B) is appropriate when the utilities are underground, sufficient sidewalk width is allocated, and there are frequent driveways (cyclists would tend to use the pedestrian right-of-way if modification (A) were used in this case). When crossflows are necessary, modification (B) associated with single family dwelling units, utility rights-of-way, and parking, may reduce conflicts over modification (A). In multi-family development areas, modification (A) would be preferred over (B) to yield a clearance from frequent motor vehicles departing from driveways.

COMMERCIAL LAND USE

As with Alternative 1.1, impact studies must be performed even if low pedestrian flow and bicycle demand are anticipated. Modification B is definitely not recommended, as it affords no set-back from the associated land use. The feasibility of modifications A and B, depend basically on the parking turnover rate and the bikeway demand, assuming sufficient paved sidewalk area is allocated to meet pedestrian demands, and land use impacts are favorable.

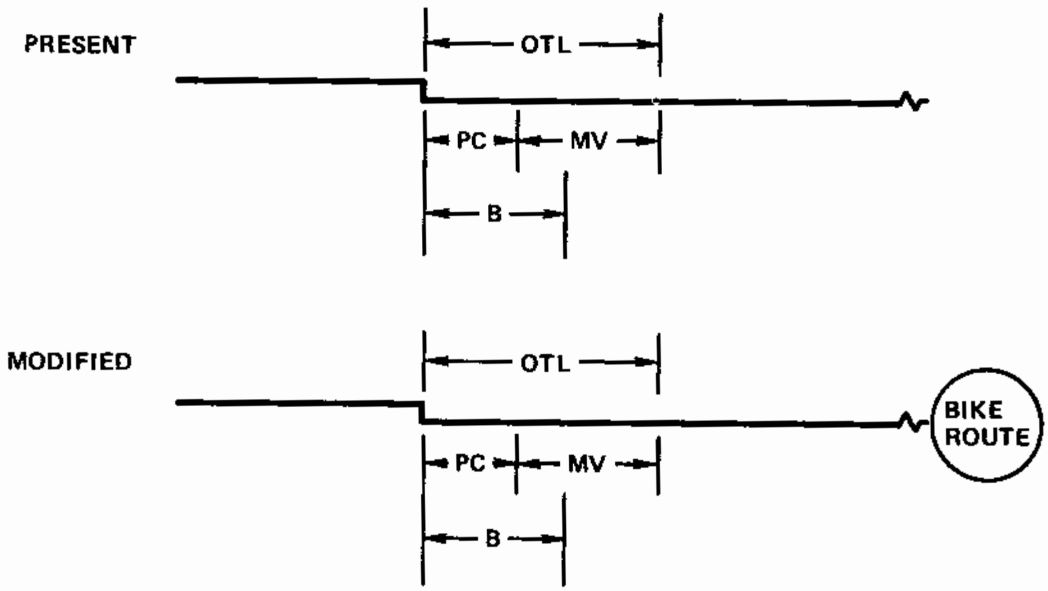
3.7.2 ROADWAY ALTERNATIVES

Incorporating the bikeway on the roadway provides more possibilities than with the sidewalk, however requires more careful consideration as the conflicts both from parked cars and motor vehicles pose more serious consequences to the cyclist. Thus the parking density, turnover rate, volume of traffic on the outside lane, traffic mix, speed and anticipated bike volume are major determiners of the feasibility of sharing the roadway (Class III) or separating the bicycle by varying degrees from the motor vehicle (Class II).

As with the sidewalk alternatives, roadway alternatives should also be subject to minimum width requirements. These are discussed where appropriate under each alternative and are presented in detail in Section 3.7.4.

In the discussion of the alternatives an emphasis is placed upon considering impacts of the proposed alternatives on the associated land use. Just as land use considerations are important in highway location decision making, it is especially important that impacts be considered in bikeway location decision making as well.

Roadway Alternative 2.1. One-Way Class III Bikeway on Roadway: Bicyclists Share Right of Way with Parked Cars and Motor Vehicle Traffic



SAFETY CONSIDERATIONS:

Only insofar as provision of signs and stencilled messages warn motorists that bicycles may be present, this alternative provides only marginal improvement over the null roadway alternative, since no defined right-of-way is specified. Cyclists are subjected to conflicts from doors of parked vehicles opening on their right, and passing vehicles on their left.

OTHER CONSIDERATIONS:

This alternative is feasible only when low bicycle demand is anticipated, parking turnover is low, motor vehicle volume and mean speeds in the outside lane are low, the traffic mix is essentially passenger cars, and the outside traffic lane is sufficiently wide to accommodate the bicycle.

The minimum required width of the outside traffic lane will vary depending upon the density of parked cars. If the average separation between parked cars is greater than 150 feet, the parked cars will not be considered as continuous barriers[1]. On narrow two-lane roads meeting the above conditions with the additional stipulation that through motor vehicle traffic is restricted, a minimum of 10 feet should be allowed for the motor vehicles and 3.3 ft. + 0.8 ft. should be allocated for a single effective lane of cyclists. The minimum width of the outside traffic lane in this case is thus 14.1 feet (28.2 ft. total minimum road right-of-way)[2].

At higher parking densities the parked cars will be considered continuous barriers. As a minimum, allowing 8 feet for parked cars (conservative), 4.1 feet for the cyclist without a door-opening allowance, and 10 feet for the motor vehicle to allow for parked car clearance, the minimum recommended width of the outside lane is 22.1 feet under these conditions.

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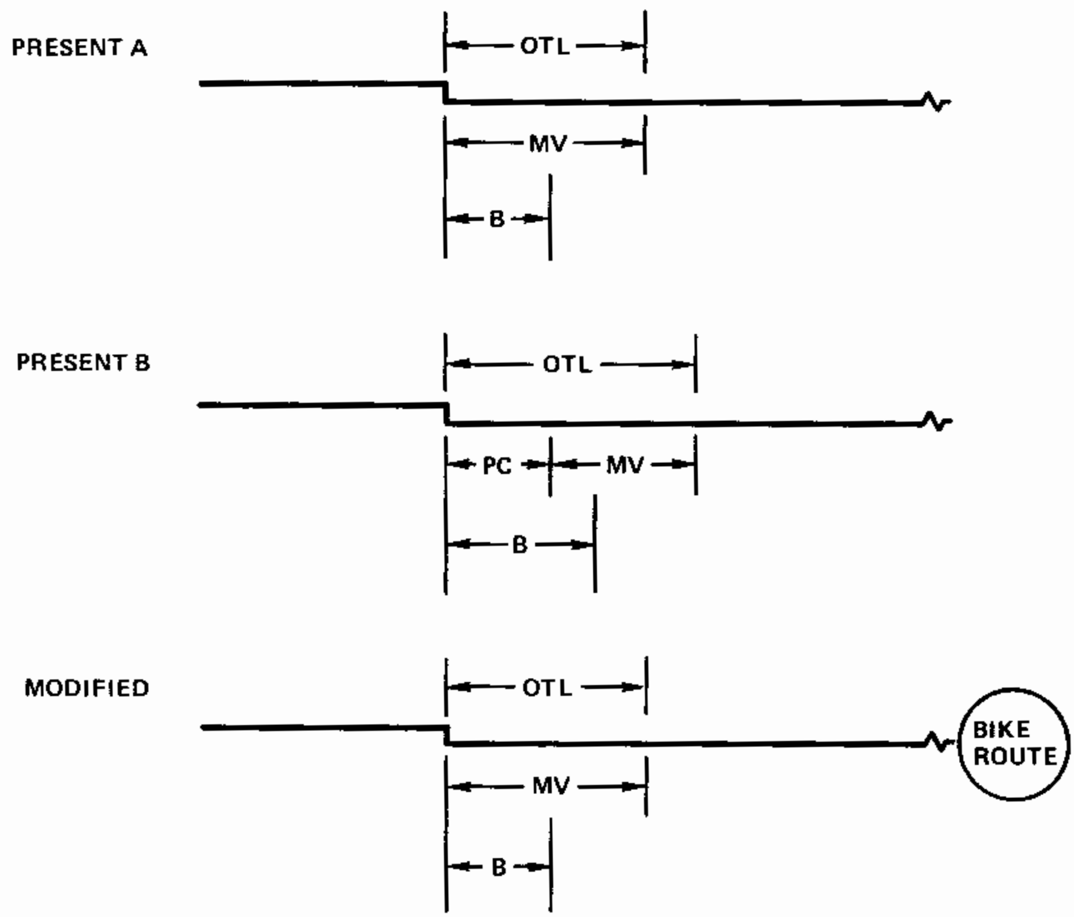
[1] This is sufficient to allow the bicycle to utilize for through travel the space normally occupied for parked cars.

[2] Through traffic is restricted in this case since the outside lane is not wide enough to accommodate parked cars and moving motor vehicles without causing moving motor vehicles to encroach to the opposite side of the street in the presence of a cyclist.

Roadway Alternative 2.2. One-Way Class III Bikeway on Roadway: Bicyclists Share Right of Way with Motor Vehicles (No Parking Allowed on Present Street or Parking Removed)



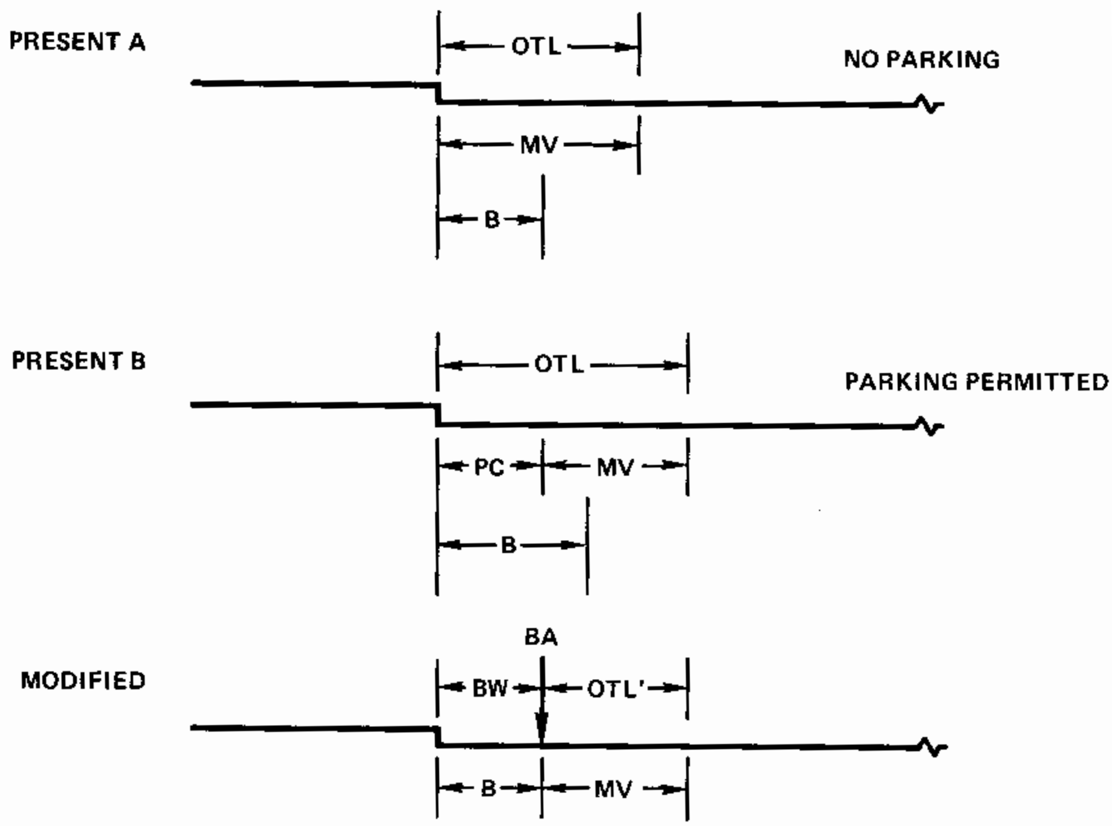
SAFETY CONSIDERATIONS:

Only insofar as provision of signs and stencilled messages warn motorists that bicycles may be present, this alternative provides only marginal improvement over the null roadway alternatives (Present A, Present B) since no defined right-of-way is specified. If the outside lane is sufficiently wide, alternative 2.3 will achieve increased safety over this alternative.

OTHER CONSIDERATIONS:

This alternative is essentially similar to alternative 2.1, with the exception that parking is eliminated (Present B) to afford space for bicycle traffic - without specifically designating a bicycle lane. If it is feasible to remove parking and sufficient width exists, then Class II alternatives would be more feasible in all cases subject to the increased cost (at minimum) of striping a lane on the roadway. Otherwise, the minimum recommended width of the outside lane for this alternative is 14.1 feet.

Roadway Alternative 2.3. One-Way Class II Bikeway on Roadway: Bicyclists Have Semi-Exclusive Right of Way. (No Parking Allowed on Present Street or Parking Removed)



SAFETY CONSIDERATIONS:

Providing a minimum barrier (stripe) and insuring that the outside traffic lane affords minimum clearance, this alternative reduces parallel conflicts of bicycle and motor vehicle by defining and channeling separate rights-of-ways; since encroachment by moving vehicles is possible with striping, as is encroachment of the bicycle onto the motor vehicle lane, striping does not effectively eliminate cross-conflicts. Cross conflicts are minimized by providing a berm or island to separate the flows, however conflicts by out-of-control vehicles are still possible, although rare.

OTHER CONSIDERATIONS:

1. Elimination of on-street parking:

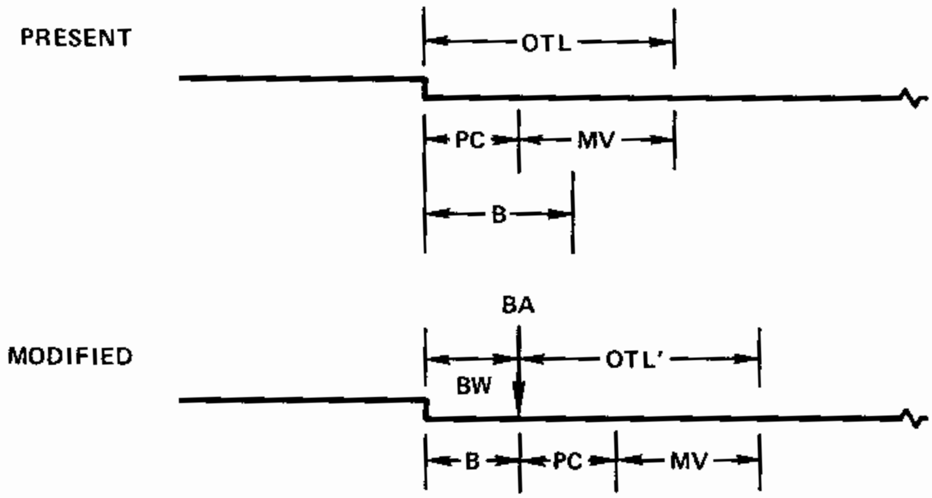
   In this section the total elimination of on-street parking is considered; if this is not feasible and bicycle demand peaks when on-street parking demand is minimal, roadway alternative 2. 6 should be considered for its feasibility.

   The consideration to totally eliminate on-street parking depends on: (1) the land use; (2) the availability of off-street parking facilities; (3) the proximity of alternative street parking; and (4) the demand for parking on the street. It should be emphasized that if elimination of parking is contemplated, the impact of that decision on the associated land use must be determined. Chapter Four contains a discussion of this problem.

2. Local Ordinances

   It should be emphasized that if a physical barrier is not employed with this alternative, ordinances must be passed and enforced to prohibit use of the bikeway as a parking lane.

Roadway Alternative 2.4. One-Way Class II Bikeway on Roadway Between Curb and Parked Cars



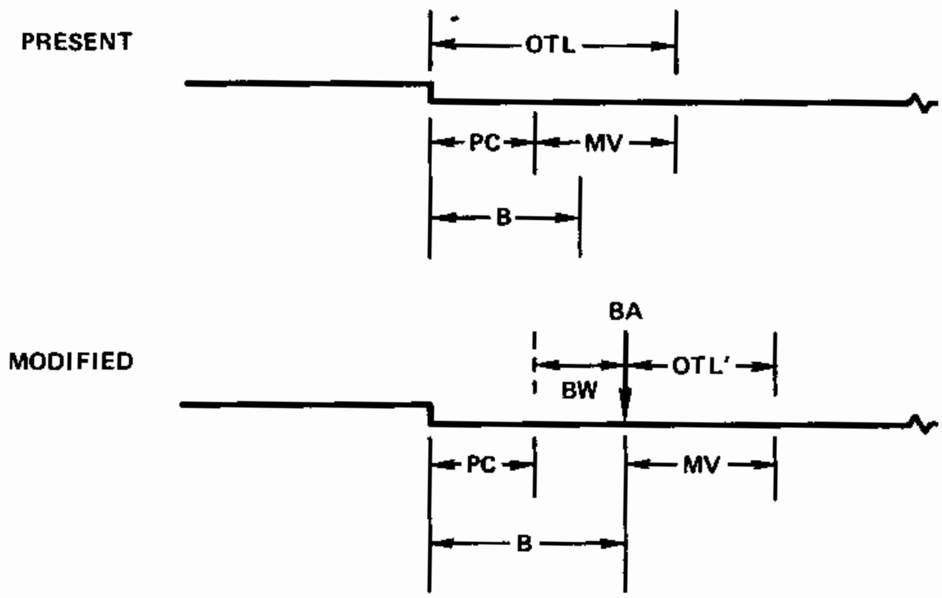
SAFETY CONSIDERATIONS:

This alternative effectively eliminates moving motor vehicle-bicycle conflicts by employing the parked car as a physical barrier. To keep parked cars from encroaching on the bicyclist right-of-way, a curb barrier is recommended. Depending on parking turnover rate and subsequent pedestrian cross flows, this alternative trades-off pedestrian/bicycle/car-door-opening conflicts with the increased safety from elimination of moving motor vehicle interactions.

OTHER CONSIDERATIONS:

The overall efficacy of this alternative is increased by a high parking occupancy coupled with a low turnover rate. In situations where these conditions are accompanied with high traffic volume in the outside lane, this alternative is ideal from the standpoint of the bicyclist. The desirability of this alternative is lessened by a high parking turnover rate which generates a high rate of pedestrian crossflow. This is especially troublesome where there is heavy bicycle demand. If routing of this alternative through commercial areas is contemplated, impacts on the associated land-use must be ascertained.

Roadway Alternative 2.5. One-Way Class II Bikeway: Parking Allowed Between Bikeway and Outside Traffic Lane



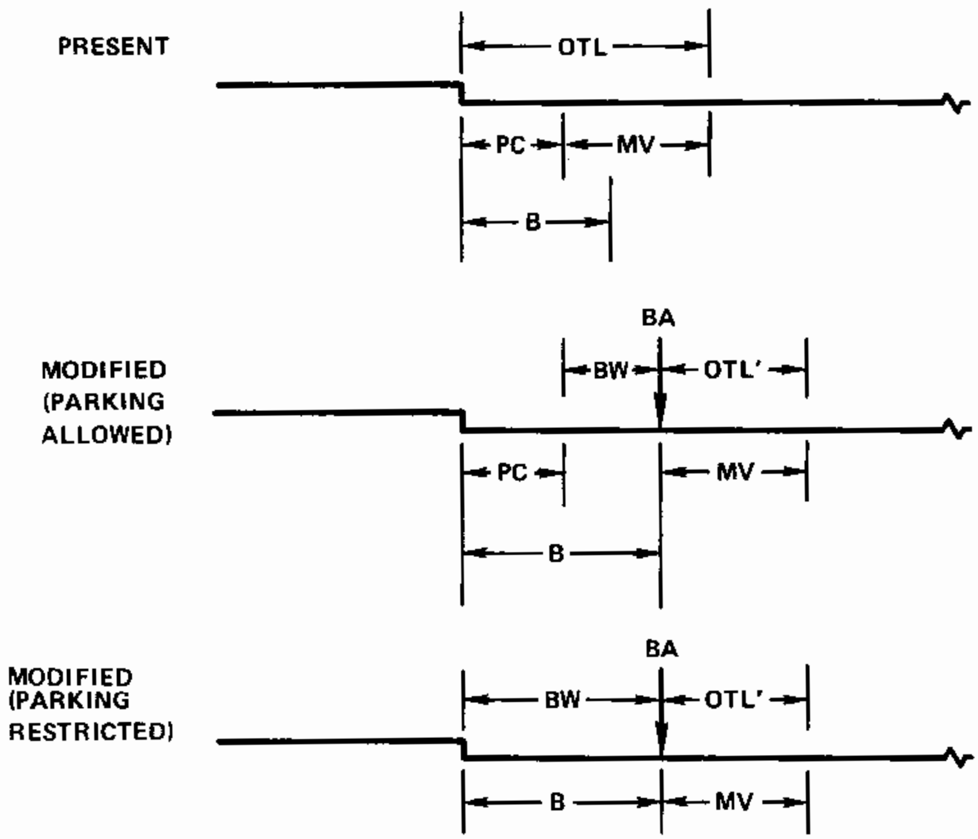
SAFETY CONSIDERATIONS:

This alternative separates moving traffic from the bicycle by defining an encroachable right-of-way. Since motor vehicles must cross the bikeway to park, it is not feasible to employ a physical barrier with this alternative. Consequently, the degree of protection from non-intentional encroachments is minimal. With a symbolic barrier (stripe) this alternative yields reduced safety to the bicyclist over alternative (2.3) by allowing intentional encroachment by parking vehicles, and by increasing the likelihood of door opening conflicts. Parallel moving motor vehicle/bicycle conflicts are reduced over those in the null (present) alternative.

OTHER CONSIDERATIONS:

Subject to the parking lane, bikeway, and outside traffic lane meeting minimum width specifications (See Section 3.7.4), this alternative is recommended only under conditions of low parking turn-over rate and low volume and mean speed in the outside lane; since no physical barrier exists between the bikeway and the traffic lane, this alternative becomes increasingly more unattractive as the mean speed of traffic on the roadway increases, and is particularly unattractive where the traffic mix contains a high proportion of trucks and multi-axle vehicles, or where the proposed bikeway runs along a bus route.

Roadway Alternative 2.6. One-Way Class II Bikeway with Restricted Parking



SAFETY CONSIDERATIONS:

This alternative is similar to alternative 2.5 with the exception that parking may be restricted during periods of peak bicycle flow. When restricted parking is in force this alternative yields increased safety to the bicyclist by increasing the effective clearance to the outside traffic lane.

OTHER CONSIDERATIONS:

For this alternative to be effective, parking restrictions should be in force during periods of peak bicycle flow. Where bicycle usage is primarily transportational and follows a defined morning and evening peak, this alternative may be appropriate assuming the pre-existing roadway is operating considerably below capacity during these hours. If high motor vehicle flow is present over the day, this alternative would prove hazardous on off-peak hours especially when coupled with dense parking and high turnover rates.

3.7.3 APPLICABLE AND RECOMMENDED BARRIER TYPES FOR THE EXISTING STREET ALTERNATIVES

The degree of cross-penetrability of the bikeway is a function of the type of barrier employed at the interfaces between the bikeway and the adjacent rights-of-way. Barriers at the interfaces can range from symbolic (e.g. striping), to physical (e.g. berms, median barriers, islands, fences). Symbolic barriers may be used to indicate to cyclists, drivers, and pedestrians their separate rights-of-way. However, symbolic barriers may be easily encroached either voluntarily or involuntarily by conflicting modes at the same grade. Thus without adequate clearance between adjacent travel modes the degree of safety provided by symbols such as lines or pavement markers is marginal, particularly where bikeways are located on streets with high motor vehicle and cycle traffic.

Physical barriers serve both the functions of delineating the edge of the bikeway right-of-way, and minimizing encroachments. In the absence of adequate horizontal clearance between the bikeway and the adjacent motor vehicle right-of-way a physical barrier is inherently safer than a symbolic one.

In France (28), the National Highway Safety Council has concluded that physical barriers should be provided for all bikeways that are immediately adjacent to traffic lanes. In the United States, the City of Palo Alto, California[1] has recommended physical barriers on bikeways

[1] Report from the City Manager (CMR:757:1), Palo Alto, California, March 4, 1971, 23 pp.

at the approaches to major intersections. The City of Davis, California[1] has provided physical barriers where bikeways have been placed between the parking lane and the curb.

"Natural" barriers, such as hedges, fences, and so on, may exist along proposed bikeway routes and should be considered in terms of separating the conflicting travel modes. In fact, the choice of the bikeway alternative itself may provide an effective barrier. For instance, the Class II sidewalk Alternative (1.2) provides a physical barrier between bicyclists and motorized traffic by grade separating them; this is enhanced with provision of a setback. As another example, parked motor vehicles in Alternative 2.4 form an effective barrier between the bikeway and moving traffic.

Aside from the natural barrier effect created by the style of bikeway that is chosen, additional symbolic or physical barriers are needed for Class II bikeways. The choice of which barrier to apply depends on many factors of which safety is but one. In Alternative (1.2) for instance, a physical barrier would reduce the ease of cross pedestrian movements and would not be recommended when significant cross-flow is anticipated. As another example, in Alternative (2.4) a stripe would not insure that parked cars would keep to their right-of-way.

Six low-cost candidate barrier types that have been used and appear feasible were investigated for the six Class II bikeway alternatives; these were, striping, full-width coloring, pavement markers (dots), reflectorized pavement markers, low-berms (continuous), and low-berms (non-continuous). The suitability of each barrier in each alternative was then determined. Table 3.7.1 summarizes the resulting recommendations. It should be noted that each of the applicable or

[1] City of Davis, California, Typical Bike Lane and Bicycle Path Layouts, Department of Public Works, 7/1/71 and 9/23/71

TABLE 3.7.1 APPLICABLE AND RECOMMENDED STRIPING AND/OR BARRIER TYPES FOR THE EIGHT ALTERNATIVES

BIKE-WAY ALTER-NATIVE	APPLICABLE STRIPING OR BARRIERS						
	STRIPE	FULL WIDTH COLORING	PAVEMENT MARKERS	REFLEC-TORIZED PAVEMENT MARKERS	LOW BERM (CON-TINUOUS)	LOW BERM (NON-CON-TINUOUS)	REMARKS
1.1 pg 59	-	-	-	-	-	-	Class III
1.2 pg 61	R	A[5]	NR	NR	A[6]	NR	
2.1 pg 64	-	-	-	-	-	-	Class III
2.2 pg 66	-	-	-	-	-	-	Class III
2.3 pg 68	A	A[5]	A[2]	A[1]	A[3,4]	A[3]	
2.4 pg 70	NR	NR	NR	NR	A[4]	R	
2.5 pg 71	R	A[5]	A[2]	A[1]	NR[7]	NR[7]	
2.6 pg 73	R	NR	A[2]	A[1]	NR[7]	NR[7]	

LEGEND

R = Recommended NR = Not recommended
A = Applicable

1 Recommended with striping when night use of bikeway is anticipated.
2 Recommended with striping to act as an enhanced barrier while allowing penetration for parking or emergency stops.
3 Recommended when bikeway is to be incorporated on high volume street, and:
(a) Adequate width is available on "shoulder" traffic lane to allow emergency stopping,
(b) Bikeway is greater than one lane to allow for passing and/or maintenance vehicles.
4 Drainage channels must be provided.
5 Can be considered when new surface is applied.
6 Applicable only when significant cross-flow of pedestrians (i. e. to parked cars) is <u>not</u> anticipated and bikeway is of sufficient width to allow passing.
7 Not recommended due to merging hazard. NOTE: this includes mountable barriers.

recommended barrier types are feasible in the short run view both in terms of cost and flexibility. More sophisticated barriers can be considered in a longer range viewpoint, subject to the availability of adequate right-of-way, and would be particularly effective where high bicycle demand is coupled with high motor vehicle volume and speeds. For example, in Alternative 2.3 a grade separated island would provide safer separation of bicycle, pedestrian, and motor vehicle traffic than the more penetrable barriers listed in Table 3.7.1.

3.7.4 MINIMUM NUMBER OF BIKEWAY LANES, MINIMUM EFFECTIVE WIDTH, ACTUAL WIDTH, AND RECOMMENDED MINIMUM SPACE REQUIRED FOR THE CLASS II AND CLASS III BIKEWAY ALTERNATIVES

The recommended minimum and maximum number of bikeway lanes for the Class II bikeway Alternatives 1.2, 2.3, 2.4, 2.5 and 2.6 are given in Table 3.7.2. Minimum lane recommendations are based upon the type of barrierization employed (See Section 3.7.3). Where striping is provided, bicycle passing can occur by leaving the bikeway; however when curb barriers are employed, a minimum of two bikeway lanes are recommended to allow bicyclists to pass each other within the confines of the barriers. A maximum of one lane is recommended for roadway Alternatives 2.5 and 2.6, since if demand, level of service, or safety would warrant more than one bikeway lane, Alternative 2.4 should be used, or the bikeway should be routed on another street.

The minimum effective bikeway width, actual width and minimum space required to provide the Class II and Class III bikeway alternatives on urban streets are given in Table 3.7.3. These dimensions are based on providing the minimum number of bikeway lanes recommended in Table 3.7.2 for each alternative. It should be noted that the minimum space recommendations for the sidewalk alternatives are based upon providing one "lane" for pedestrians. If pedestrian volumes are moderate or if the associated land use dictates, additional space for multiple pedestrians-abreast should be allowed.

TABLE 3.7.2 RECOMMENDED MINIMUM AND MAXIMUM NUMBER OF BIKEWAY LANES FOR THE CLASS II BIKEWAY ALTERNATIVES

ALTERNATIVE	MINIMUM NO. OF LANES	MAXIMUM NO. OF LANES	REMARKS
1.2 pg 61	1	No set maximum	
2.3 pg 68	1	No set maximum	with stripe
	2	No set maximum	with type B-3 curb barrier: allows passing
2.4 pg 70	2	No set maximum	With type B-3 Curb barrier: allows passing
2.5 pg 71	1	1[(a)]	
2.6 pg 73	1	1[(b)]	

NOTES:

(a) Where more than one bikeway lane is required, and there is heavy parking turnover, route bikeway on another street; otherwise use alternative (2.4).

(b) If more than one bikeway lane is required and there is heavy offpeak parking turnover, route bikeway on another street; otherwise use alternative (2.4).

3 MINIMUM SPACE FOR CLASS II AND CLASS III BIKEWAY ALTERNATIVES (GIVEN FOR ONE SIDE OF STREET ONLY)

Note: Dimensions in Parenthesis are Based on Liberal Maneuvering Allowance

Bikeway Alternative	Minimum Bikeway Width		Recommended Minimum Space Required	Remarks
	Effective	Actual		
1.1 (pg.59)			5.8' (6.3') Paved Sidewalk	Low Bike and Pedestrian Volumes
1.2 (pg.61)	3.3'	4.8'	7.3' (7.8') Figure 3.7.1(a)	6.3' Paved, 1.5' Set-back
		3.3'	5.8' (7.1') Figure 3.7.1(b)	5.8' Paved, 0.8' Clearance to Obstructions
		3.3'	5.8' (6.3') Figure 3.7.1(c)	5.8' Paved, Not Recommended in Commercial Areas
2.1 (pg.64)			14.1' For Outside Traffic Lane	Low Parking Density, Through Motor Vehicle Traffic Restricted
			22.1' For Outside Traffic Lane	Medium to High Density Parking
2.2 (pg.66)			14.1' For Outside Traffic Lane	Low Motor Vehicle Volume and Speed
2.3 (pg.68)	3.3'	4.1'	4.1' Bikeway, Outside Traffic Lane Should Meet Suggested Widths in Table 3.7.4	Painted Stripe With/Without Pavement Markers See Figure 3.7.2(a)
	5.3'(6.4')	6.8'(7.9')	7.5' (8.6') Including Curb Barrier, Outside Traffic Lane Should Provide 1.0' Minimum Clearance [1]	Type B-3 Curb Barrier, 2-Lane Minimum to Allow For Passing Cyclists. (See Figure 3.7.2(b)
2.4 (pg.70)	5.3'(6.4')	6.8'(7.9')	7.5'(8.6')	Type B-3 Curb Barrier, No Door-Opening Allowance Given
2.5 (pg.71)	3.3'	3.3' To 5.3'	13.3' From Curb to Outer Edge of Bikeway. 11.3' From Curb to Outside Stripe of Bikeway	Medium to High Parking Density See Figures 3.7.3(a), (b), (c). Low Parking Density and Turnover
2.6 (pg.73)	3.3'	5.3' To 13.3'	13.3' From Curb to Outer Edge of Bikeway 11.3' From Curb to Outer Edge of Bikeway	Medium to High Parking Density Off-peak, Low Turnover Low Parking Density Off-peak

Footnote 1 (Ref. 7, Table 17.23, pg. 625).

The dimensions given in Table 3.7.3 are further based on the following considerations:

1) the minimum effective width for each alternative are those given in Table 3.2.1, Section 3.2.3.
2) horizontal clearances to obstructions (the minimums in Table 3.2.2, Section 3.2.3).
3) the type of barrier employed
4) horizontal clearance for dynamic obstructions: clearances are based upon suggested motor vehicle minimum clearances; Table 3.7.4 gives the minimum width of the traffic lane adjacent to the bikeway as a function of the street designation and land-use to provide the necessary clearances.

The minimum dimensions and space required for the Class II alternatives for different barriers, striping, and clearance possibilities are illustrated in Figures 3.7.1, 3.7.2, and 3.7.3.

3.7.5 APPLICABLE MINIMUM MODIFICATION COST COMPONENTS FOR THE CLASS II AND CLASS III BIKEWAY ALTERNATIVES

Cost components in this section are based upon providing the bikeway when it is physically possible to do so with a minimum of modifications.

"Minimum modifications" might include such elements as signs, striping, barriers, stencilling, curb cuts, ramps, and removal of existing striping (i.e., parking lane channelization). This invariably means that the existing street includes sufficient right-of-way for the bikeway, or that it is feasible to remove parking or a traffic lane to accommodate one of the bikeway alternatives. More extreme modifications such as widening the roadway or sidewalk and re-locating utilities are not considered, as cost estimates will vary widely depending upon the existing conditions.

TABLE 3.7.4 SUGGESTED MINIMUM WIDTH (IN FEET) OF TRAFFIC LANES FOR URBAN STREETS*

		COLLECTOR		LOCAL	
EXPRESS-WAY	ARTERIAL	Single Family Residential Area	Other	Single Family Residential Area	Other
12	11	10	11	10	11

*SOURCE: Standards for Street Facilities and Services, Procedure Manual 7A, National Committee on Urban Transportation, Public Administration Service, Chicago, 1958, p. 23. Tabled in: Ref. 7, p. 624.

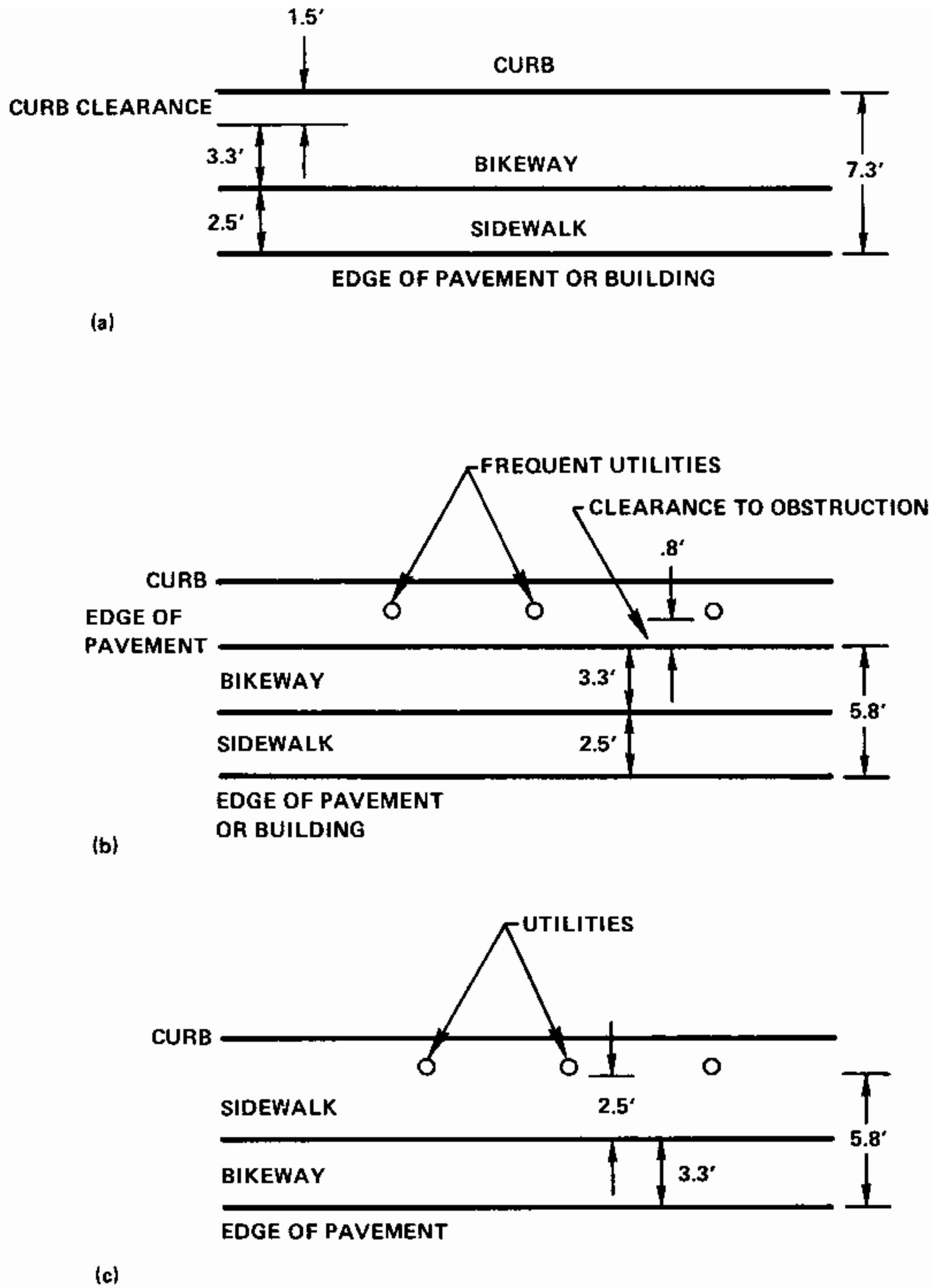


Figure 3.7.1. Alternative 1.2.

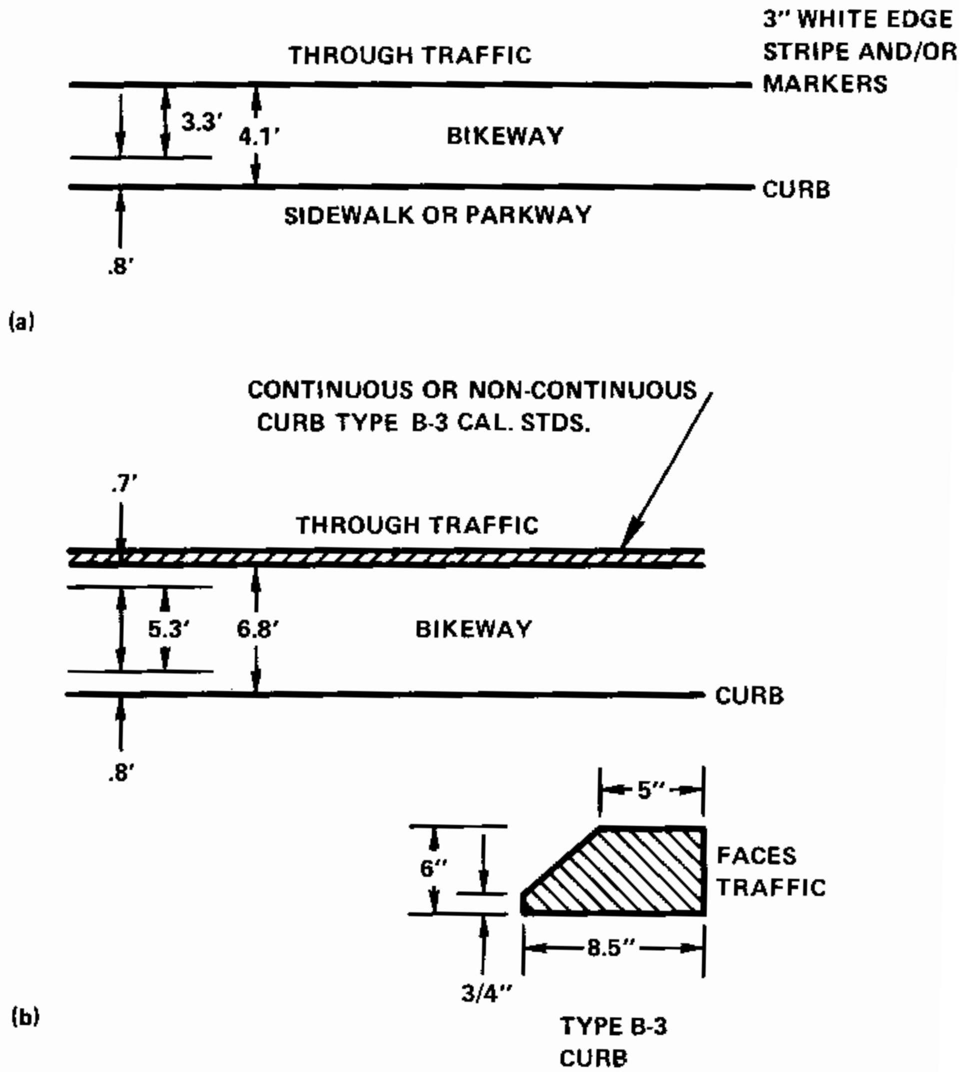
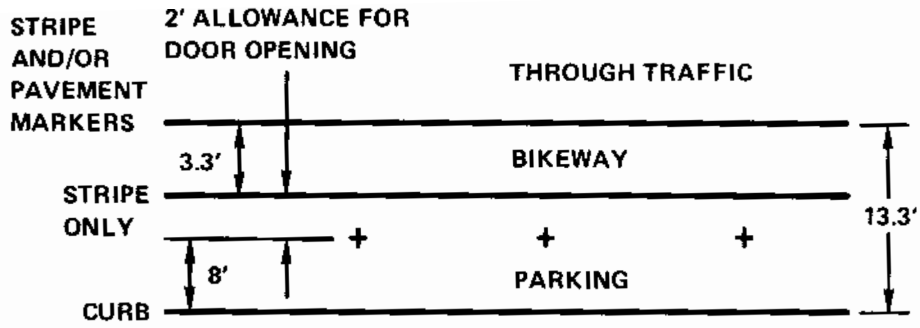
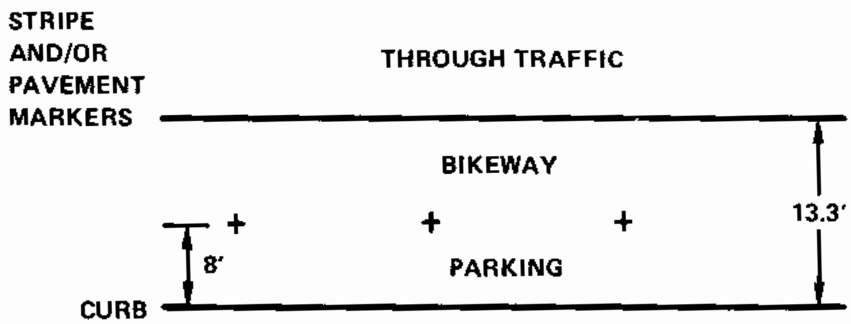


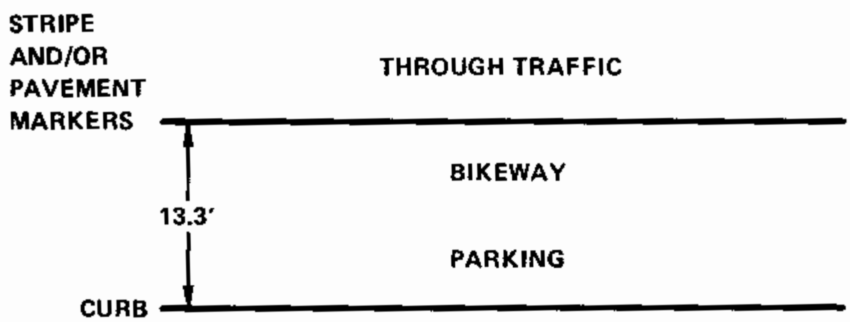
Figure 3.7.2. Alternative 2.3.



(a) Parking Stall Provided, Low Parking Turnover Anticipated. (Designed to Meet Specification in California Planning Manual, Part 8–Traffic Figure 8-602.6) (Ref. 16): Bikeway Striped on Both Sides. [Applicable for Alternative 2.5 Only]



(b) Parking Stalls Provided, Low Parking Turnover Anticipated: Bikeway Striped on Traffic Side [Applicable for Alternatives 2.5, 2.6]



(c) Parking Stalls Not Provided, Low Parking Turnover Anticipated: [Applicable for Alternatives 2.5, 2.6]

Figure 3.7.3. Alternatives 2.5 and 2.6.

To determine whether the existing street contains the minimum right-of-way to incorporate a bikeway alternative at minimum modification costs, the tables in Section 3.7.4 are useful as guidelines. The following example should prove informative:

EXAMPLE: Class II bikeway Alternative 2.3 is to be symmetrically applied upon an urban arterial street. Parking is to be prohibited. Owing to the traffic mix and vehicle speeds on the arterial, a curb barrier is to be employed between the bikeway and the outside lane.

a) From Table 3.7.2, Section 3.7.4, the bikeway will need a minimum of two effective lanes for each side of the street.

b) From Table 3.7.3, Section 3.7.4, the minimum space required on one side of the street for the bikeway - including the curb barrier - is 7.5 feet.

c) From Table 3.7.4, Section 3.7.4, the minimum recommended width of the through traffic lanes is 11 feet.

d) The minimum space required for the roadway over the entire cross-section as a function of the number of effective through M.V. traffic lanes/direction is:

No. of effective M.V. Traffic Lanes/Direction	Minimum Roadway Space Required
1	2 (7.5) + 2(11) = 37'
2	2 (7.5) + 4(11) = 59'
3	2 (7.5 + 6(11) = 81'

e) Additional space should be allocated in the above example to account for turning pockets and medians if they exist on the candidate roadway.

If conditions in d) and e) are met on the candidate roadway, or if removal of a traffic lane is feasible, the alternative can be symmetrically applied at minimum cost - otherwise more extreme modifications, if feasible, will have to be made.

Table 3.7.5 enumerates the minimum modification cost components for the Class II and Class III alternatives. Component elements are keyed to the appropriate section in Appendix A where these cost elements and others of relevance to bikeway design can be found. The appendix code is as follows:

Appendix Section	Modification
VI-f	curb barrier
VII-f	curb cut (bikeway ramp)
VIII	signs
IX-a, b	stripe edge of bikeway
IX-h, i	remove traffic stripe
IX, c-f	re-stripe traffic lanes
X	pavement markings (stencil)
XI	pavement markers

3.8 INTERSECTIONS AND CROSSINGS

The purpose of this section is to present and discuss several problems and solutions associated with providing for the bicyclist at road traffic intersections and crossings. Since intersections vary widely in characteristics, the emphasis in this section is towards investigating the requirements that need be considered in channeling intersections to provide for the safe and efficient movement of bicyclist, motorist and pedestrian.

TABLE 3.7.5 APPLICABLE MODIFICATION COST COMPONENTS FOR CLASS II AND CLASS III BIKEWAY ALTERNATIVES*

BIKEWAY ALTERNATIVES	APPLICABLE MODIFICATION COST COMPONENTS
1.1	VII-f, VIII, X
1.2	VII-f, VIII, IX-a, b, X
2.1	VIII, X
2.2	VIII, X
2.3	VI-f, VIII, IX, X, XI
2.4	VI-f, VIII, IX, X
2.5	VIII, IX, X, XI
2.6	VIII, IX, X, XI

*See Appendix A for Unit Costs.

The importance of comprehensive planning in intersection design to safely accommodate the cyclist cannot be over-emphasized, for the number and intensity of potential conflicts at intersections can far outweigh those on the mid-blocks. Poor planning of bikeway intersections may result in increased accident likelihood as the cyclists' perception of risk may not be consistent with actual conditions at the intersection. In accordance with planning and design of bikeway intersections the authors of one German source expressed the following concerns:

> "In the vicinity of intersections, the cyclist often gets involved in accidents because he cannot clearly perceive dangers.... In general, one assumes that only the cyclist who makes the left turns is in danger. In poor planning, the cyclist who is travelling straight or makes a right turn is much more endangered because he is confident to be safe on the right side and he does not suspect possible danger. In the construction of bikeway path systems one has to acknowledge these dangers. One has to plan in such a way that the cyclists can recognize dangers in time in such spots where motor vehicle traffic touches or interests bicycle traffic." (Ref. 26, pg. 15)

3.8.1 CLASS I GRADE-SEPARATED INTERSECTION AND ROAD CROSSINGS

The most effective way to separate conflicts between cyclists and motor vehicles where the bikeway must cross a roadway is by total grade separation of the conflicting flows. Such an approach is employed in Stevenage, England. At road-bikeway crossings, the roadway is generally raised 6 feet and the bikeway depressed 4 feet to obtain a ten-foot grade separation of the competing travel modes. The 10-foot separation yields more than adequate vertical clearance for the cyclist at the crossing, and where the roadway parallels the bikeway, effectively insures that the cyclist will keep to the bikeway rather than use the motor vehicle roadway. Aside from safety considerations, increased road and bikeway capacity at the crossing attain over at-grade designs, especially if the flows are high. The University of California at Davis has one such grade separated crossing which effectively separates heavy campus bikeway traffic from motor vehicle traffic on an overhead arterial.

One advantage to the bikeway underpass is that cyclists can gain speed on the downgrade to the underpass, thus making subsequent pedaling upgrade easier; this is a direct contrast to many overpass designs which require cyclists - due to limited available right of way - to dismount and walk their bicycles up and down the ramps because they are too steep to safely negotiate while mounted. On the other hand, the cost of a bikeway underpass can easily be higher than the cost of a bikeway overpass, and if the underpass forms a lengthy "corridor" it may present a hazard in high crime areas.

When the only feasible route for a proposed bikeway must cross major heavily travelled arterial streets, and high bicycle usage is anticipated, it is recommended that, wherever feasible, grade separation should be employed to separate the flows. This recommendation also holds when the bikeway must cross heavily traveled intersections where significant bicycle traffic might disrupt the orderly flow of traffic.

In densely populated urban areas with insufficient existing road rights-of-way, providing total grade separation at intersections - while attractive from safety considerations - may be completely prohibitive from the standpoint of costs. As grade separation warrants for bikeways do not currently exist, it is recommended that in cases where significant bicycle traffic would disrupt motor vehicle flow if grade separation were not provided, then all means should be taken to route the bikeway elsewhere.

In any event, in the design of a grade separated crossing the bicyclist's requirements with respect to grade, turning radius, width, super elevations, and speed should be carefully considered so that the resulting facility will not increase the likelihood of bicyclist/bicyclist conflicts.

Since grade separation may not be feasible - although highly desirable - in many cases where the bikeway crosses a roadway or where the bikeway is routed along existing streets and must cross intersections, the following sections contain a treatment of at-grade designs (Class II and Class III).

3.8.2 BIKEWAYS CROSSING INTERSECTIONS AND ROADWAYS AT-GRADE

In intersections where separate channelization is not provided for cyclists, the cyclist will frequently follow a multiplicity of paths to cross or turn at the intersection, thus contributing to the generation of bicycle/motor vehicle accidents. Figure 3.8.1 (a, b) illustrates several possible trajectories of cyclists negotiating non-channelized intersections, together with the prevalent types of motor vehicle/bicycle conflicts[1]. In Figure 3.8.1 (a) the cyclist approaches the intersection on the road-grade; in Figure 3.8.1(b) the cyclist approaches the intersection on the sidewalk. Intersections non-channelled for cycle traffic should only be contemplated when low motor vehicle and bicycle volume exist at the intersection, motor vehicle speeds are low, and a negligible proportion of the total motorized traffic consists of right turners. Otherwise, some method of channelization should be employed.

While channelization will not eliminate all of the dangerous maneuvers illustrated in Figure 3.8.1, it will tend to greatly limit them. Furthermore, proper channelization will reduce the incidence of the more prevalent accident types associated with bikeways crossing

[1] Figure 3.8.1 is a condensed version of Figures 8-10 of reference 26, pp 15-17.

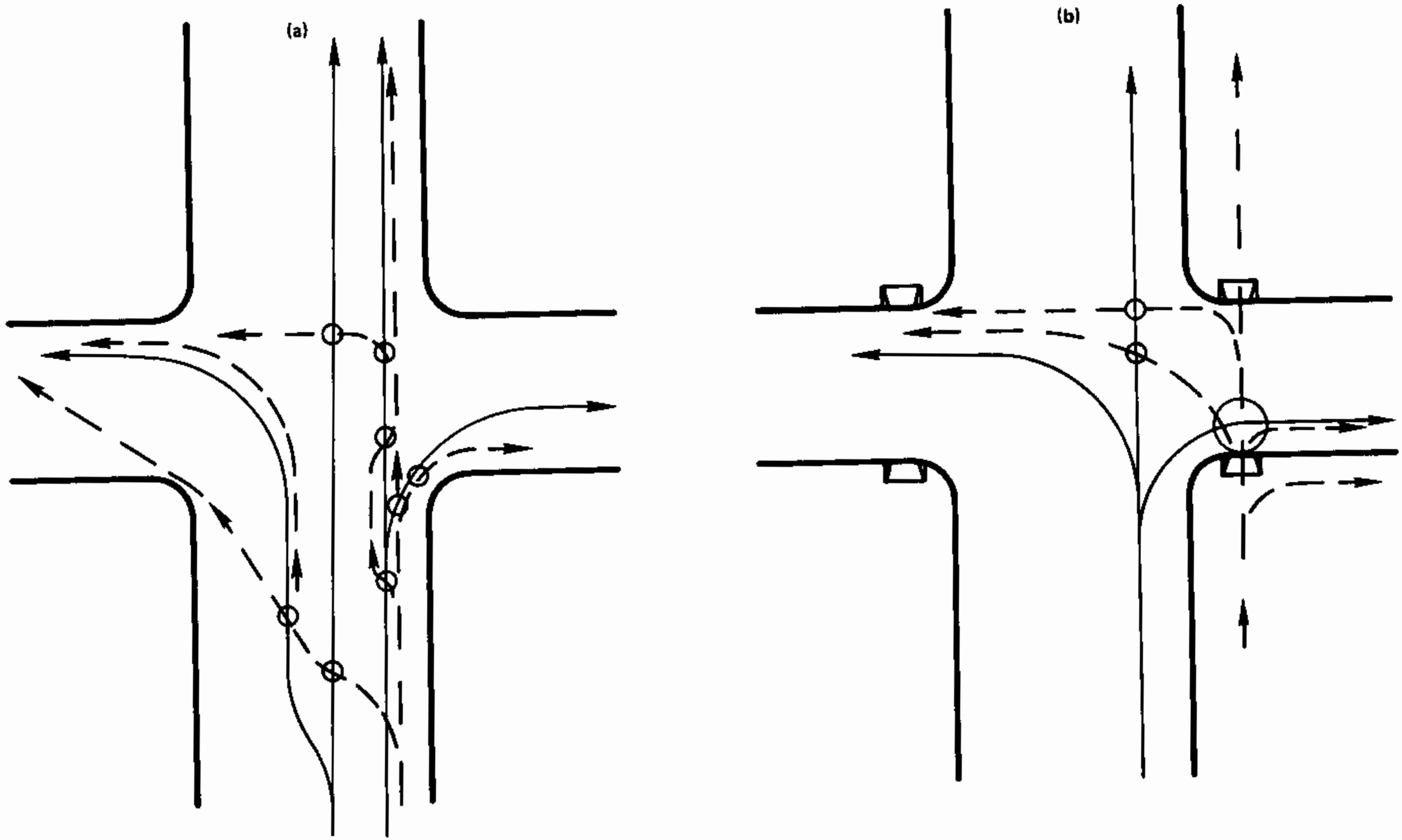


Figure 3.8.1. Various Methods Used by Cyclists to Cross Intersections.

- – – → Possible Cyclists Trajectories
- ——→ Automobile Trajectories
- ○ Conflict Points

intersections. Paramount among these are accidents involving straight through bicycle traffic and right-turning motorists.

In the remainder of this section various designs for channelized intersection crossings shall be presented and discussed. These designs are to the most part based on European intersection design recommendations, and appear highly applicable to bikeway development in the United States as well.

3.8.2.1 INTERSECTIONS CHANNELIZED FOR BICYCLE TRAFFIC

For bikeways approaching an intersection on the roadway alongside the curb, channelizing stripes may be utilized to provide a shelter for cyclists. Figures 3.8.2 and 3.8.3 illustrate two methods of channelizing cyclists within an intersection.[1] In Figure 3.8.2 a portion of a Swedish design to treat heavy left turn cycle traffic is shown (23). Figure 3.8.3 illustrates a crossing design where the bikeway approach is on the sidewalk and the bikeway departure on the opposite side of the street is routed on the roadway next to the curb.

German and Dutch methods used to reduce the potential conflicts of through cycle traffic with right turning automobiles, suggest offsetting the bikeway crossing 16.4' - 32.8' (5-10 meters) from the intersection. With a crossing-offset cyclists do not conflict with through auto traffic or cross traffic, and the angle of interception between the cyclists and right turning motorists is favorable since neither motorists nor cyclists must turn their heads more than 90^{o} to see approaching vehicles. A bikeway crossing offset also allows a queue area for motor vehicles on the cross street so as not to block the movement of through automobile traffic on the main street. Further, if the intersection is signalized, right turns on red may be permitted since queued vehicles would not obstruct the bikeway crossing.

[1] Figures in this section are not to scale.

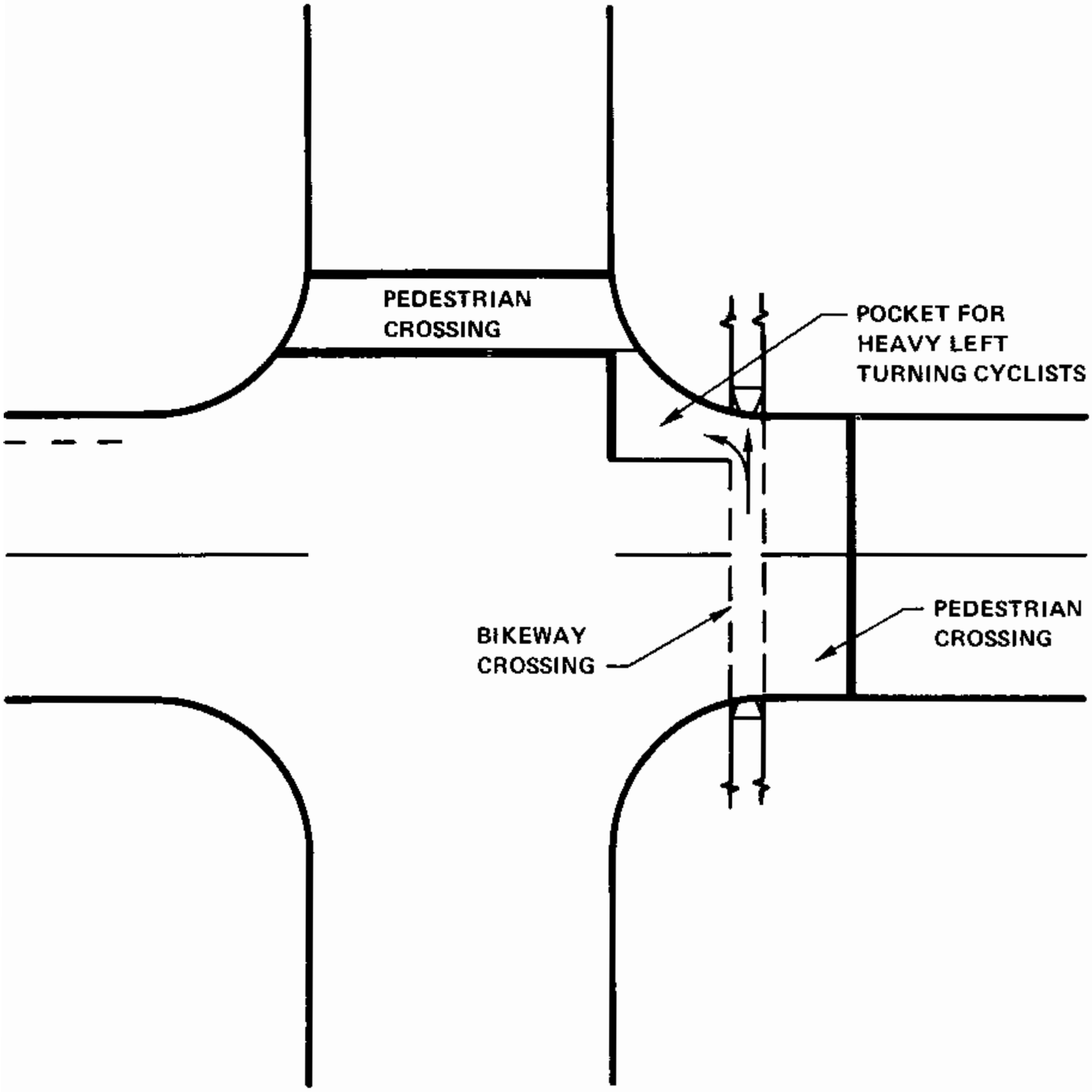


Figure 3.8.2. Intersection Design with Queue Pocket for Left Turning Cyclists. (Ref 23, Figure 17c)

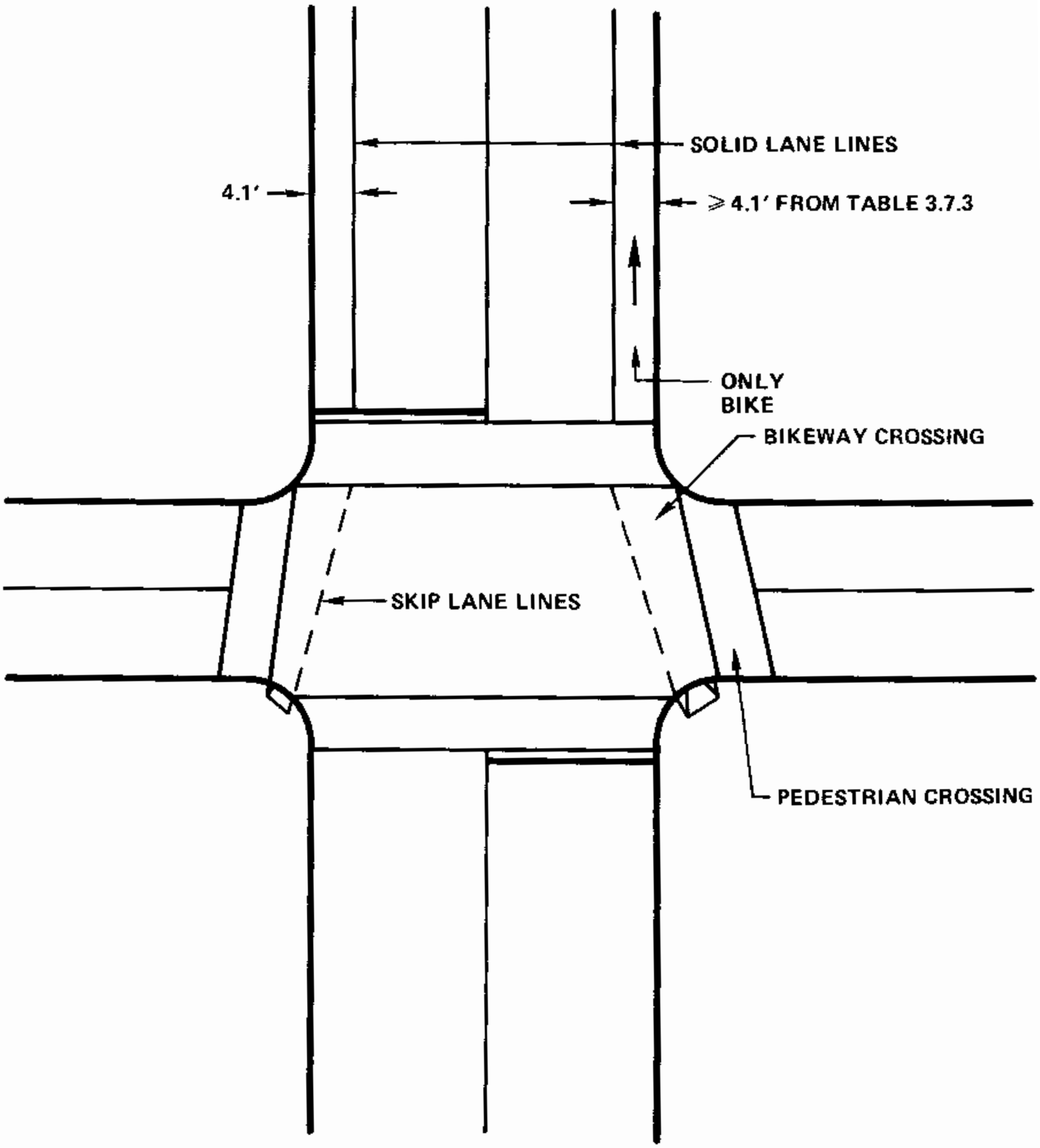


Figure 3.8.3. An Intersection Design where the Bikeway Changes from a Roadway Alternative to a Sidewalk Alternative at the Intersection.

When the bikeway crossing passes through a traffic island, according to Dutch specifications the island should be ≧ 9.8' (3 meters) wide at the crossing and of a different surface color. The island then provides a safe queue area for cyclists from motor vehicle traffic, as is especially desirable with wide intersecting roads. A design incorporating an offset-crossing through a traffic island is illustrated in Figure 3.8.4.

Figures 3.8.5 - 3.8.8 illustrate several methods of marking bikeway and pedestrian crossings recommended in Dutch and German sources. In Figure 3.8.5 the bikeway crosses the road at curb cuts. In Figure 3.8.6 the pedestrian crossing is demarked by elongated rectangular markings. Figure 3.8.7 illustrates that where a bikeway crossing must be angled other than 90^{o} with respect to the roadway, the markings should be parallel to the direction of travel on the road. This would hold in Figure 3.8.3 if rectangular markings were used instead of skip lane lines. Finally Figure 3.8.8 illustrates a crossing configuration similar to Figure 3.8.5, however, with triangular markings to indicate that the bicycles have the right-of-way over other modes of traffic. This marking is applicable as a supplement to signing in a controlled intersection where cyclists within the crossing would normally have the right-of-way.

Figures 3.8.9 - 3.8.11 shows three German intersection designs where the bikeway on an arterial street crosses a collector street (Reference 26, pp. 18-20). The designs are appropriate when low volumes of right and left turn motorized traffic exist on the arterial. The designs, however, are characterized by poor angles of interception between right turning motorists and straight through cyclists. In Figure 3.8.9 the bikeway approach (2 effective lanes/direction) is on the sidewalk with 2.3' clearance allocated for the curb dropoff (See Table 3.2.2). In Figure 3.8.10 the bikeway approach is on the roadway with a 4.9 foot at-grade separation between the bikeway and the outside motor

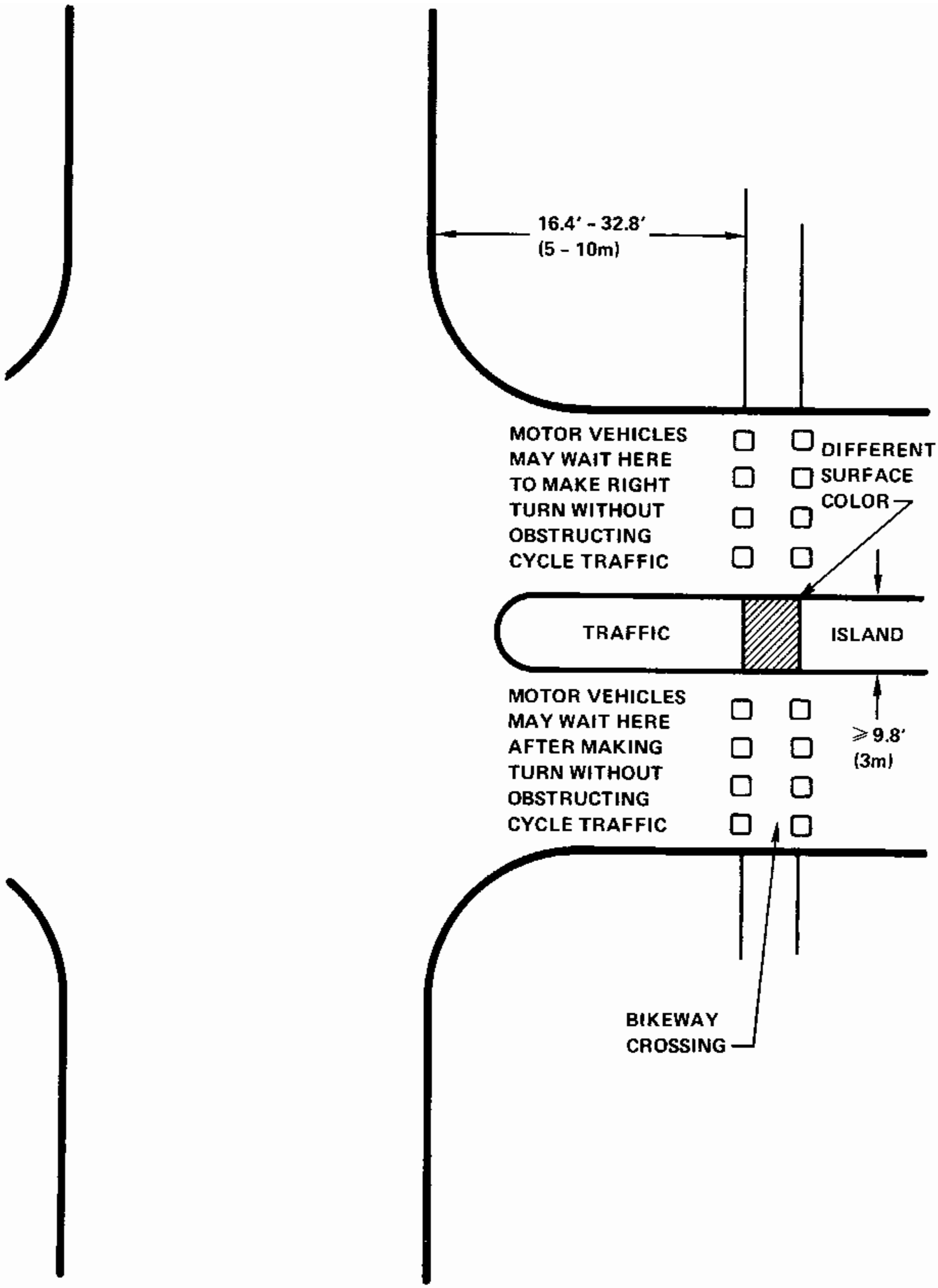


Figure 3.8.4. Intersection Design with Queue Areas for Turning Motor Vehicles. (Ref. 26, 35)

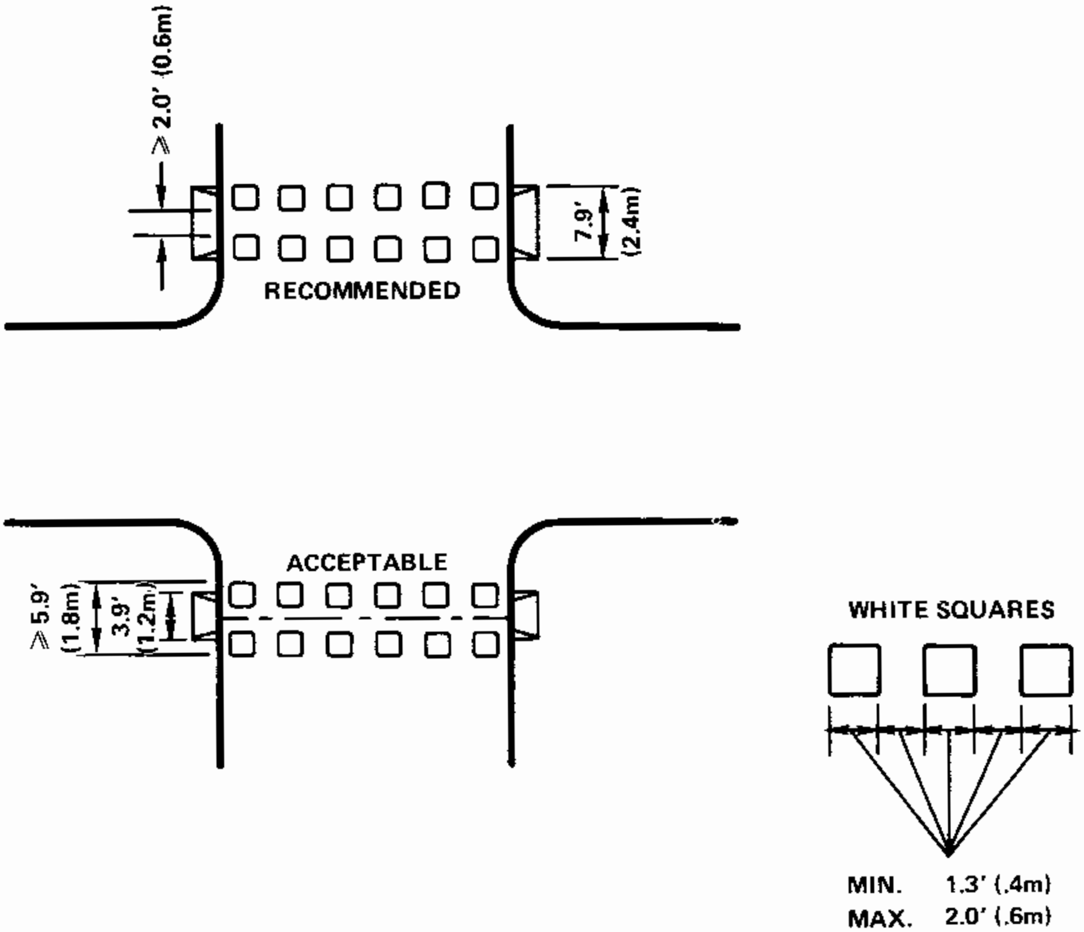


Figure 3.8.5. Recommended Bikeway Crossing Markings [Ref. 35]

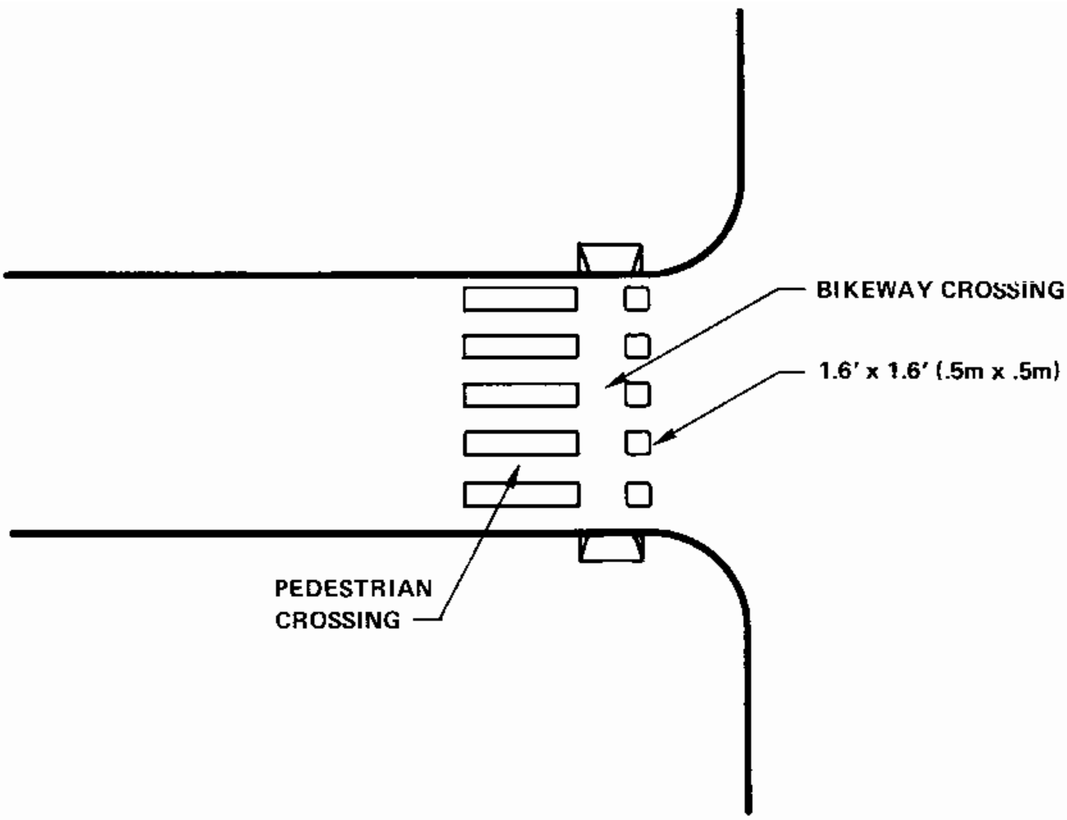


Figure 3.8.6. Recommended Bikeway and Pedestrian Crossing Markings [Ref. 26]

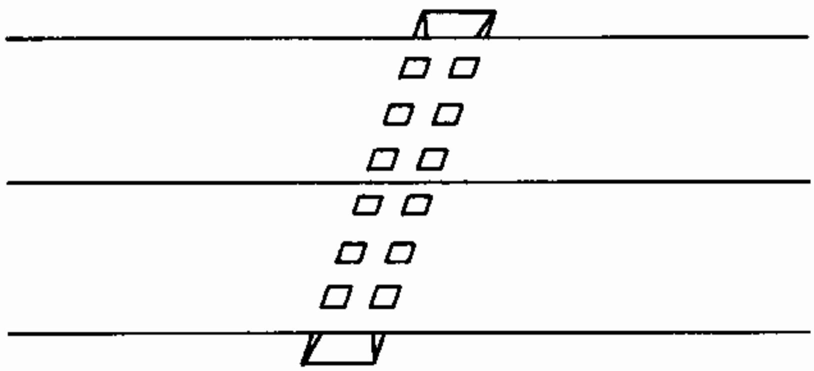


Figure 3.8.7. Bikeway Crossing Blocks Should be in Pairs Parallel to the Direction of Motor Vehicle Traffic. (Reference 35)

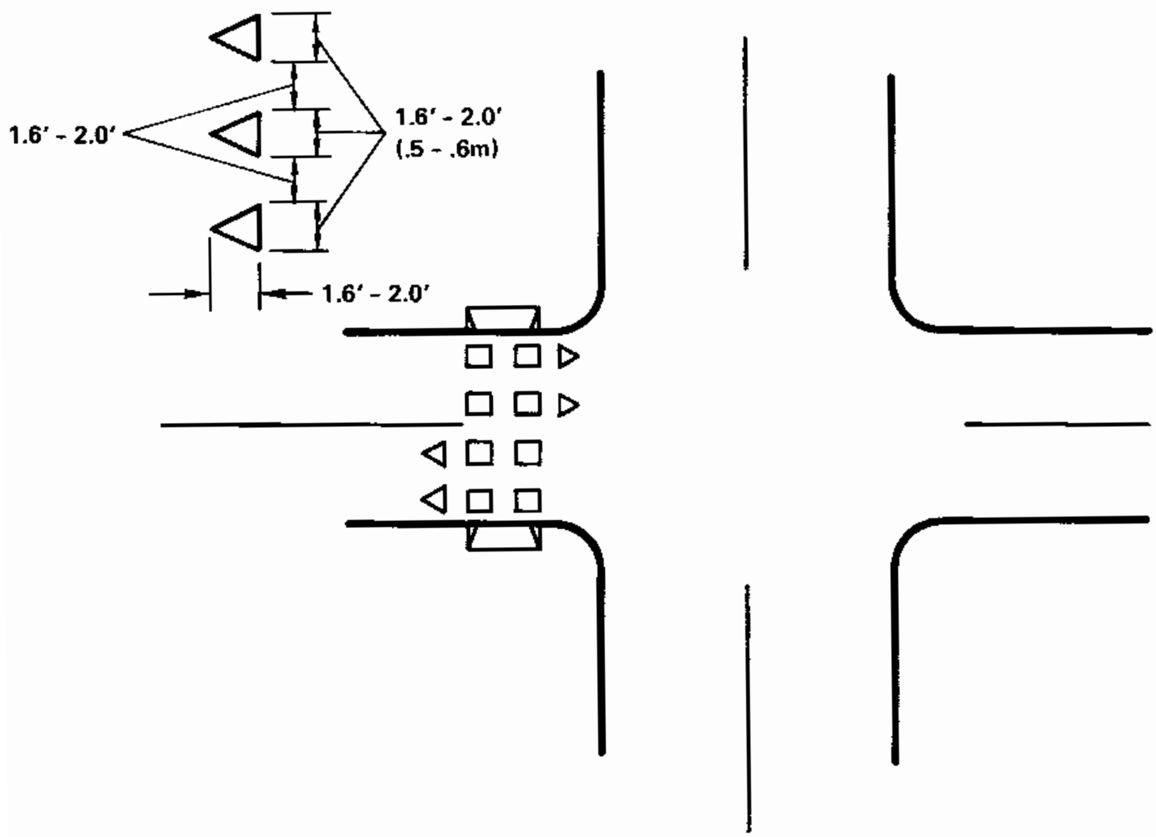


Figure 3.8.8. A Bikeway Crossing Design Where Cyclists have the Right-of-Way over Motor Vehicles. (Reference 35, p. 51)

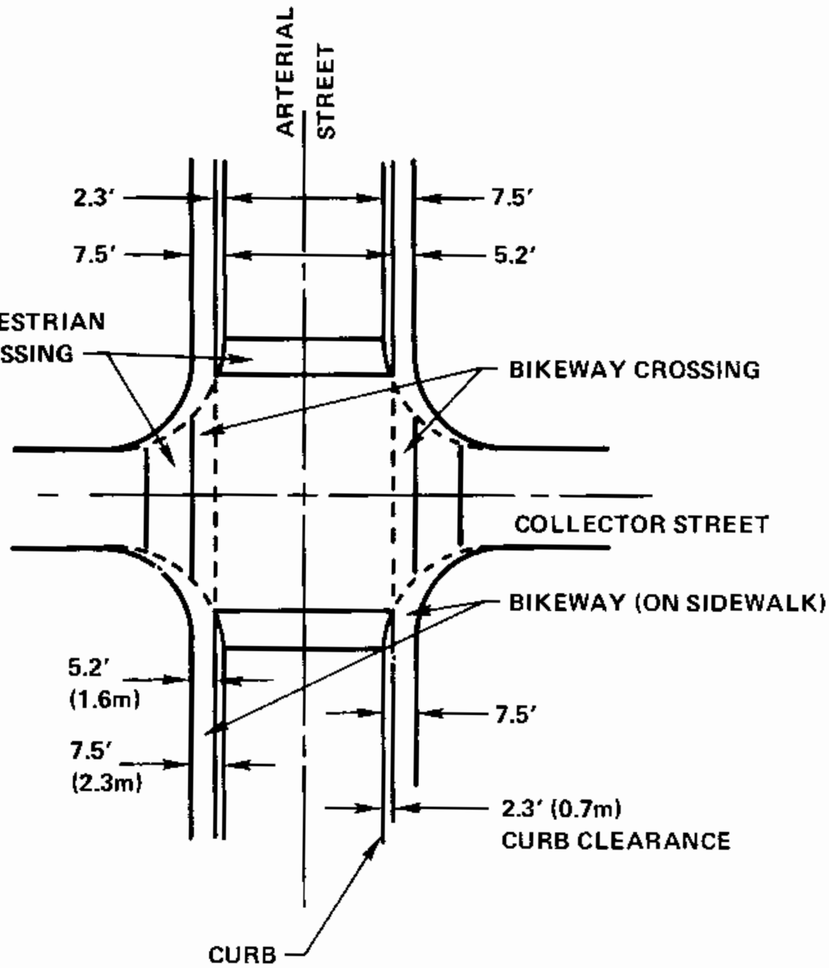


Figure 3.8.9. Recommended German Intersection Design: Bikeway on the Sidewalk of an Arterial Street Crossing a Collector Street. (Ref. 26, p. 18).

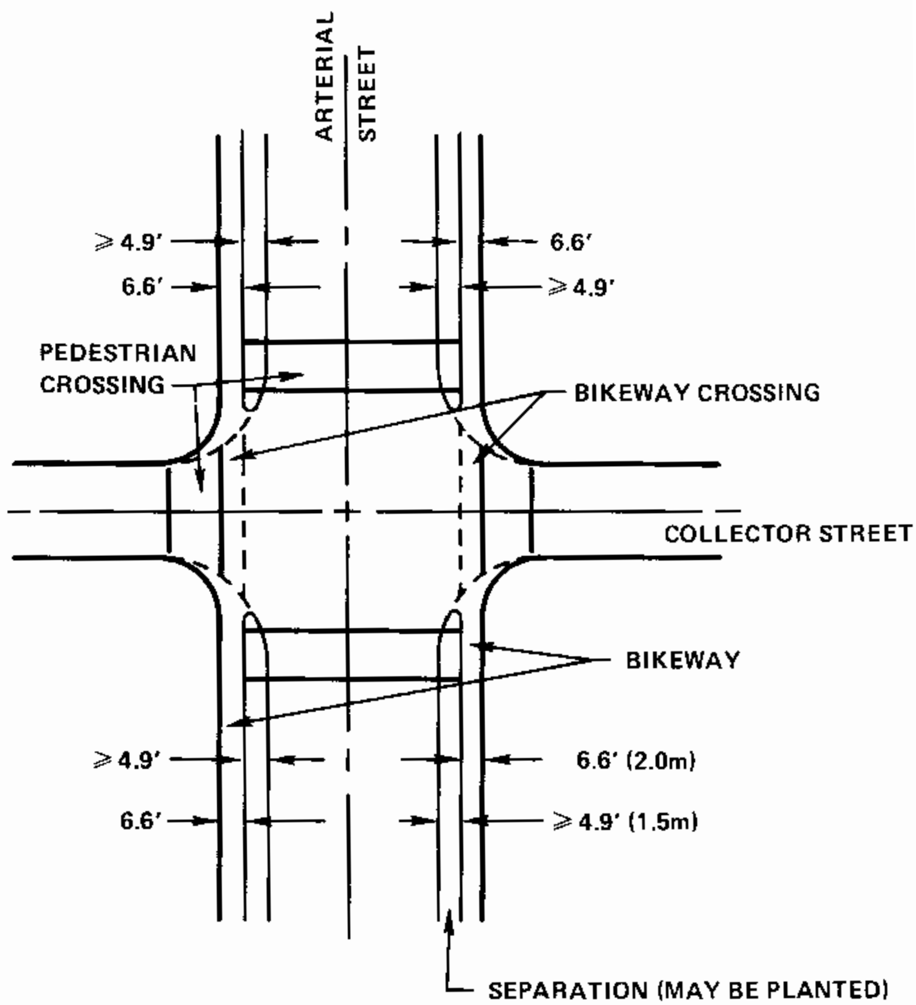


Figure 3.8.10. Recommended German Intersection Design: Bikeway on an Arterial Street Crossing a Collector Street. The Bikeway is Separated from Motor Vehicle Traffic by a Strip. (Ref. 26, p. 19).

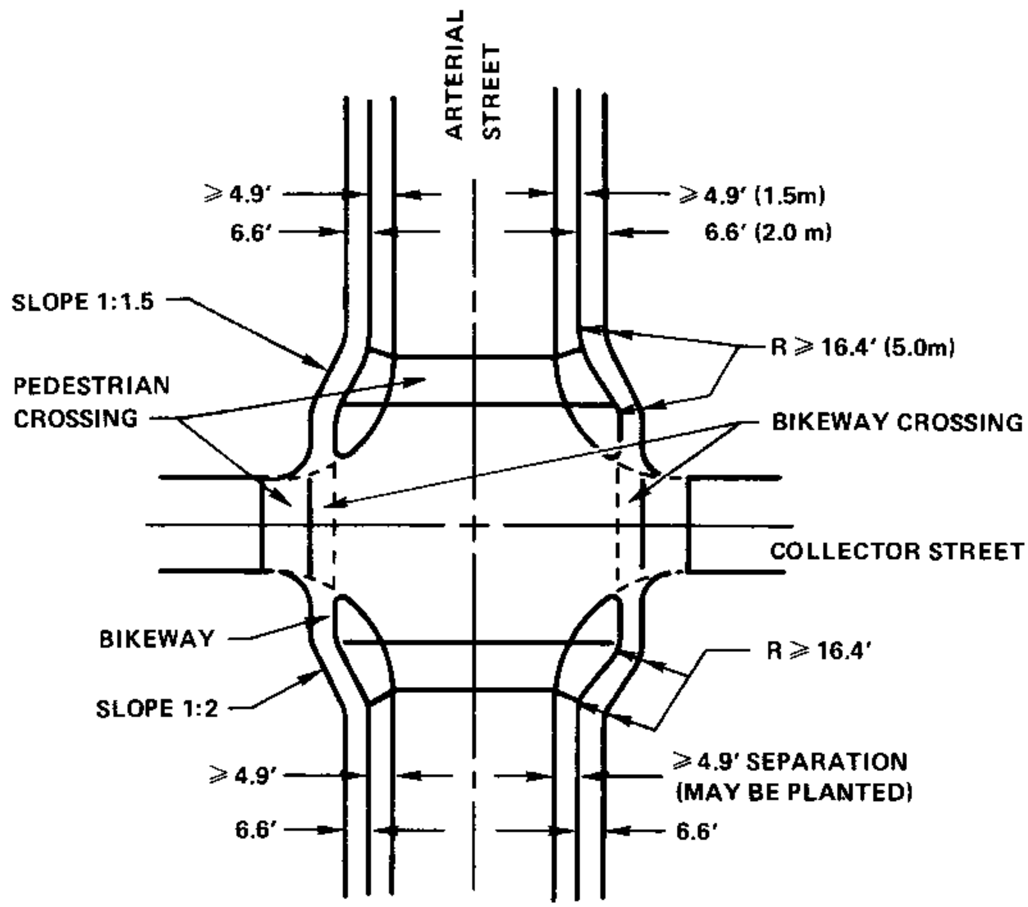


Figure 3.8.11. Recommended German Intersection Design: Bikeway on an Arterial Street Crossing a Collector Street. Bikeway is Separated from Motor Vehicle Traffic by a Strip. The Physical Design of the Bikeway Approach (Sharp Turns with Small Radii) Forces Cyclists to Reduce Their Speed Before Entering the Intersection. (Ref. 26, p. 20)

vehicle lane[1]. If greater than 4.9' separation is allocated, the German reference (26) recommends that the separation be planted with low growing bushes to prevent motor vehicles from using it as a parking lane. Figure 3.8.11 is essentially similar to the design in Figure 3.8.10, however, a flaired deceleration region is provided on the bikeway to facilitate safe crossing of the collector.

Figures 3.8.12 and 3.8.13 give two German intersection designs for a bikeway on an arterial street crossing a collector where there exists higher proportions of left and right turning traffic (bike and motor vehicle), than in the prior designs. In both designs the separated bikeway is ended approximately 250' before the limit line, and continues as a striped bike lane. Left turning cyclists may maneuver into the channelized left turn lane at the intersection to make their turn. It should be noted that if there is heavy right turning motor vehicle traffic and a right turn lane is provided, through cycle traffic is endangered. Similar remarks hold for the provision of the left turn bike lane in the presence of heavy straight through motor vehicle traffic.

Figure 3.8.14 illustrates a design for a major arterial intersection, with heavy turning movements (both cycle and motor vehicle) and intersecting bikeways. Cyclists at the approaches to the crossings are forced by the design to reduce their speed. The cyclists cross the motor vehicle lanes at right angles to the opposing motor vehicle flows, thus yielding a favorable angle of interception between cyclists and motor vehicles. Left turning cyclists are forced by the design to negotiate the intersection in counterclockwise direction.

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[1] The separation is considerably more liberal than employing a painted 3" continuous white stripe as in Table 3.7.3. More liberal allowance (not necessarily 4.9') should be considered if heavy through traffic exists on the arterial.

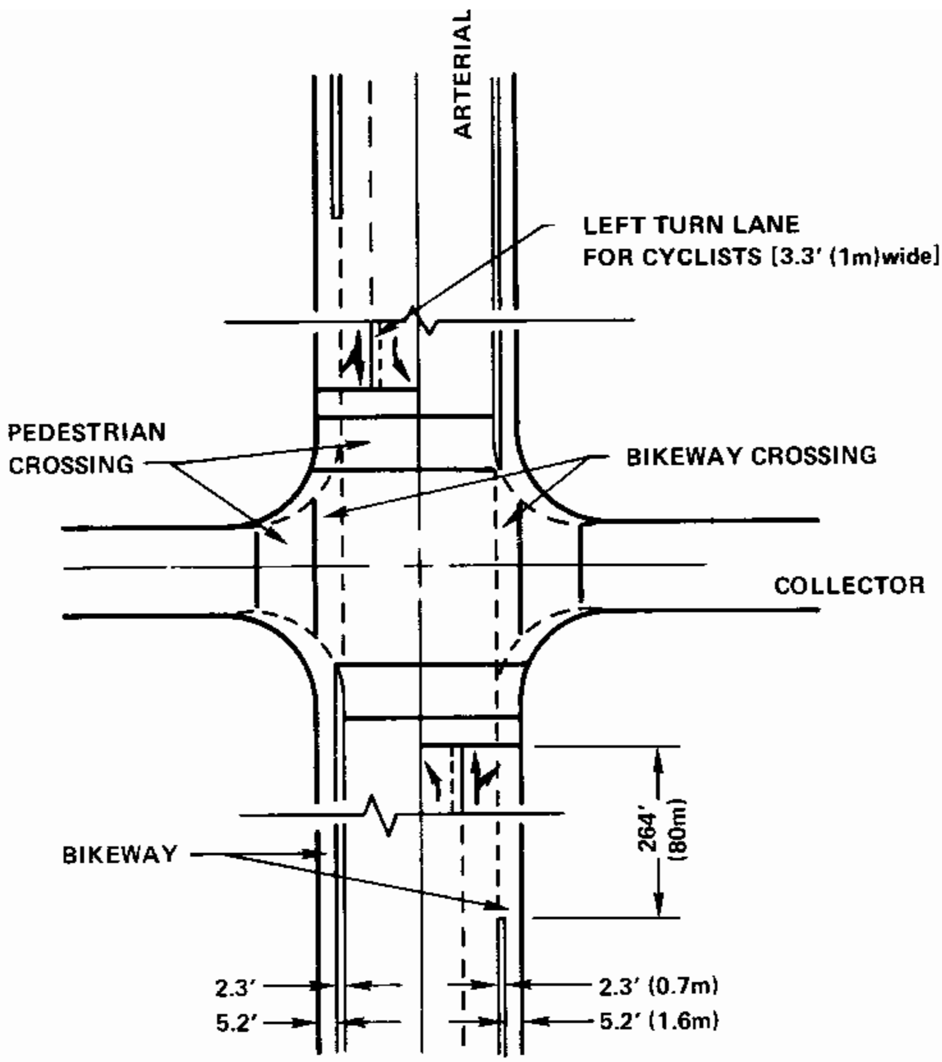


Figure 3.8.12. Recommended German Intersection Design with Bikeway on an Arterial Street Having Heavy Turning Movements onto the Collector Street. (Reference 26, p. 21)

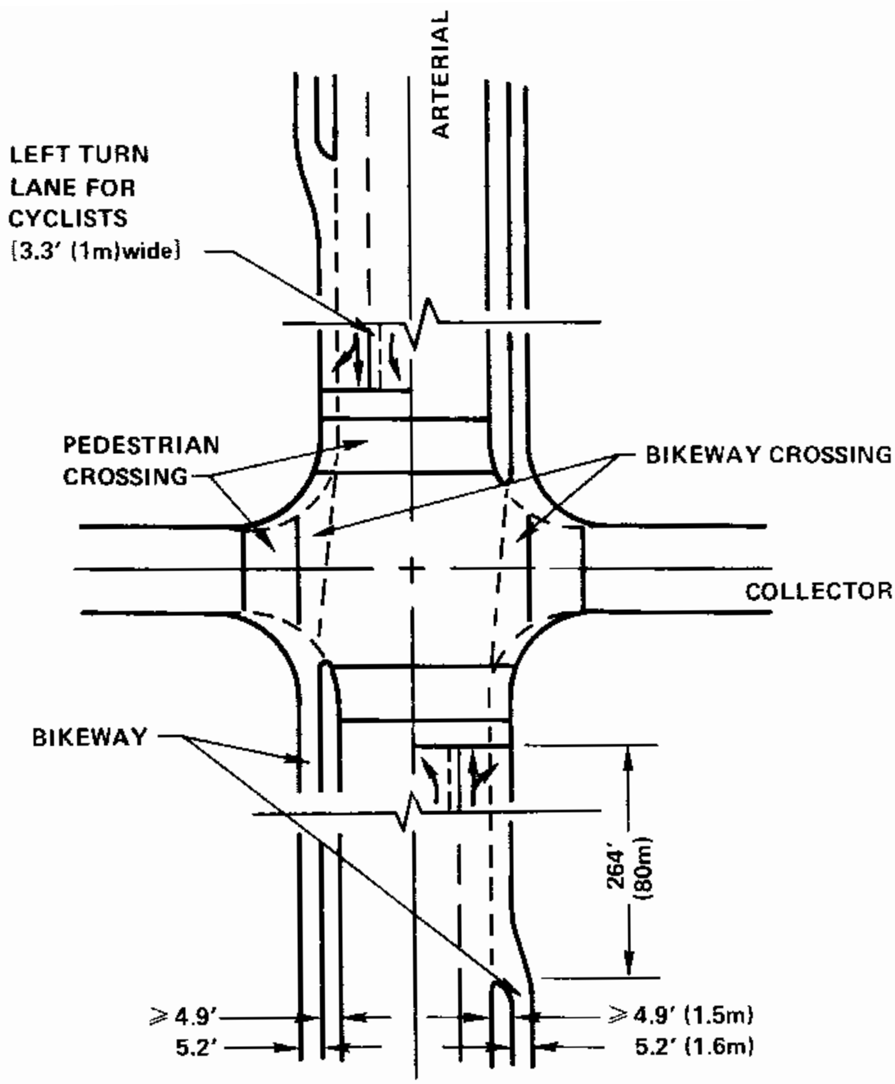


Figure 3.8.13. Recommended German Intersection Design with Bikeway on an Arterial Having Heavy Turning Movements onto the Collector Street. (Reference 26, p. 21)

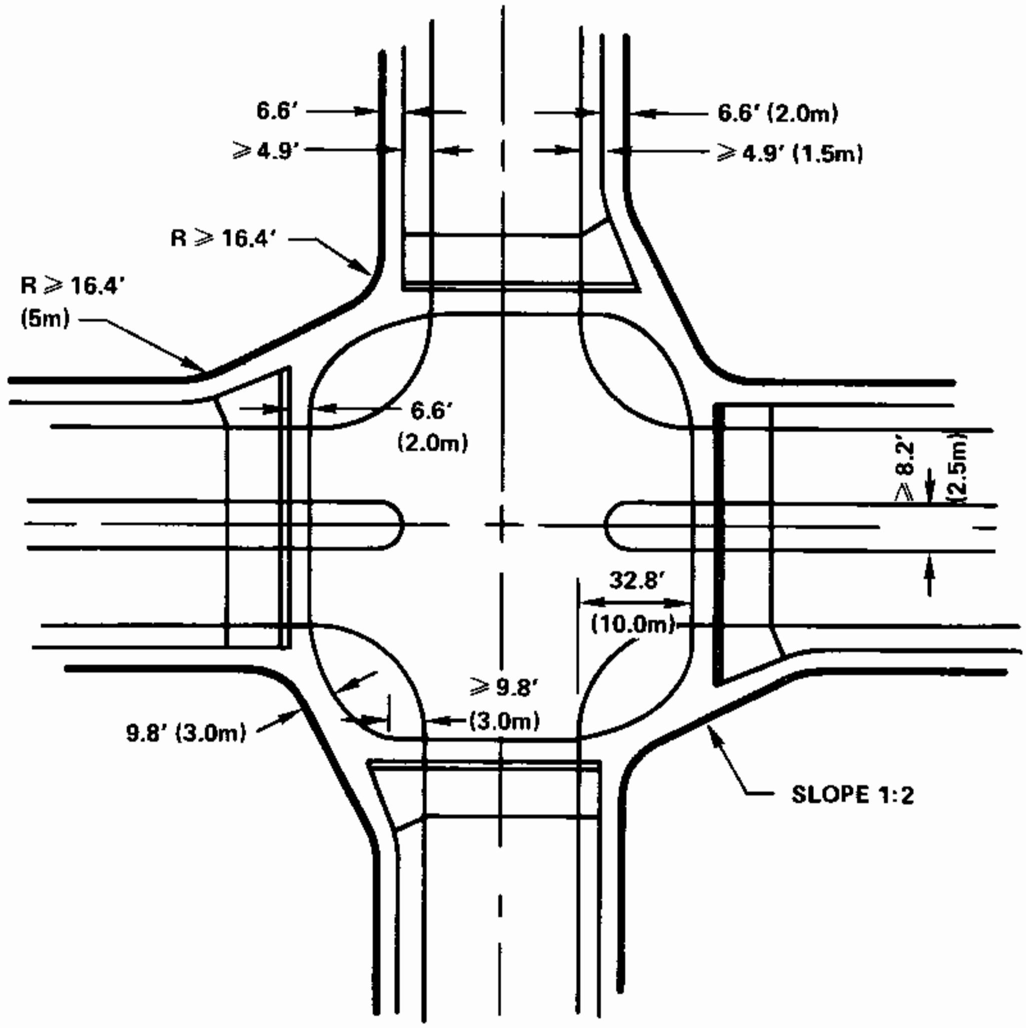


Figure 3.8.14. Recommended Intersection Design for Intersecting Arterial Roads with Bikeways on Each Road. Intersection is Asymmetrically Designed to Provide Bicycle Queue Areas at the Entrance to the Crossings. (Reference 26, p. 23)

In conclusion it should be emphasized that the efficacy of the various at-grade intersection designs presented in this section depends to a large extent on cyclists staying to their defined rights-of-way. This can be partially assured by passage of appropriate laws governing cyclists' use of bikeways at intersections together with selective enforcement of these laws.

3.8.3 SIGNALIZATION

Bikeways that must cross heavily travelled arterial streets, where grade separation is infeasible, should do so at signalized intersections. In these cases traffic signals can be helpful in controlling cross-flow conflicts of bicycle, pedestrian, and automobile traffic. Until such time as separate bicycle channelization is provided in intersections, the question of whether cyclists should be required to dismount and walk their bicycles across signalized intersections remains a matter of individual judgment. However, information available to this study indicates that there is little likelihood of cyclists complying with such restrictions.

Signalization can be utilized to separate and control angles of potential conflict by the addition of a new phase (and signal head) for cyclists. (15) To accommodate right turning motor vehicle traffic, the green bicycle phase, if provided, may be terminated before the motor vehicle green phase so as to allow right turning motor vehicles to negotiate their turn unhindered by straight-through bicycles.

Where the bikeway is on a low volume street and crosses a semi-actuated controlled intersection, "pedestrian type" actuators should be employed for the cyclist. These actuators may be positioned for separated or shared access. Cases in which separated actuators would be recommended are when a shared actuator would require cyclists to dismount to trip the signal or when queueing of one mode would obstruct the path of another. Actuators situated conveniently for bicyclists are employed in Davis, California, and contribute to the efficacy of their bikeway system.

One major problem with the timing of many existing signals is that the amber interval does not allow for adequate clearance of cyclists. One solution to the problem is to increase the length of the amber. When this is contemplated on intersections where the bikeway intersects a heavily travelled arterial, due consideration must be made of the effect on delay that would attain by reduction of the proportion of effective green allocated to the arterial. Another approach with the same reservations is to provide a 3-4 second all-red clearance interval on the arterial, but if during peak traffic demands, the intersection is operating near saturation, such modification would be inappropriate. In such cases, either the bikeway should be grade separated, the green period for cycles should be terminated early, (which requires a new signal head) or the bikeway should be routed elsewhere.

Thus, signalization should play an important part in the planning of a route; when costs are considered, the presence of one critical intersection along a proposed Class II bikeway may very well be the determiner of whether the bikeway will be safe and effective for the cyclist, and at the same time not disrupt the flow of motor vehicle transportation in the region of the bikeway route.

3.8.4 BIKEWAY TRANSITIONS FROM SEPARATE RIGHT-OF-WAY TO SHARED FACILITY

In this section several European designs are presented for ending or beginning a one-way bikeway (Class I, Class II). Figures 3.8.15 - 3.8.18 illustrate several Dutch and German off-ramp designs. These designs are characterized by a gradual merging of bikeway traffic onto the shared motor vehicle lane. Figures 3.8.19 and 3.8.20 illustrate two designs for transitioning from a shared facility to a Class I or Class II one-way bikeway.

It should be emphasized that transition designs should give proper attention to drainage. It is also recommended that appropriate signing procedures be followed at all bikeway transitions. Signing procedures are discussed in Section 3.10.

In cases where the bikeway must abruptly terminate at a roadway there are no recommended designs. However common sense dictates that the physical arrangement and signing of the termination be such that it would require the cyclist to stop or dismount before merging with cross traffic.

3.9 BICYCLES ON FREEWAY RIGHTS-OF-WAY

Bicycle use of the freeway roadbed is not specifically prohibited by California law; however the practice is strongly discouraged by the Department of Public Works;

> The hazards involved in permitting nonmotorized traffic on the freeway roadbed is such that the practice is not encouraged. Where no other reasonable alternative is available and nonmotorized traffic volumes are light, non-motorists may be permitted to use the freeway

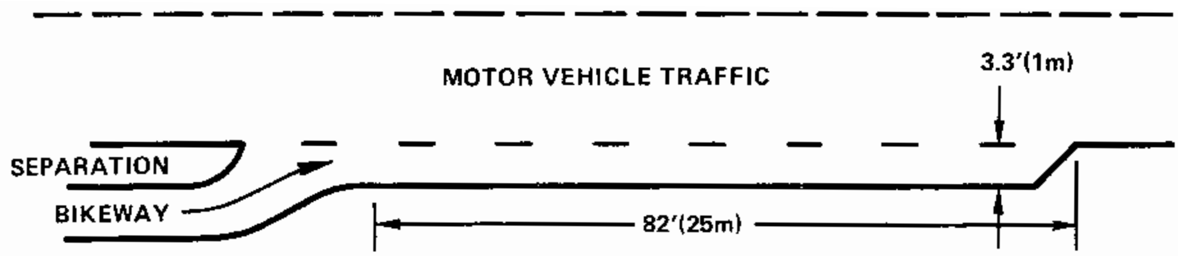


Figure 3.8.15. Dutch Design for Ending a One-Way Bikeway. The Roadway has the Same Width Along Its Whole Length (Ref. 35, p. 43)

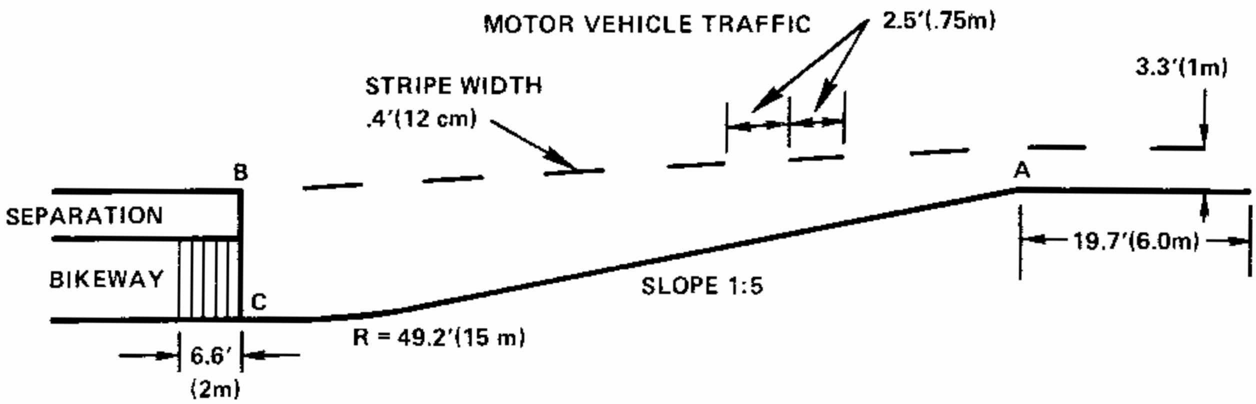


Figure 3.8.16. German Design for Ending a One-Way Bikeway. The Area Enclosed by Points A, B, C Should be of a Different Surface Color. [Reference: Der Senator für Bau-und Wohnungswesen, Radwege, Auf- und Abfahrten, B.07, Berlin,Dec. 30, 1969.]

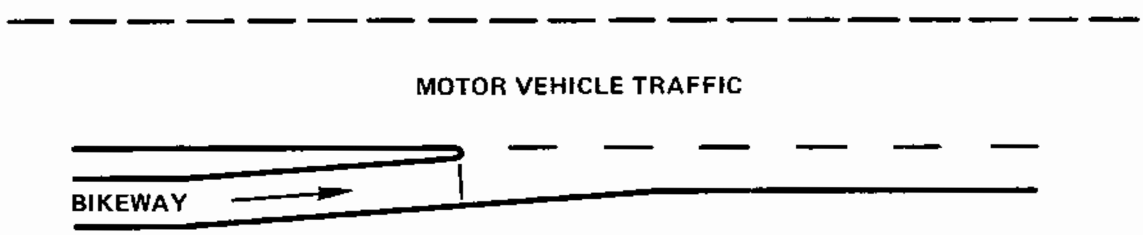
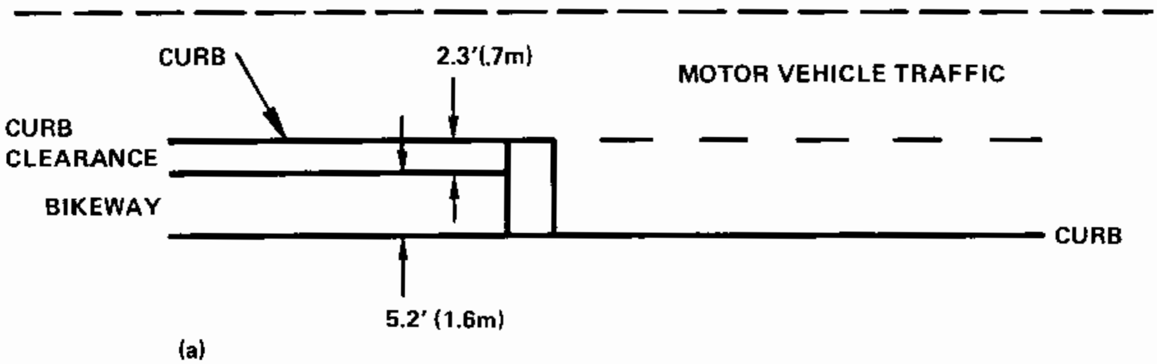


Figure 3.8.17. Dutch Design for Ending a One-Way Bikeway Combined With Widening the Roadway. (Ref. 35, p. 42).



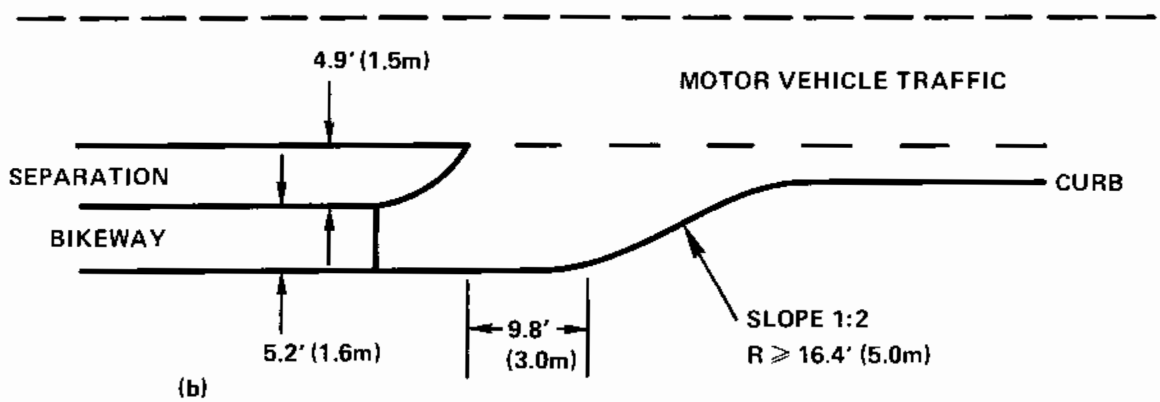


Figure 3.8.18. Basic German Designs of Bikeway Off-Ramps. (Ref. 26, p. 14). (Note: Same Cross-Sections are Applicable for On-Ramps).

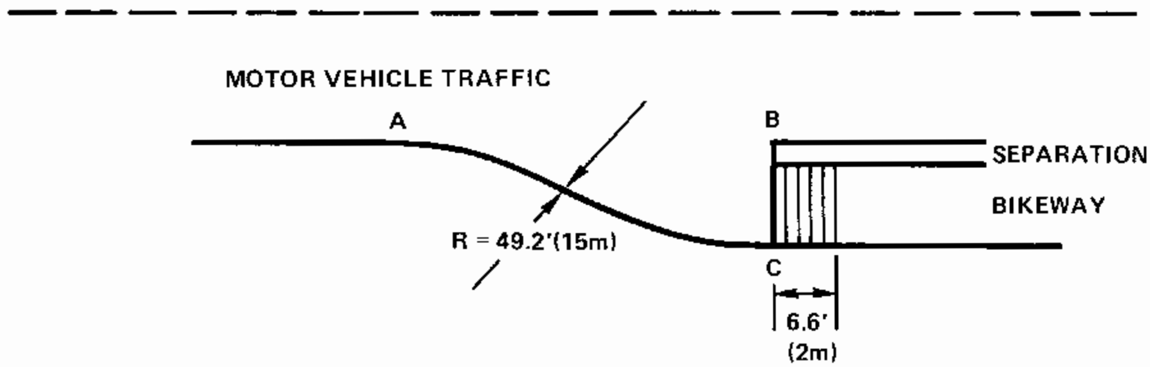


Figure 3.8.19. German Design for Beginning a One-Way Bikeway. The Area Enclosed by Points A, B, C Should be of a Different Surface Color [Reference: Der Senator für Bau-und Wohnungswesen, Radwege, Auf- und Abfahrten, B.07, Berlin,Dec. 30, 1969]

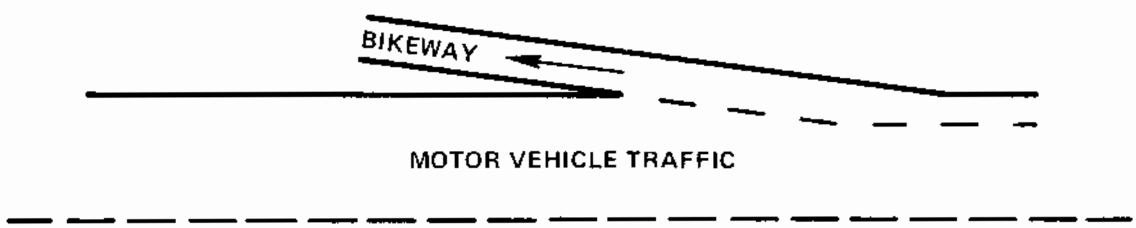


Figure 3.8.20. Dutch Design for Beginning a One-Way Bikeway (Ref. 35, p. 42).

roadway in accordance with Vehicle Code Section 21960. Normally, where traffic volumes are heavy, nonmotorized traffic should not be permitted. (17)

Section 21960 of the California Vehicle Code (18) states:

> The Department of Public Works and local authorities may, by order, ordinance, or resolution, with respect to freeways or designated portions thereof under their respective jurisdiction, to which all rights of access have been acquired, prohibit or restrict the use of the freeways or any portion thereof by pedestrians, bicycles or other nonmotorized traffic or by any person operating a motor driven cycle.

As with bicycle use of the sidewalk discussed earlier, similar remarks hold here. It is one thing to allow bicycles to have access to a freeway right-of-way and quite another to designate a portion of that right-of-way as a bikeway. While safety considerations to both bicyclist and motorist should predominate in both cases, in the latter case a bike-way designation may tend to generate bicycle usage. Thus what might be acceptable for a few particularly cautious cyclists might be totally un-acceptable under conditions of heavy and not necessarily discriminate usage by the general bicyclist population (including children).

On heavily travelled urban freeways, the right of access to the freeway roadbed (i.e., the shoulder) by bicyclists would pose substantial problems at the on- and off-ramps to the system. The presence of motor vehicles parked or stalled on the shoulder would also restrict the use of the shoulder by bicycles. Furthermore, due to the considerable difference in merging velocities of motorists and bicyclists, and the inability of the cyclist to decide upon appropriate gap acceptance behavior, the presence of the bicycle would pose substantial hazards to ramp traffic and bicyclists. Since alternate routes clearly exist in most urban regions, it is strongly recommended that heavily travelled freeways in urban areas continue to be restricted to use by motorized vehicles only.

On rural freeways to which all rights of access have been acquired and where there is no service road and therefore no alternative open to the cyclist, it is recommended that the right of access be accompanied with appropriate protection for the cyclists. This can only be provided by a Class I facility within the freeway right-of-way, designated as such as a bikeway for the exclusive use of bicycle traffic. Owing to the high speeds of motorized traffic and the associated wind turbulence, use of the roadbed should be therefore restricted solely to motor vehicles. Physical separation, in conjunction with barriers if the roadbed is at the same grade as the bikeway, should be provided to insure that cyclists stay to their right-of-way. At off-ramps, at grade, bicyclists should be required to exit using the off-ramp right hand shoulder and re-enter using the on-ramp right hand shoulder.

3.10 BIKEWAY SIGNING

3.10.1 NECESSITY

To ensure the safe and efficient operation of all classes of bikeways, adequate signing procedures are required. Depending upon the class of the bikeway and the nature of the bikeway route, signs may be necessary to warn cyclists of dangerous conditions, obstacles, or hazards, to establish rights-of-way, to exclude undesired vehicles from the bikeway, and to warn motorists and pedestrians of the presence of bicycle traffic. As stated earlier, local ordinances in addition to signing, may be necessary to ensure that the bikeway right-of -way is not violated.

3.10.2 STANDARD SIGNS

Standard signs serve an intra- as well as inter-system function. In providing intra-system uniformity, standardization permits greater ease in comprehension by cyclists and, on Class II and III bikeways, motorists as well. Inter-system uniformity provides comparable benefits to newcomers and visitors who are unfamiliar with an area and who are likely to lose their way when cycling on bikeways that are either not clearly marked, or equipped with unusual and often confusing signs. With improved comprehension, standard signs also aid in response accuracy, thereby improving the overall safety and efficiency of the system.

Standard signs authorized by the National Joint Committee on Uniform Traffic Control Devices and which are appropriate for use on bikeway routes include the following, as listed in the 1971 Manual of Uniform Traffic Control Devices (65):

1. BIKE ROUTE (D11-1) - used for marking an officially designated bicycle trail, this 24 inch x 18 inch guide sign has a white legend consisting of a bicycle symbol, the words BIKE ROUTE in 3" Series C letters, and a border in white on an interstate green background. This sign is intended to guide cyclists along a predetermined route. The bikeway route may consist of Class I, Class II, or Class III bikeway elements.

   When necessary, a supplementary sign with a directional arrow may be placed below the BIKE ROUTE sign. This supplementary sign is a horizontal rectangle 24 inches x 6 inches with a white arrow and border on a green background.

2. BIKE XING (W11-1) - used for warning motorists in advance of a point where an officially designated bike route crosses a roadway. This 30 inch x 30 inch diamond shaped sign has a black bicycle symbol on a yellow background. Beneath it, a

yellow horizontal rectangle 24 inches x 18 inches bears the legend BIKE XING in 6 inch black Series D letters. Both plaques have a black border and are reflectorized so as to be effective at night.

3. NO BICYCLES (R 5-6), PEDESTRIANS PROHIBITED (R 5-3), and MOTOR DRIVEN CYCLES PROHIBITED (R 5-8) are selective exclusion signs that regulate types of traffic which may or may not enter a particular right-of-way. The NO BICYCLES sign consists of a square upper plaque measuring 24 inches on a side with a black bicycle symbol circumscribed by a slashed red prohibitory circle. The lower plaque, 24 inches x 18 inches reads "NO BICYCLES" in black letters. Both signs have a black border on a white background.

Addtional standard signs which may be particularly relevant to to Class I bikeways include the "Curve," "Winding Road," "Stop Ahead," "Stop," "Yield Ahead," "Yield," and "Slide Area" designations. According to the California Traffic Planning Manual these signs are available in several different sizes. Although 30" x 30" are the standard dimensions, reducing this size by a multiple of 6 inches (to 24" x 24") may be desirable for placement along Class III bikeways. A similar procedure, combining a substandard sized warning sign with the standard "Bike Route" designation has been adopted in Japan (51).

At present there is little uniformity in signing practices for the bicycle. A wide variety of designs, often incorporating local pride or history, are utilized on all classes of bikeways across the country. In general, standard signs are recommended wherever applicable along the bikeway route. However, since it is recognized that the few uniform signs outlined above may not apply equally well to all situations, certain additional sign messages are suggested for further study. These include:

1. "Begin" or "End Bike Route" - this would consist of the standard "Bike Route" sign with an above mounted supplemental "Begin" or "End" plaque. Its use would be to inform bicyclists of the origin and termination of a Class I, II, or III bikeway.

2. "Watch for Bikes" - This warning sign would be the standard yellow 30" x 30" diamond shape. Since the "Begin" or "End Bike Route" designation may not be adequately comprehended by motorists, the "Watch for Bikes" sign may be used to supplement it. Its use would be to warn motorists that slow moving bicycle traffic may be encountered regardless of whether a bikeway is located at that point.

3. "No Motor Vehicles" - comparable to "No Bicycles" - this black and white sign would be similar to that currently in use throughout Europe. If adopted here, its use would be to exclude all motor vehicles from entering Class I or II bikeways.

4. "Bike Parking" - based upon the standard "Parking" design, this sign would be positioned at or near bicycle storage facilities along any class bikeway, and would be used to inform bicyclists of the location of these facilities.

3.10.3 STENCILLED PAVEMENT MESSAGES

The use of white pavement stencils as a supplement to existing signs has been growing in importance for all traffic modalities. At intersections, directional markings (arrows) have already become a common method of channelization. As an extension of this trend the use of symbolic stencils as an adjunct to signs on Class I and II bikeways presents a promising alternative which has begun to be realized both in this country and abroad.[1]

In Europe a pavement stencil consisting of an elongated bicycle 3.5 feet wide and 7 feet high is sometimes painted on the surface of Class II bikeways. The large size of the symbol is intended to ensure motorists' recognition of the bikeway and hence of the presence of slow moving traffic. In this country, a stencil of the standard "Bike Route" sign, 24" x 18", is available through the Bicycle Institute of America (12). Due to its small size, this marking is only recommended for use where it is not intended to warn motorists of the presence of bicyclists. Pavement markings for motorists should be as large as the bikeway width will permit, and made of as few letters as possible. Therefore, "Bikeway" is recommended. The decision, which word to place on top, is determined by how elongated the letters are, which in turn is decided by the width available and the expected speed of automobile traffic. For narrow width bikeways the design and standardization of a symbol for use in pavement markings is recommended using the European symbol as a model.

In most situations, the use of symbolic pavement stencils is recommended to supplement posted signs. This is particularly true on upgrades where the cyclist, preoccupied with his pedaling efforts, will tend to be looking more toward the ground than to the side of the bikeway. Also, pavement stencils are useful at locations where pedestrians are likely to attempt to use or cross the bikeway, such as at intersections.

At this time it is recommended that the BIA stencil be used as a supplement to posted signing only on Class I bikeways where only bicyclists will need to read it. For Class II and Class III bikeways, the largest possible "BIKEWAY" marking is recommended.

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[1] Pavement markings in intersection crosswalks are treated in Section 3.8.2.1.

Lettered pavement stencils "BIKE ONLY" may be used to supplement the selective exclusion signs to discourage motorists from entering Class I and Class II bikeways at various places along the bikeway where motorists might not be aware of the bikeway. These markings are currently employed in such communities as Davis, California, where they are an especially well suited supplement to standard route and warning signs. When painted on a Class II bikeway surface at the far side of an intersection, "Bike Only" reinforces the "Bike Route" sign. The message conveys the fact that not only are bikes to be expected along the bikeway route, but that they are the only through traffic allowed on the bike right-of-way.

The "Bike Only" stencils utilized in Davis consist of the words "Bike" and "Only" spelled out in 4 foot high reflectorized and elongated white letters, separated by a 6 foot space; a 7 foot long arrow specifying the direction of travel may be added. The length of the complete marking totals approximately 31 feet, and its width is approximately 6 feet. In order to be utilized on Class II bikeways narrower than 6 feet, the stencils would have to be reduced in size, thereby detracting from their impact and visibility to the motorist. However, even in this case the "Bike Only" designation, especially with existing street alternative 2.4, is highly recommended at the interfaces of the bikeway with street intersections.[1]

Other markings that can be used include "STOP," "YIELD AHEAD," "YIELD," "PED XING," "SLOW," and turn arrows.

3.10.4 SIGN PLACEMENT

On Class II and III bikeways, lateral and vertical placement procedures are essentially the same as those regularly employed along the roadway.

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[1] The City of Davis had earlier tried the symbols "BIKE LANE" and found that motorists did not interpret them as excluding motorized traffic.

On Class I bikeways neither mud splattering nor damage due to automobile collisions (the bane of signs along motorized routes) are probable. Signs may thus be located considerably closer to the edge of the bikeway than to an automobile lane. Such positioning will place the sign closer to the center of the cyclists' visual field, and hence be more desirable in terms of improved visibility. Both Swedish (23) and Canadian[1] standards for such placement specify a 3 foot lateral displacement; Dutch (35) standards call for 2 feet; and, German (26) standards require only one foot between the edge of the bikeway and the nearest edge of the sign.

The vertical placement of the sign is also vital to its efficacy. The eye height of an average adult is considerably higher from the ground when seated astride a bicycle than in an automobile. However, automobile signs already are placed above 7 feet in order to reduce the likelihood of pedestrians striking their heads on them. Both Dutch and Canadian bikeway standards specify a 7 foot distance from the lower edge of the plaque to the ground. Such a standard appears appropriate in Class II and III designs. Slightly lower vertical clearance may be desirable on Class I bikeways since the sign is positioned outside of the edge of the bikeway. A current practice of placing signs one atop the other on a single post, rising to heights of 12 or more feet is not recommended, however, even though the cyclist is seated higher than his auto-driving counterpart, and does not have an upper limit (the windshield area) to limit his field of view.

The use of overhead signs presents another alternative for Class II and III bikeways. Although positioned higher than ordinary ground mounted signs, they are directly ahead of the cyclist and well within his visual field. Such installations require a minimum 8.2 foot clearance, from the lower edge of the sign to the bikeway. However, in order to ensure their proper visibility, frequent trimming of overhanging trees is necessary. The

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[1] National Capital Commission, <u>Typical Signing Plan for Bicycle Path at Street Crossing</u>, Standard Drawing 3459-E26, Project Design Agency, Ottawa, Canada, June 1971.

overhead sign is particularly recommended for establishing rights-of-way on Class II sidewalk alternatives. In such situations it is one of the most effective means for reducing confusion and improving the safety of both cyclist and pedestrian users.

3.10.5 BIKEWAY SIGNING STRATEGY

The foregoing has delineated general specifications for standard signs and pavement messages directed to motorists, pedestrians and bicyclists. Implementation of a bikeway or bikeway-route signing strategy, however, requires a global orientation towards the bikeway as an element of the total transportation system, both in its own right and in conjunction with other modes of traffic. Viewed from this perspective, the issue of signing is not one of isolated posts or markings conforming to the above specifications, but of an integrated system of traffic control devices throughout the entire bikeway route system.

Clearly, conditions on a bikeway vary along its length. These include singularly unique physical features of both the route itself, and the surrounding area. Thus grades, width, intersections with other streets, to cite a few examples, may vary from one bikeway to the next. And adjacent land usage may vary from open space to single family residences, to schools, to shopping centers, to downtown commercial districts, etc. These myriad features impose quite different demands on both the cyclist negotiating the route and other traffic either sharing or in close proximity to the bikeway. Since signing is essentially an information transferring process whereby the vehicle operator is informed of hazards, directions, and/or various road conditions, wide variations in these features necessitate comparable diversity in signing procedures. Therefore, although "typical" route signing procedures may be defined these should not be applied blanket-wise to all situations. In the final analysis signing for each proposed bikeway and/or bikeway route must be determined for the specific conditions involved. However, certain procedural guidelines can be set down depending upon the class of the bikeway and the particular route segment that is to be signed.

3.10.6 SIGN SPACING

Along the major portion of the bikeway route, the spacing between signs should follow the recommendations in the Manual for Uniform Traffic Control Devices (65) which states that spacing "be determined in units of time as determined by the expected vehicle approach speed." Since unconstrained bicycle speeds on level grades average 10 mph, as compared with over 30 mph for motor vehicles on surface streets, it is urged that guide signs which relate specifically to cyclists be more closely spaced than comparable signs required for automobile traffic. For a 10 mph bikeway design speed a minimum of 10, and possibly as many as 20 signs per mile in each direction could be required (19). Sign locations would depend upon the nature of the bikeway route, conflicting paths that are encountered, and other decision points. The following sections discuss certain of these situations, and recommend general considerations for use in signing.

3.10.7 POSITIONING OF WARNING SIGNS

On Class II and III bikeways existing warning signs can generally be applied to both bicyclists and motorists. Frequently, however, these are not sufficient to meet the bicyclists' needs. While certain surface conditions (including storm drains, gratings, and surface irregularities) may be harmless to a motorist, they represent significant hazards to the cyclist. Thus, additional signs directed solely toward the bicycle user may be required along the bikeway.

On Class I bikeways, all warning signs must be positioned to meet bicyclists' requirements. These requirements depend, first of all, on whether the cyclist must come to a complete stop or merely slow down. In order to sign for the most extreme case, it is recommended that warning signs be positioned a minimum of 50 feet in advance of the hazardous condition. This criterion allows for a 1.5 second reaction and interpretation time lag, followed by a single-wheeled braking to a panic stop of a 120 pound rider travelling at 15 mph on dry asphalt. (22). Daytime visibility and sign legibility would provide a safety margin, depending on how far in advance of the sign the cyclist could read and comprehend it. However, the reduction in visibility at night and during poor weather calls for conservative standards such as those recommended.

The placement of warning signs directed toward the motorist should conform to standard roadway practices. In urban areas it is suggested that the "Bike Xing" sign be positioned approximately 1/2 block before the bikeway crosses the roadway. This is comparable to existing practice relating to the "Ped Xing" sign. Additional signs such as "Watch for Bikes" appear suited to variable placement according to engineering judgment.

All signs directed toward the motorist should be reflectorized for adequate nighttime visibility. The illumination of bicycle-directed signs on Class I, II, or III bikeways will be required as the situation demands, depending upon the degree of hazard to which the sign refers, the amount of anticipated nighttime usage, and the adequacy of existing illumination.

3.10.8 BIKEWAY ORIGIN AND TERMINATION

In order to inform the bicyclist of the origin and terminus of a bikeway, a combination of the standard "Bike Route" sign with an above-mounted supplemental "Begin" or "End" plaque should be used. However, since it appears highly unlikely that the motorist will adequately respond to this rather small (24" x 18") guide sign, it is recommended that warning signs including "Bike Xing" (W11-1R), and "Watch for Bikes" (discussed above) be positioned to warn motorists that bikes may be encountered. On Class I bikeways a "Stop" (R1-2) or "Yield" sign may also be necessary to encourage greater caution among cyclists exiting from the bikeway.

In addition, it is recommended that not one, but several signs direct cyclists to the bikeway. As illustrated in Figure 3.10.1, "Begin Bike Route," with supplementary directional arrow should be positioned at appropriate locations near the origin of a Class I bikeway. Figure 3.10.2 sets forth comparable criteria for Class II or III bikeways.

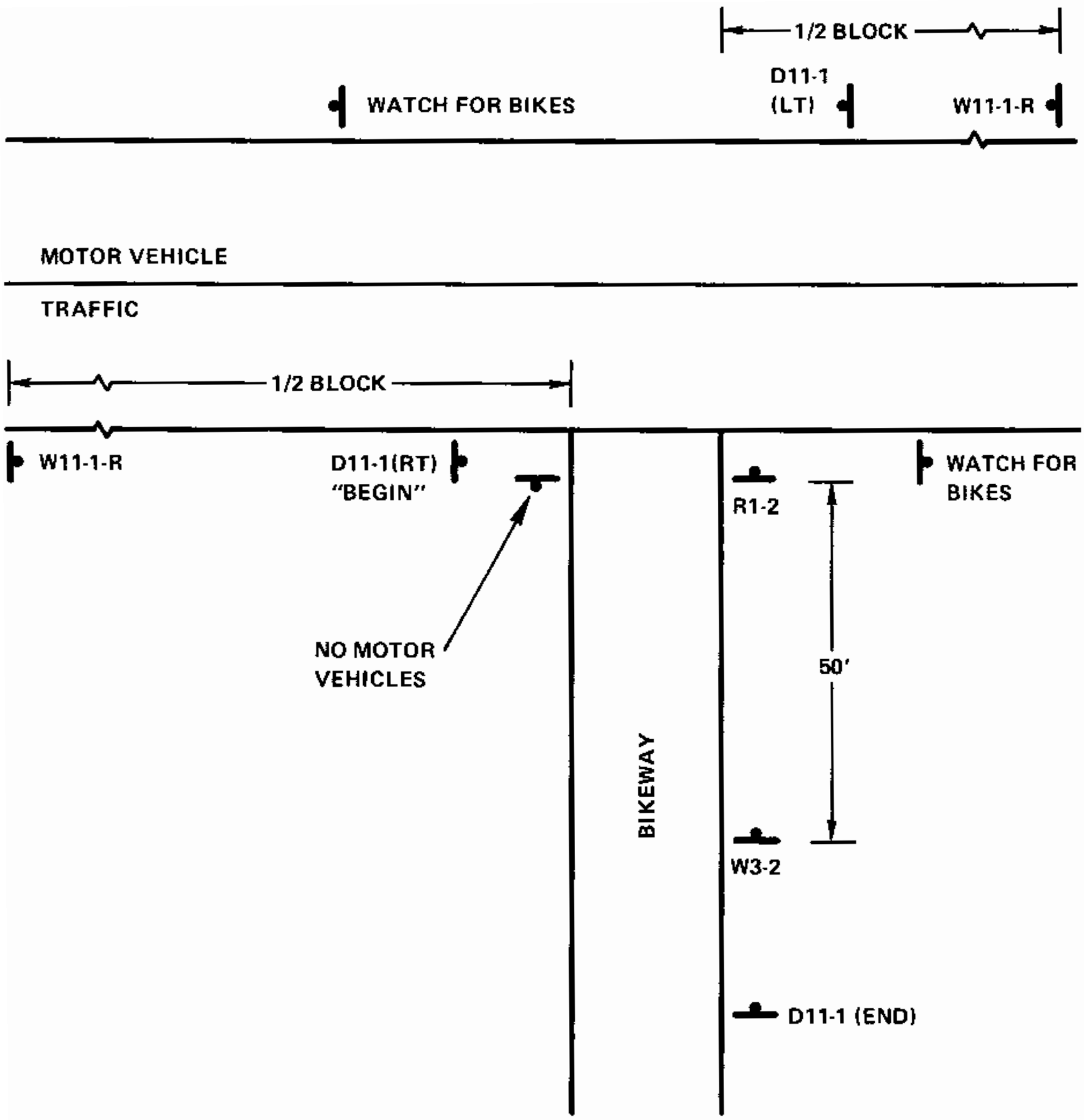

Figure 3.10.1. Signing Plan for the Beginning and Ending of a Class I Bikeway

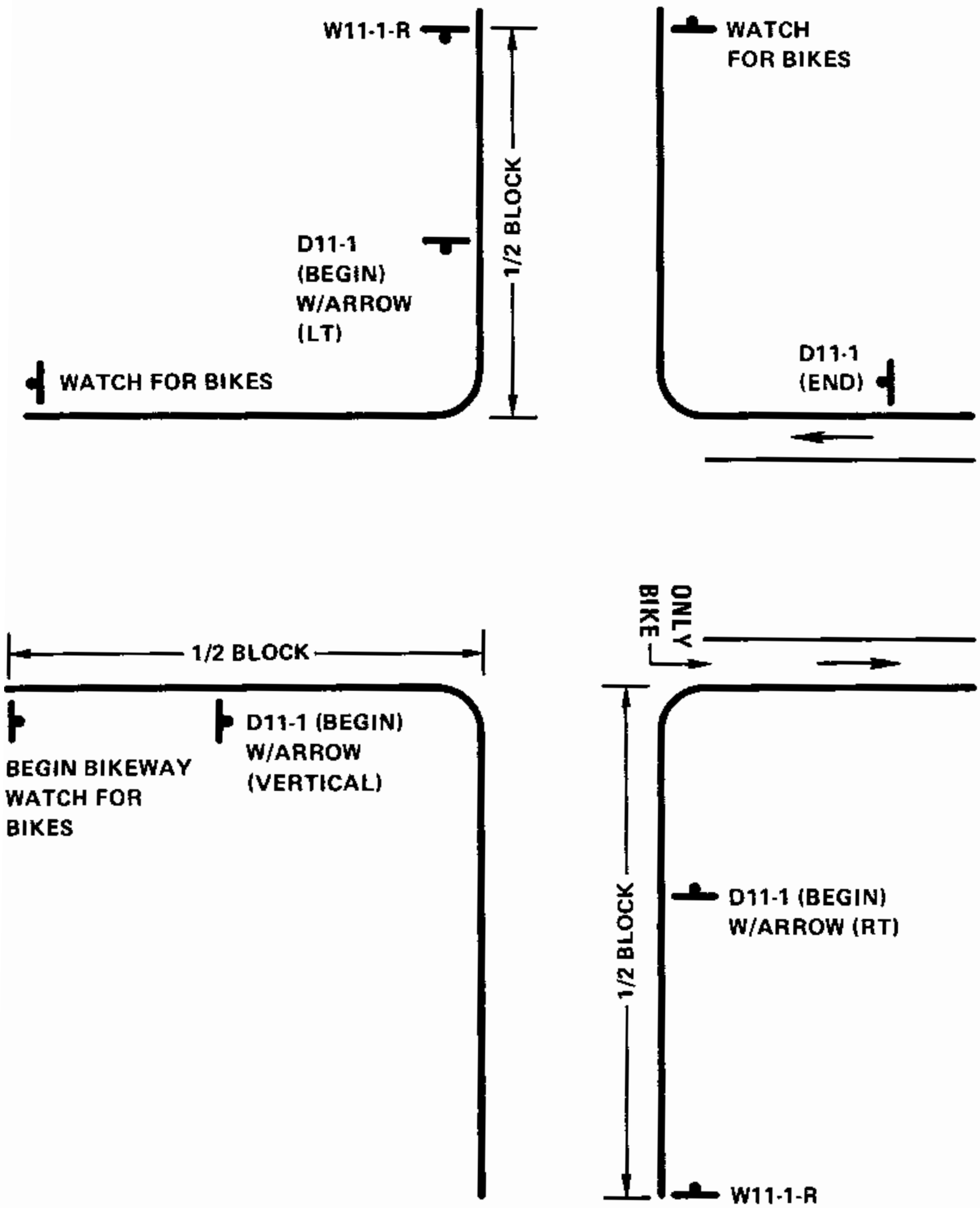

Figure 3.10.2. Signing Plan for the Beginning and End of a Class II Bikeway

3.10.9 INTERSECTION SIGNING

In urban areas "Bike Route" guide signs should generally be positioned at every intersection.[1] Figure 3.10.3 illustrates such a procedure for a relatively small intersection where there is no obstruction of vision from one side of the street to the other. In such cases placing the "Bike Route" (D11-1) sign at the far side of the intersection permits it to serve a dual purpose. In addition to its usual role of designating the bikeway, it takes on the added function of confirming the route's unchanged direction following the intersection. The exact placement of the sign is, however, variable. Since it must be visible to bicyclists approaching the intersection, the sign should be located not more than 20 feet from the far corner of an 80 foot right-of-way. This criterion allows for a 125 foot legibility distance and 0.75 second reading time for the 3" high Series C letters used on the standard sign. Moreover, a variable location encourages the use of existing posts for mounting the sign, which in turn reduces overall cost.

Bikeways crossing relatively large intersections, or those for which the view is restricted (perhaps due to a sharp curve in the street immediately before or after the intersection, or the angle of the crossing itself), require additional signs. Degraded visibility necessitates a guide sign before (with no specific positioning specifications), as well as a confirmatory one after the intersection. Although confirmatory signs are usually posted 10-80 feet from the far corner, a range of perhaps 10-50 feet is considered adequate for the slower moving bicyclist.

The "Bike Xing," sign (W11-1-R) is requisite to all situations in which a bikeway crosses another right-of-way. "Bike Only" pavement markings provide an additional supplement to posted signs. They may be particularly useful at intersections to insure that right-turning motorists

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[1] However, should the surrounding land use be such that the route's straight continuation is readily apparent, signing may be slightly less frequent.

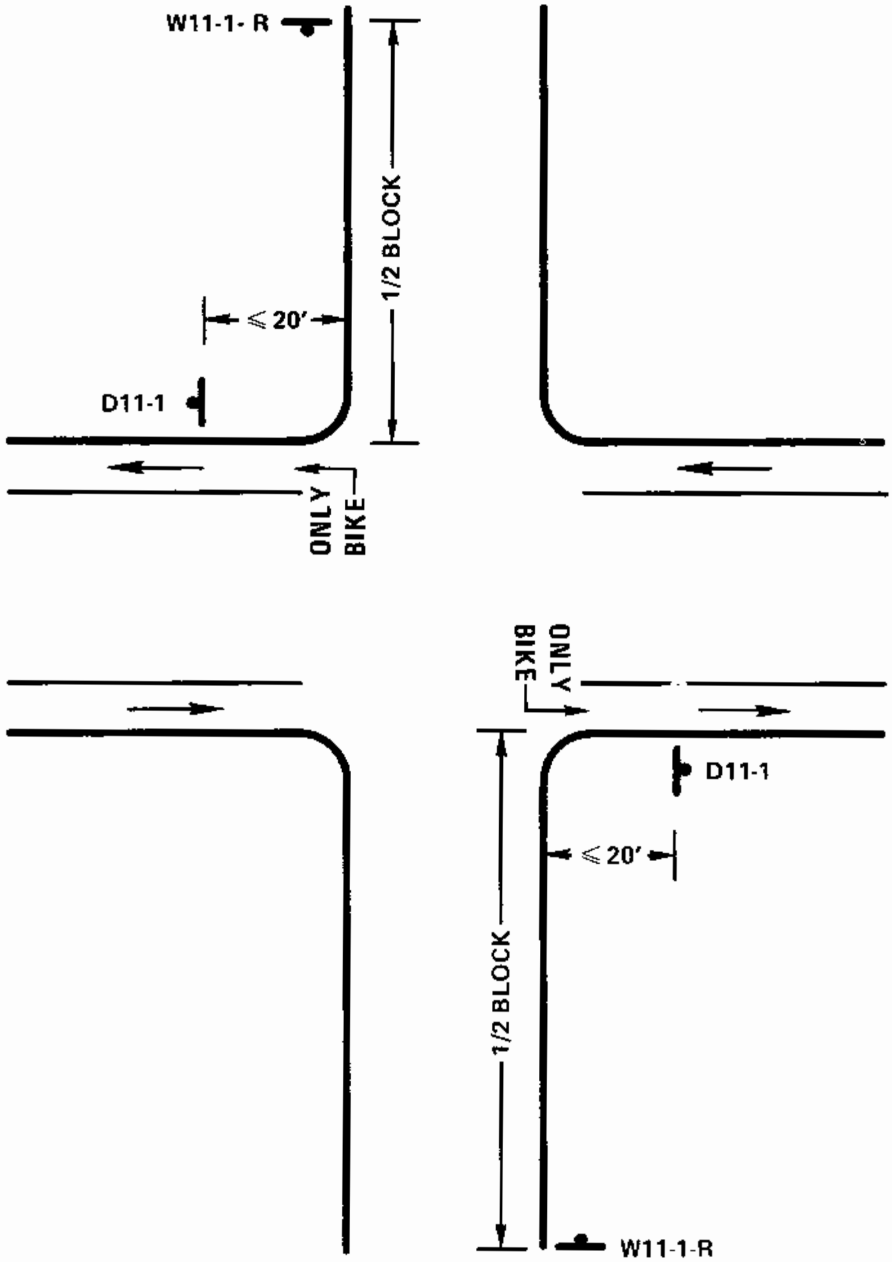

Figure 3.10.3. Intersection Signing Plan: Class II Bikeway Crossing a Non-Bikeway Street

do not stray into the bikeway. Normal layout for these markings begins at channelized entrances to the bikeway.

Figure 3.10.4 illustrates a difficult signing problem. When two Class II bikeways cross at an intersection, it is difficult to adequately convey to the cyclist the directional alternatives open to him. Since 3-headed arrows are not only bulky, but oftentimes confusing, 2 separate signs may be necessary. The first, delineating the crossing bikeway by means of a double arrow should be positioned before the intersection, while the second, designating the continuing route (perhaps with an additional vertically mounted arrow for emphasis) should be located as close as possible to the far corner. However, this solution presents added difficulty at those intersections with poor visibility, and for this reason necessitates further study.

3.10.10 ESTABLISHING RIGHTS-OF-WAY ON CLASS II OR III SIDEWALK ALTERNATIVES

If a bikeway segment is intended to accommodate significant amounts of both bicycle and pedestrian traffic, some method of mode separation will be necessary to delineate rights-of-way. Signs, pavement markings and lane striping may all be used for this purpose. Although careful study of each situation will reveal different requirements and thus a diversity of "optimal" sign strategies, a combination of signs and lane striping generally appears most effective both in terms of improved visibility and safety. Several countries including Sweden, Germany, Japan and the Netherlands have incorporated this approach into their bikeway signing. Utilizing overhead signs with separate bicycle and pedestrian symbols, this procedure clearly and distinctly specifies the usage permitted on either side of the lane stripe. Downward pointing arrows may also be employed to further emphasize the demarcation and lane assignment.

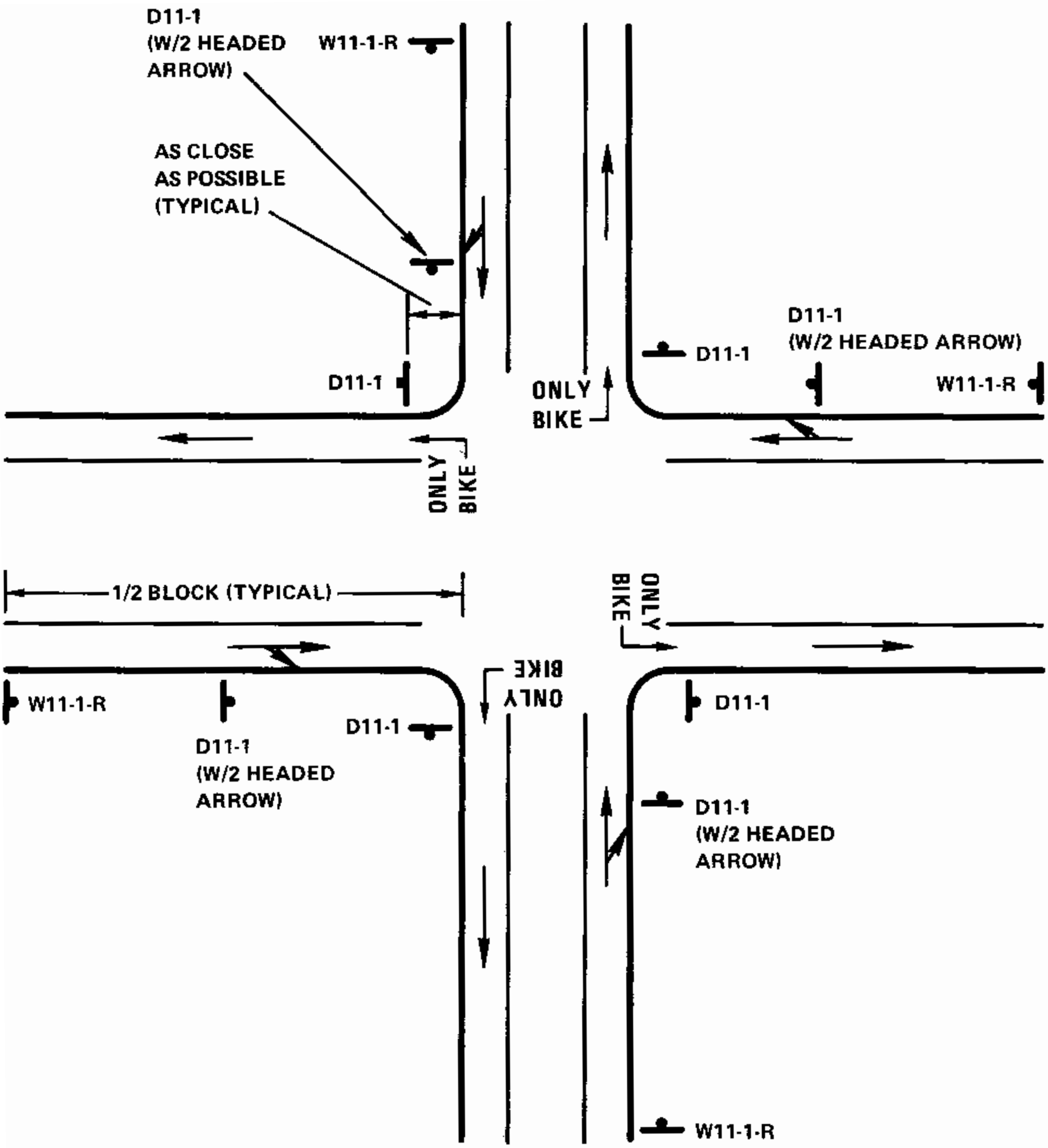

Figure 3.10.4 Intersection Signing Plan: Two Class II Bikeways Cross at a Road Intersection

3.10.11 DESIGNATION OF BICYCLE PARKING FACILITIES

Since bicycles propped against available stationary objects (including buildings, posts, and trees) may constitute a serious detriment to both movement and safety, improved bicycle parking facilities are highly recommended. (See Section 4.4, "Bicycle Parking"). In order to encourage greater usage of these facilities, signing will be necessary to inform the bicyclist of their location. The international parking symbol, coupled with a bike design has been used in Switzerland for this purpose (11). Such a sign, positioned at the side of the bikeway and indicating those points where bike parking is available, is highly recommended for all classes of bikeways. An arrow or other directional supplement to show precisely where the facilities are located would also be desirable.

3.10.12 CONCLUSIONS REGARDING BIKEWAY SIGNING

Based upon the foregoing discussions, the following conclusions are drawn:

1. Adequate signing is necessary at all decision points along the bikeway. These include:

   (a) Signs informing the cyclist of upcoming directional changes.

   (b) Confirmatory signs to insure that route direction has been accurately comprehended.

2. Route or guide signing must be provided at regular intervals in order that:

   (a) Newcomers to the route know that they are travelling on an officially designated bikeway.

   (b) Cyclists already on the bikeway, especially in Class III, do not stray from it and lose their way.

3. Warning signs informing motorists that bikes may be encountered should be positioned:

(a) Whenever a bikeway crosses the roadway,

(b) When a bikeway either begins or ends,

(c) At any other points where large numbers of bikes may be expected. (e.g., parks, schools, recreational facilities).

4. In urban areas, motorist-directed warning signs should be positioned a minimum of one-half block before bikes may be encountered.

5. Warning signs informing bicyclists of potential hazards require the following specifications:

(a) Along Class II and III bikeways, signs directed toward the motorist may also aid the cyclist. Little, if any, modification of existing procedures is necessary in such cases.

(b) Along Class I bikeways and for all hazardous conditions on Class II or III bikeways for which there are no existing signs specific bicycle-directed warning signs should be erected. In order to provide sufficient response time, these should be positioned not less than 50 feet in advance of the condition toward which they are directed.

6. As an aid in uniformity, speed, and accuracy of comprehension, standard signs are recommended. Localities now having bikeways with non-standard signs are urged to gradually convert to those specified in the Manual on Uniform Traffic Control Devices, while those communities contemplating future bikeways are encouraged to invest in standard signs.

7. Stencilled pavement messages consisting of the standard "Bike Route" design are generally not recommended for use on Class II or III bikeways, with the possible exception of Class II sidewalk alternatives.

However, the "BIKE ONLY" stencil with 4 foot high reflective letters is recommended as a useful supplement to prevent turning or straight through motorists from entering a Class I or II bikeway.

8. Since certain situations along the bikeway are not amenable to presently standardized signs, it is recommended that additional study be given to several possible improvements, including "No Motor Vehicles," "Begin" or "End Bike Route," "Watch for Bikes," and "Bike Parking."

9. In studying the modification of existing signs and possible adoption of new ones, the need for uniformity cannot be over-stressed. This extends to route terminology as well as standardization. If a single nomenclature such as "bikeway" is adopted, then uniform signs and markings should incorporate this standard term into their design. Thus the "Bike Route" sign may be restricted solely to Class III facilities which afford minimal protection to cyclists, while the sign "Bikeway Route" be restricted to those routes which contain predominantly Class I and Class II sections. Table 3.10.1 summarizes the bikeway signing recommendations.

3.11 BIKEWAY LIGHTING

Adequate lighting is prerequisite to the safe operation of any bikeway for which considerable nighttime usage is anticipated. Specifically, lighting provides information concerning the demarcation and direction of the bikeway, its surface condition, and the presence of obstacles including pedestrians, other vehicles, and fixed objects, whether stationary or in motion.

Bicycles do not have headlights adequate to illuminate the bikeway at speeds in excess of 3 mph, (walking speed); therefore, the bikeway must be illuminated from fixed luminaires. These luminaires must not only light the path, they also must reveal the presence of the bicyclist. Therefore, luminaires must be mounted high enough to shed light on the bicyclist, i.e., at least 10 feet.

TABLE 3.10.1 SUMMARY OF BIKEWAY SIGNING RECOMMENDATIONS

	CLASS I	CLASS II	CLASS III
Lateral Placement	1-3 ft. from edge	Roadway criteria	Roadway criteria
Vertical placement	7 ft.	7 ft.	7 ft.
Positioning before hazards	50 ft.	not less than 50 ft.	not less than 50 ft.
Sign Spacing	At all decision points	10-20/mile	10-20/mile
Sign Message	Standard	Standard	Standard
Sign Illumination	If considerable night usage, must be illuminated	Roadway criteria	Roadway criteria
Sign Size:			
a. Route	Standard	Standard	Standard
b. Warning	May be less than standard	Standard	Standard
Overhead Signs: Clearance	8.2 ft.	8.2 ft.	Not recommended
Stencilled Warnings - Size and Use:			
a. "BIKE ROUTE" (D11-1)	24" x 18"	Recommended for sidewalk use only (24" x 18")	Recommended for sidewalk use only (24" x 18")
b. Bicycle symbol	-	3.5 x 7.0 ft.	3.5 x 7.0 ft.
c. "BIKEWAY" (lettered)	size to be determined	size to be determined	size to be determined
d. "BIKE ONLY" (lettered)	6.0 x 31.0 ft. (Total)	6.0 x 31.0 ft. (Total)	-
Additional Signs:			
a. "NO MOTOR VEHICLES" (wht)	Rectangular 24" x 18"	Rectangular 24" x 18"	
b. "WATCH FOR BIKES" (Yel)	-	Diamond 30" x 30"	Diamond 30" x 30"
c. "BEGIN, END BIKE ROUTE" (Grn)	Standard	Standard	Standard

NOTE:
- Indicates designation is not generally recommended.

3.11.1 METHODS OF DISCERNMENT

In general, bikeway lighting may incorporate either of two methods of discernment. If the light sources or illuminated surfaces are positioned behind an object, the object is seen in silhouette. The illumination of bicycle crossings is an especially salient case for which silhouette lighting should be employed. This will be discussed further in a latter part of this section.

The second method of discernment, reverse silhouette, pertains to objects whose brightness or reflected brightness is greater than that of the immediate background. On the bikeway, a cyclist's bike headlight and rear reflector may emit or reflect sufficient light to be discerned in this manner by an approaching motorist, provided that the two vehicles are travelling as points along the same line. This would not hold true when motorist and bicyclist approach from different directions, as at a bicycle crossing. Similarly, bicyclists may not be revealed to each other unless exterior illumination is provided.

3.11.2 VARIABLES AFFECTING BIKEWAY LIGHTING

Many variables affect the type, strength and continuity of lighting required along roadways. Although such considerations are commonly incorporated into roadway lighting procedures, no comparable study has been addressed to how these factors affect bikeway illumination requirements.

Some of these variables are:

1. The nature of land use abutting the right-of-way. This includes rural/urban differences as well as strict residential/commercial/industrial distinctions. The extent of night usage by both cyclist and motorist would appear to be related to the adjacent land use. For example, bikeways running through industrial areas may have little night usage, while those in residential or commercial areas might be highly travelled during the early nighttime hours.

2. Night accident records - Based upon the type, frequency, and severity of nighttime accidents involving the bicycle, continuous illumination may be more or less necessary and would relate to all three classes of bikeways.

3. Night street crime experience and security requirements - The extent to which roadway illumination tends to reduce the incidence of crime may be debated. However, the relationship itself is widely accepted, and appears directly applicable to all bikeways, and especially the Class I type. Should the incidence of robberies, muggings or other street crimes be significant, improved illumination on bikeways would definitely be in order to protect users.

4. Type, speed and turning movements of vehicles at night - If the illumination of the bikeway is such that dark spots are present where vehicles are negotiating curves, turns, or other directional changes, serious safety hazards may ensue. This pertains to bicycles as well as motor vehicles. If the vehicle operator is making a turn while travelling at a high speed (as with a bicyclist on a downgrade), the possibility of an accident is greatly increased with insufficient and/or "patchy" illumination that does not provide continuous delineation of the bikeway alignment. Because bicycle headlights are so weak, it is not practical on Class I bikeways to use reflectorized delineators such as used on highways.

5. Roadway construction features - These include:

a) Pavement width and surface character.

b) Presence of grades and curves.

c) Location and width of curbs, sidewalks and shoulders.

d) Type and frequency of access locations.

e) Intersections.

f) Other potentially hazardous conditions, including storm drains, drainage gratings, and the location of ramped curbs at those points where the bikeway (Class II or III) is channeled onto the sidewalk.

All these features present added considerations in the selection of an appropriate lighting configuration. Generally, Class II and III bikeways would utilize existing roadway illumination, and although this may be adequate for most situations along the route, additional lighting may be required. Based upon the foregoing considerations it is recommended that additional lighting be provided along Class II and III bikeways when existing facilities inadequately illuminate surface characteristics which are potentially dangerous to the cyclist. In addition, fixed obstacles such as storm drains and gratings, and route features (including the location of ramped curbs, sidewalks and crossings) must be adequately illuminated if nighttime use of the facility is anticipated.

For Class I bikeways all the preceding variables must be considered in the determination of the degree of illumination required. To date very little work has been directed towards this question. Hopefully, the preceding list of considerations will provide a basis for additional study.

3.11.3 LUMINAIRE CHARACTERISTICS

For Class II and III bikeways, standard luminaire characteristics are employed. Should criteria for Class I bikeways be developed, the following range of conditions must be specified:

a) Luminaire mounting height, transverse (overhang) location, and longitudinal spacing.
b) The overall arrangement of luminaires.
c) The percentage of lamp light directed toward the pavement and adjacent areas as a function of the reflective characteristics of the bikeway surface and surrounding area.
d) The most economical light source to be used, as determined by initial and maintained lumen output per watt, length of service, and general lamp costs.

e) The maintained efficiency of the system.

3.11.4 ILLUMINATION REQUIREMENTS AT BIKEWAY CROSSINGS

Bikeway crossings represent probably the sole exception to the general lack of criteria regarding bikeway illumination requirements. The Dutch (35) have studied this area and conclude that back lighting (silohuette type) is indispensable for all bikeway crossings. Moreover, inherent features of the bicycle itself (in particular its lack of visibility when viewed from the side), as well as the surface distributions of various luminaire configurations, require considerable attention. If inadequately located, blind spots will reduce the likelihood of motorists and other traffic clearly viewing the bicyclist. In addition, the cyclist passing under poorly placed lights may experience a false sense of security and think himself visible to oncoming traffic. Thus, both motorist and bicyclist, inadequately informed of road and traffic conditions, may fail to exercise sufficient caution.

As a general rule, for isolated bikeway crossings, the following recommendations can be made:

1. Transition illumination should be provided on the bikeway not less than 330 feet on either side of the crossing. This allows 15 seconds for a bicyclist travelling at 15 mph to adequately adjust to light conditions of one-half the strength of that present at the crossing. Depending upon the roadway (major, minor or collector) and area classifications (downtown, intermediate or rural), crossing luminance should be between 0.2 foot-candles for rural minor roadways to 2.0 foot-candles on a downtown major roadway. Gradually decreasing the illumination by one-half for each additional 15 seconds of travel as recommended by the Illumination Engineers Society, (IES), (33) thus establishes a direct relationship between the degree of illumination present at the crossing, and the extent of transition lighting required on both approach and departure paths of the bikeway;

similar transition lighting, however, based on motor vehicle speeds, should be provided on the roadway as well.

2. Luminaires should be asymmetrically positioned, shaded and broad beamed. Proper positioning is necessary to ensure sufficient illumination of the entire crossing and the elimination of possible blind spots.

3. At the crossing, roadway illumination should be not less than 0.3 foot-candles (35). Although this criterion is safely below that recommended by the IES for most urban roadways, increased lighting may be required for crossings on rural minor roads.

4. All bikeway crossings should be further delineated by painted markings, reflectorized to improve their nighttime visibility to motorists.

3.11.5 CONCLUSION REGARDING LIGHTING

Systematic research to determine the illumination requirements along all classes of bikeways has been exceedingly rare. Because bicycle requirements differ from those of motor vehicles, Class II and III bikeways, generally designed to utilize existing light installations, may be inadequate for bicyclists. Certain considerations pertaining to both the improvement of these facilities and the assessment of requirements along Class I bikeways have been presented. Additional study to determine the weight to be accorded to these various factors is recommended.

CHAPTER FOUR
SPECIAL TOPICS

4.1 BIKEWAY PLANNING CONSIDERATIONS

The planners of bikeways for existing and especially future communities must consider that bicycle movement is part of the larger transportation system, and therefore should be planned and designed to reflect this relationship. Realization that the bikeway is a related element in a many faceted transportation system relates the bikeway to such important factors as mixed-mode travel which implies providing planned options for combination with auto, train, walking and bus facilities. These interfaces as well as the present and future relation of the bikeway to other systems of travel should be considered not only in long range plans but also in short term planning of bikeways for areas where immediate action must be taken.

4.1.1 FLEXIBILITY

When land use and demand changes occur after a bikeway system has been established, appropriate adaptations to accommodate the changes will be necessitated. These may range from realignment of the bikeway to its complete removal.

The more separated the bikeway is from the abutting or associated land use, the less it will be affected by land use changes. Class I bikeways entirely independent of the roadway are best planned where the need will be permanent. To account for changes in traffic load along the existing bikeway, projections of density within the current zoning should be determined. For example, a vacant commercially zoned area between two already existing commercial building areas should have an associated bikeway segment that reflects the area's probable future use rather than its present vacant use. Therefore, it is probable that a bikeway going through a given area might be composed of several segments, each of a different capacity or design that would accomodate future as well as present use demands and land use changes.

The second consideration involves the adaptability of the bikeway for realignment. A Class III bikeway marked by signs alone provides the most adaptability in such a situation, for the sign can be removed and used elsewhere. Using painted lanes is slightly less flexible in an area where land use change is probable. Still more inflexible are physical barriers and separated roadways, which require still more effort to reconvert or transform to cope with a change in land use or demand.

4.1.2 DENSITY PATTERNS

Some models of accessibility and population density predict that as the travel time from residence location to work location increases, the numbers of persons living at that distance decreases. Clark and others[1] have done empirical work to derive the functional relationships between residential and work locations and have found that population density appears to decrease exponentially from the city centers. Implications of this model for bicycle usage are strong.

For trips shorter than two miles the bicycle may have definite advantages over other forms of transportation as far as the travel time is concerned. As the trip length increases, the bicycle soon loses this advantage.[2] In this respect, general usage of the bicylce for commuter trips implies that the distance between home and work must remain small (say 3 miles or less). Accessibility will therefore indicate that if there

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[1]There has been much work on accessibility models. See, for instance, Ira S. Lowry, Seven Models of Urban Development: A Structural Comparison, Rand Report P-3673, (Santa Monica, Calif., 1967), or the several articles on urban models presented in the May 1965 edition of the American Institute of Planners Journal.

[2]Mixed -mode travel is considered in section 4.5.

is a marked increase in population density and more people can live closer to where they work, the bicycle may become a popular form of commuting transportation. This discussion, of course, applies to only the larger cities where at present most home to work trips exceed optimal bicycle riding distances. The marked trend to increased rates of change of residence and the boom in trailer homes both indicate an increased likelihood that more people will be living closer to their place of work.

4.1.3 LOCATION CRITERIA WITH RESPECT TO LAND USE

Plans for location of bikeways can be generated in the same general manner as plans for highways. However, since the cyclist is very sensitive to minor changes in grade, route length, environmental quality, and congestion, the planning of the route must be done with particular care for the unique demands of the bicycle user. The following seven criteria for determining bikeway route location with respect to land use have been extracted from many individual cities' reports and correspondence to the project regarding their bikeways and bike routes.[1, 2, 3, 4]

1. Information should be collected concerning other existing bikeways, both legally designated and user designated, and any proposed bikeways in the region, (especially important in metropolitan areas with adjacent autonomous communities). Planners should be cognizant of both existing and proposed bikeways, and efforts should be made to integrate the bikeway segments into a unified system.

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[1] References(8,15,19, 27, 32, 38, 48, 57, 62)

[2] Sacramento Region, Bikeway Action Committee, Bikeways, Sacramento Region, (no date), 10pp.

[3] City of Stockton, California, Bicycle Report, by the City of Stockton Public Works Dept., Planning Dept. and Police Dept., (no date), 17pp.

[4] Ltr to Dr. Slade Hulbert, ITTE, UCLA, from Floyd Enloe, Superintendent of Parks and Golf Courses, City of Palm Springs, Oct. 18, 1971.

2. Although demand data, both present and projected, is imperfect and difficult to obtain, it is necessary in determining both locations and types of bikeways. Origin-destination (O-D) data must be collected to give the decision maker an idea of where the users are coming from, where they are going, and how many there are. Use of O-D surveys and traffic counts are valuable here and are most accurate when used to describe only the present actual trips made. Projections and predictions are extremely difficult. This, and additional material on demand is discussed in detail in Section 4.6.

3. Scenic features, both natural and manmade, should be exploited if at all feasible. Consideration of some recent work on the perception of the urban user could significantly influence the quality of this aspect of bikeways. Bikeways with a good view of a skyline, a park, an historic monument, or a plaza, if economically feasible, should be considered.

4. Consideration of the different trip types is important, e.g. journey-to-work paths might be located in closer conjunction with arterials than would school-trip bikeways whose use would occur at different times of day and day of the week.

5. Future projected uses of the land is probably one of the most important criteria for the decision maker, because in allocating land resources for bikepaths the decision maker excludes this land from other use. Consideration of future projections of land use might lead the decision maker to include some areas in the bikeway system and exclude others. Projection data is helpful in determining location, as well as type of bikeway.

6. The bikeway should be compatible with the adjacent land use of the segment. For example, if heavy pedestrian traffic is a characteristic of the sidewalk of a shopping area, the separation of the cyclist from the pedestrian is important. A bikeway through a natural park area

should not be environmentally incongrous; that is, it should not create barriers (with fences), or be artificially raised or be laid out with only the shortest route or smallest grades in mind, which would ignore the natural landscape or topography. A bikeway through a residential or commercial area should also not be aesthetically incongruous. It should be placed and constructed so as to provide a smooth flow through the area, while at the same time not presenting an overt barrier to the pedestrian.

Therefore, the arrangement of the particular segments of the bikeway should give attention to the characteristics and ecology of the adjacent land uses, so as to make the bicycle an integral part of and not an intrusion on the existing use pattern.

To aid in locating a bikeway route, an overlay method could well be used. In such a method transparent sheets, each colored to represent a particular factor, (e.g. existing street lighting or scenic views) are laid over each other to illustrate their suitability. The patterns of highest and lowest suitability with respect to the factor considered would then show through and the necessary alterations and additions could be made. This is an excellent graphical method for visualizing the interaction of multi-factor location criteria, and has been successfully used to aid in highway design,(41, pg. 31-41).

4.1.4 IMAGEABILITY

In order to achieve maximum usage and enjoyment by the users, bikeways should be planned so that they are "imageable" and pass through an "imageable" environment wherever possible. Lynch, (39), explains that "imageable" environments are ones which remain as vivid memories even after short exposure. Although there are no set characteristics for a facility or an area to qualify as being imageable, it is known that some areas with a confusing array of streets and monotonous skylines are not easily cognized by the average person. Lynch's analysis was extended to road systems by Appleyard, Lynch and Myer, (3), and it does not seem inappropriate to suggest that bikeways, to a lesser degree, can be subject to the same type of consideration.

It is generally conceded that finding one's way through a city should be more of a pleasurable experience than an ordeal. For the typical cyclist, the bikeway designer must be concerned with both distance perception and orientation of the cyclist. As an example, a bikeway should not wind indiscriminately through bland areas of the city where major landmarks are not clearly visible.

Not only should Class I bikeways be located in particularly scenic areas, but if possible, Class II bikeways should be located in particularly imageable areas, as well. This type of location is important to both the casual cyclists who appreciate the imageability and to the commuter or frequent rider who desires the added variety thus afforded.

4.2 COMMUNITY PARTICIPATION IN BIKEWAY ROUTE PLANNING

4.2.1 HISTORY OF PARTICIPATION

Early in 1962 a couple from Homestead, Florida, Mr. and Mrs. George Fichter, had their efforts rewarded as the first bikeway system in the United States was dedicated.[1] Since then countless concerned citizens and bicycle riding groups have pushed for bike path systems in their own cities, lobbying their local governments for safer bicycle routes for themselves and their children.

The efforts of cyclists pressing for safer bicycle routes have taken many different directions. For example, the American Society of Civil Engineers Student Chapter at the University of Hawaii, (2) and the Palos Verdes Peninsula Bikeways Committee (47), each produced reports on the feasibility of bike paths which rival in quality similar reports produced by the governments of our largest cities. "Bike-ins," have been

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[1]Bicycle Institute of America, Bikeways, The Homestead Story, (no date), 8pp.

held in scores of cities throughout the country to draw attention to the need for better and more bicycle paths, (34).

John Auerbach, Executive Director of the B.I.A., at the National Symposium on Trails strongly reiterated the role of citizen participation in the planning of bike route systems. Noting the community efforts with some of the earliest developed bicycle path systems, he stated, "the Pasadena and Coral Gables Bikeways... were the result of the dedicated and herculean efforts of local housewives who galvanized support from local service clubs, and cajoled and bullied local officials into a state of numbed acquiescence." (64, p. 27).

The various city governments planning to implement suggestions for bikeways have an abundance of persons willing to help with the overall process. Southern California, for example, boasts over two dozen bicycle clubs (10) whose memberships have many concerned adults. And, on the national scale, the League of American Wheelmen and the Bicycle Institute of American stand ready to assist local communities in formulating bike route plans.

With such a strong history of community participation in the bikeway movement it seems particularly incongruous that the feasibility studies produced by the various cities show a conspicuous lack of community input. The planning of a bikeway system seems just the proper place to effectively use community participation in the plan formulation. Yet this appears not to have been done to any significant degree by the various cities or at least the written reports do not reflect such community participation.

4.2.2 TECHNIQUES FOR ASSESSING IMPACTS

Community participation in bikeway planning should not end simply because citizens finally aroused their local governments to act. Rather, it should be a standard procedure of planners to seek community aid in formulating even the finest details of the proposed bikeway. In a recent report developed at the Urban Systems Laboratory of M.I.T. (40), newly described planning principles are applied to the problem of the impacts of new highways upon environmental values. Although the investigators describe the planning process for highway design, their formulation is sufficiently general to apply to bikeway system design, as well.

It was found that environmental impacts of highway location could not be properly assessed without the formal input of all concerned interest groups (40). As different route locations are decided upon, community opinion must be obtained in a systematic manner. All alternatives, including the alternative of not locating the highway at all, should be analyzed to determine relative impacts. This general procedure is firmly based on the recent work of various planning theorists who have found that plans can only be formulated properly with the extensive help of the citizens of the community.

In the report, a formalized structure was presented for dealing with problems of highway route location. While this structure is not necessarily applicable directly to the problem of bikeway location, it is informative if the members of the "location team" in the structure are listed. The location team's purpose is to determine which route alternative is best from the standpoint of community impacts; team members fulfill the following roles:

1. Agent of the Responsible Decision-Making Authority.
2. Technical Advisor to the Decision-Maker.
3. Ombudsman and Spokesman.
4. Impartial Negotiator.
5. Community Advisory.
6. Impartial Developer of Alternatives and Factual Information.

While this seems to be an elaborate array of personnel for locating a bikeway, these roles should be represented among those actually deciding the location to insure impartiality and to assure that the proper significance of all facts is made clear.

The location team can then use any techniques it deems necessary to arrive at the best location alternative. In the M.I.T. report thirty-three techniques applicable to the problem of highway route planning are listed. Those techniques which are of particular significance and appropriate to bikeway route system planning are:

1. Educating the public about the decision making process.
2. Monitoring new developments affecting one or more of the relevant urban systems.
3. Monitoring actual impacts of recently built bikeways.
4. Establishing and maintaining contact with bicycle user groups and the community in general.
5. Using advisory committees.
6. Analyzing past and current plans made by or for a particular community.
7. Presenting the public with a range of alternatives.

These methods should be used with the thought that bikeway planning has had a long history of community participation and that the public is receptive to this type of participatory planning effort.

As shown in this report, bikeway route planning can be considerably more difficult than it appears on the surface. While consideration of the technical aspects of bikeway planning is fundamental in the design process, the social implications of a particular bikeway location are equally important. Consider, for example, the problem of eliminating on-street parking. Will some types of business suffer differentially if parking is eliminated? Is there sufficient off-street parking available? Will pedestrian trips increase? Will shoppers avoid the business street when parking is removed? These questions and many others can only be adequately considered if the problem is brought directly to the local citizens. When this one problem is amplified by the hundreds of problems which could be encountered during a route system location planning process, it can be seen that community participation is indispensable.

4.3 MIXED-MODE JOURNEYS

Bicycle journeys, like most current urban transportation, may often involve the use of other vehicles during the course of a journey. This very real possibility should be included among the factors to be considered in bikeway system planning. The sale of folding bicycles, that easily fit into storage areas of automobiles, and bicycle-carriers mounted on the rear of automobiles, reflect the increasing importance of the bicycle in mixed-mode journeys. The practice of mixing modes can also be extended to include associations with rail and road public transport systems such as subways and buses.

It is perhaps too early to tell to what extent such mixed-mode utilization represents a sizeable proportion of the cycling population. Research into the sales of folding bicycles and carriers should begin in the near future in order to determine the actual attractiveness of carrying a bicycle as a "secondary" transport vehicle. The study should also include user surveys, in order to determine trip-purposes, maximum desirable travel distances for each mode, and the desirability of utilization of bicycles in conjunction with public transport systems.

Actual practices in the state and other parts of the country provide some indication of future possibilities with respect to multi-modal travel. A bicycle-bus was initiated across the San Francisco Bay Bridge for a limited period of time to carry cyclists and their bicycles between Oakland and San Francisco, (37). This type of accomodation is less frequent than the practice of providing bicycle parking racks at major stations of commuter transport systems. The D.R.P.A. Transit Co. in New Jersey, The Chicago & Northwestern R.R., The Marine & Aviation Commission in New York City, have all provided bicycle racks for commuters at many stations (31). The Bay Area Rapid Transit District has proposed to install similar facilities when the system becomes operational (31).

Bikeway system planning, it would appear, should proceed well beyond the assumption of uni-modal bicycle utilization to include the important aspects of routing to and from mode transition points and the provision of adequate storage facilities for bicycles and/or automobiles at those points.

Large scale utilization of bicycle carriers on automobiles and/or storage facilities at transit system stations, if realized, would conceivably affect many aspects of urban activity. Mixed-mode travel involving the bicycle extends the effective range and purposes of the cycle. Whereas the singular use of the bicycle may be limited to a trip distance of perhaps 2-5 miles, the combination with the automobile may extend this to 10, 15, 20 or more miles. For example, with respect to recreational areas, mixed-mode usage could result in more intensive use of Class I bikeways, and as a result increase the attractiveness of the recreational area.

With respect to concentrated employment areas, mixed-mode provision could result in a shift in the transportation complex of downtown areas and central business districts. In such an eventuality it is possible to envisage increased automobile parking in the peripheral areas, with increased bicycle usage for transport into and within the centers. If the shift is sizeable, this may significantly relieve parking and traffic congestion in the centers.

On another tack, the planning implications of limited bikeway systems should be investigated. That is to say, if mixed-mode usage becomes more prevalent than singular bicycle use, then a bikeway system network that criss-crosses an entire urban area may be less effective than a set of short-length bikeways within, and radiating out from, employment or other trip generation centers to peripheral automobile parking facilities.

4.4 BICYCLE PARKING

A most important component of a bikeway system is the provision of parking facilities at appropriate locations, together with locking devices to dissuade casual and professional theft.

Inherent in any mature transport system is a requirement for parking facilities. With the exception of schools, playgrounds, libraries and so on, parking facilities for bicycles in large cities are almost completely non-existent. While the current practices of leaving bicycles unattended on sidewalks, or chaining them to lampposts or signposts may be adequate at the present level of demand in many areas, a substantial increase in bicycle utilization however would most certainly require a more structured method of dealing with the parking problem. Facilities can be provided through public agencies, service organizations or, perhaps by the institutions and firms adjacent to the bikeway route. Installation of bicycle racks will often necessitate amendments to municipal bylaws and will, in the case of private firms or institutions, require obtaining permits from local agencies. New York City's Department of Traffic, for example, has openly encouraged installation of bike racks by private firms (31). Where numbers of potential parkers is great, consideration should be given to larger bicycle parking "lots". Such areas designated for parking of bicycles are feasible in public open spaces such as parks and plazas or other publicly-owned land for which no specific land-use has been designated. However, usually several scattered areas located close to destinations will serve better than a large, centrally located lot.

Consideration should also be given to the installation of bicycle parking racks in public or private automobile parking lots and structures. Estimates have been made, in Chicago, that 14 bicycles can be stored in the area occupied by one automobile. Should operators not desire substituting bicycle for auto parking spaces, many of the marginal spaces in lots and garages can be adapted for bicycles without affecting auto storage capacity or flow (31).

4.5 THEFT PREVENTION

Theft prevention devices associated with bicycle storage facilities are of utmost importance, in view of the significant current rate of bicycle theft.

There are three primary methods that can be provided to protect bicycles from theft. The first consists of a means of enclosing the bicycle in a cabinet, closet or other lockable space. It would appear that this method would be infeasible for installation on sidewalks by virtue of cost and space consumption. A second method is to make the bicycle inoperable by weaving a chain (with lock) through the frame and wheels of the bicycle. The third method involves the provision of a means of locking the bicycle either to the ground, or to a large heavy rack so that the bicycle cannot be removed without breaking the chain or lock. The University of California at Davis has experimented with three different forms of this third method of parking/theft protection. All of these are used in conjunction with a concrete block with a pre-cast slot for the front wheel. One form of security is to lock the bicycle to the block itself, by means of an eyebolt cast into the block. Another method is to lock the bicycle to a metal loop which is attached to a metal strip fixed to the ground. The third is a variant of the second in which a chain replaces the loop.

The mechanical aspects of each of these devices insures that the bicycle cannot be removed without cutting the lock, eyebolt, loop, strip, or chain. In this sense all are equally effective - up to a point. Generally speaking, the most successful method for the cyclist has entailed the use of a case-hardened steel chain with a durable lock that is woven through the frame, and front and rear wheels of the bicycle before being attached to the eyebolt, loop or structure of the racks.

Observations of cyclists at U.C. Davis have indicated a marked preference for either chains or loops over eyebolts, and for chains over loops. In selecting appropriate racks for different locations, this should be considered. It is also recommended that the choice of storage rack style should include consideration of the tubular steel variety that provides storage for 10 to 15 bikes.

All of the above styles provide a more or less convenient anchor point and some support for the front wheel. The bike user must however carry his own case-hardened heavy duty lock. He also must risk the loss of his rear wheel (by theft) and damage to his front wheel if his bike is pushed laterally, or other bikes fall against it.

These shortcomings are avoided in a design currently under development where a strong metal post about 3.5 feet high is provided to lean the bike frame against. Two heavy chains, one near the front wheel, the other near the rear wheel are securely embedded in the surface. Each chain is woven through the nearest wheel and through the frame and around the post to a common point where a lock (carried by the user) is placed through both chains.

4.6 TECHNIQUES FOR ASSESSING DEMAND - THE USER QUESTIONNAIRE

4.6.1 INTRODUCTION

In order to insure the effectiveness of a proposed bikeway system, there must be sufficient short and long run demand to warrant its construction; the system must be located with respect to existing traffic generators; and the pathways composing the system must provide advantages over the present transportation system so as to attract additional users.

This section of the report is addressed to the problem of determining the dimensions of demand for bicycle pathways in a given region. For purposes here the problem can be characterized by three steps. The first is to determine the socio-economic characteristics, preferences, and attitudes of bicycle users with respect to the roadways they use, the type of trips they take, their reason for using their bicycles, their perceived evaluation of risk, and their propensity for using bikeways if such were provided. The second step of the problem is to determine the size of the current and projected bicycle owner population in a region together with the estimation of the proportion of that population that constitutes or will constitute actual users. The third step consists of combining information from steps one and two with outputs from area-specific origin-destination studies so as to translate current and projected bicycle utilization into a demonstrable demand for bikeways in the region.

As an aid in establishing the determinants of bikeway demand, (Step 1), a special questionnaire was designed. Beyond its importance in the first step above, user characteristics, preferences, attitudes, and values obtained via the questionnaire should also aid in designing viable bikeways once potential user demand has been demonstrated. Just as in the rational design of any system involving humans, the design of bikeways must consider human factors if the system is to effectively operate and generate additional users in the future.

The questionnaire is also designed to collect data that might prove to be most helpful in estimating the size of the bicycle population in a given area (Step 2). But before describing the questionnaire developed by the project, it is appropriate to discuss some of the difficulties attendant with using indirect methods of estimating the size of the bicycle population in a given area. This is important in both the short and long term since it gives a limit to the potential utilization of a bikeway within the area by its bicycle owner population.

4.6.2 SEVERAL METHODS OF ESTIMATING BICYCLE DEMAND

An analysis of the relationship between bicycle usage and a "complementary good" provides one useful means for estimating demand.

If a good or service can be isolated that has both sufficient historical information and a demonstrable direct relationship with bicycle usage, it would be possible by means of time series analysis to estimate the present level of demand. This technique is an analysis by proxy in that it provides indirect measures of bicycle usage. One indicator of the bicycle usage in an area might be the stock levels and sales of bicycle tires in the area. It should be emphasized that the indicator need not necessarily be a bicycle oriented product. For instance, the sale of wind breakers might be directly (however, weakly) related to bicycle usage. At any rate, there may be a multitude of factors or dimensions not as yet explored that could prove to be excellent indicators for this purpose.

Other indirect methods are available to measure bicycle ownership in a given area. Among these, an analysis of bicycle registration records would make it possible to project the future growth of the bicycle population that registers with the police department by trending the growth in the number of bicycle registrations over the past years. The difficult part is attempting from this data to determine what percentage of total bicycle owners register their bicycles. There have been no organized attempts by any level of government to accurately estimate this figure. And since there is no mandatory registration, the percentage of registrants to total bicycle owners might vary considerably over time. For instance, the Los Angeles Police Department no longer has a program to actively encourage owners to register bicycles despite an increasing rate of bicycle thefts. (While the LAPD has a comprehensive program to combat the theft problem, it currently does not have the resources to promote an extensive registration program). This fact might result in a decreasing percentage of registrants to total bicycle owners despite a yearly increase in total bicycle registrations. Needless to say, the fact that a person registers a bicycle does not in itself provide information as to usage of that bicycle.

Gathering data on new bicycle sales in a limited area also raises problems. While it may be theoretically possible to obtain sales data from dealers and stores in an area, in practice this information is extremely difficult to obtain due to the reluctance of dealers to relinquish information on their sales volume. A similar difficulty exists in attempting to secure data on replacement parts and maintenance records from dealers. These later inputs are important in identifying bicycle ownership that is not reflected in an area's new sales figures.

Estimating second hand bicycle sales also poses difficulties. Since such sales are generally transacted on an informal basis it is difficult to obtain accurate estimates of the proportion of total demand that is constituted by the sales of used bicycles.

Assuming that data on new and used sales, parts replacement, and maintenance is obtained, other elements must be considered to obtain an accurate picture of evolving area-wide ownership and therefore potential bicycle utilization by owners. For instance, by estimating the expected useful bicycle life it should then be possible to indirectly determine what part of the current bicycle demand is replacement demand, and therefore, does not constitute additional users.

To project demand into the future, it is necessary to have estimates for net household formations in an area. A net migration to or from an area of a special segment of the population may increase or reduce the bicycle user population. And changes in the demographic characteristics of the area's population that presently constitute a significant percentage of the bicycle riding population may cause a shift away from or towards increased bicycle utilization. Although utilization of bicycles may not be related to aggregate changes in the demographic characteristics, values, or attitudes of the area's population in general, it may be related to changes in certain special sub-populations. So in order to accurately determine changes in the bicycle riding population it is necessary to disaggregate demand and investigate the sub-elements in terms of the special populations that are isolated. For example, some of these dimensions might include the age structure, income and education level of bicycle users. Since there are many elements of demand, the in-depth questionnaire will provide a framework for an initial demand disaggregation.

Accident records constitute still another potential source for estimating growth trends in bicycle use and ownership. Accidents when compared with sales figures can give more information than either one alone. Major drawbacks associated with accident records are:

a) In any given time period the reporting level is quite low in terms of frequency, accuracy, and detail.
b) Wide fluctuations in reporting level can be expected over relatively short (1 year) time periods, making before and after studies difficult.

The University of Michigan, Highway Safety Research Institute, in a June 1971 report (58) made good use of accident records to shed light on the question of whether or not there had been an increase in adult use of bicycles for transportation (as distinct from recreation). They analyzed available records of accidents from the Ann Arbor area and compared them with records from an adjacent county. Analyses of time-of-day and day-of-week occurrence of accidents gave a basis for estimating community use; this, when coupled with the age breakdown, suggested patterns of adult use of bicycles for transportation trips.

One must also not underestimate the importance of determining mixed-mode content in an area (for instance commutors who transport their bicycles into the area), as this element of demand will not necessarily be represented by sales and registration data of the area in which they actually use their bicycle.

In spite of the problems discussed above it nevertheless remains necessary to estimate the size of the owner population. Certainly a shift towards mandatory bicycle registration would provide the brunt of the required data while also providing funds for enforcement, administration, and combating of the growing theft problem. By questionnaire sampling of the owner population it would then be possible to estimate the proportion of that population that constitutes actual current users. Finally, in terms of future projections, a properly formulated socio-economic model can provide a means of predicting what percentage of non-owners in an area are potential bike users.

4.6.3 DESIGN OF THE QUESTIONNAIRE

The questionnaire was designed to provide three types of information. First, the socio-economic characteristics of bicycle users; second, their preferences, attitudes and values; and third, the kinds of trips made, and the cost and quality of those trips. Figure 4.6.1 shows the resulting questionnaire form.

The questionnaire was specifically designed to be mailed to bicycle owners rather than to be administered by personal interview techniques. The foremost advantage of a mailed questionnaire is that it may be widely distributed for a comparatively small expenditure. A second advantage is that it avoids possible bias that interviewers might interject into subject's responses. A correlary tendency is for the respondent to attempt to give the interviewer what he feels the interviewer expects. A third benefit obtainable from a mail questionnaire can be the assurance of anonymity. This offers the reasonable expectation that the questions will be answered honestly if not unbiasedly.

Despite these advantages, a mailed survey has several weaknesses. The percentage of replies received from a mailed questionnaire is generally less than thirty percent, especially if the questionnaire is lengthy, (as this one is), requires thought and judgment in replying, and

PART I: QUESTIONS TO BE ANSWERED BY THE HEAD OF THE HOUSEHOLD

1. How many bicycles are owned by your household? __________ Your Age __________
2. Are you a home owner? ☐ Yes ☐ No
3. If yes, for what might your house rent, if it were for rent? $______________ Mo.
4. If not a homeowner, what is your monthly rent? $______________ Mo.
5. How many years have you lived at your present address? ______________
6. What is your zip code number? ______________
7. In which city within the Los Angeles area do you live? ______________
8. How many people live in your house or apartment? ______________
9. How many years of school have you completed? ______________
10. What is your present employment status?

    ☐ Armed forces ☐ Employed ☐ Unemployed ☐ Not looking for permanent employment
11. What kind of work do you do? ____

    ____
12. When you made the decision to move to your present address, did you consider whether the area was favorable for bicycle use?

    ☐ Yes ☐ No
13. Please indicate your FAMILY level of income from all sources for last year.

☐ Less than $2,000	☐ $6,000 to $7,999	☐ $12,000 to $14,999
☐ $2,000 to $3,999	☐ $8,000 to $9,999	☐ $15,000 to $24,999
☐ $4,000 to $5,999	☐ $10,000 to $11,999	☐ $25,000 or more

PART II: QUESTIONS TO BE ANSWERED BY THE BICYCLE USER

14. How many speeds does your bicycle have? ________ Your Age ________ Sex ________
15. What is your relation to the head of the household?

    ☐ Head ☐ Spouse of head ☐ Child of head ☐ Unrelated
16. Please indicate which of the following types of transportation YOU normally use during a typical week by placing a 1 next to the type YOU use most frequently, a 2 next to the second most frequent, and so on until you have ranked all types of transportation you normally use:

    ______ Auto ______ Motorcycle ______ Public Transportation ______ Bicycle ______ Walking ______ Other

NOTE: For questions 17–23, circle the appropriate number to the right of the question. If the question is not applicable, circle NA.

	Not At All						Extremely	
17. How favorable is your immediate neighborhood for bicycle use?	1	2	3	4	5	6	7	NA
18. How important to YOU is each reason for riding your bicycle?								
A. For touring	1	2	3	4	5	6	7	NA
B. For recreation	1	2	3	4	5	6	7	NA
C. To exercise	1	2	3	4	5	6	7	NA
D. For transportation	1	2	3	4	5	6	7	NA
E. To save time	1	2	3	4	5	6	7	NA
F. To save money	1	2	3	4	5	6	7	NA
G. For environmental reasons	1	2	3	4	5	6	7	NA
H. To ride with my friends	1	2	3	4	5	6	7	NA
I. To ride with my family	1	2	3	4	5	6	7	NA
J. Other (specify) ______________	1	2	3	4	5	6	7	NA
19. To what extent do each of the following factors inhibit YOU from using your bicycle for NON-recreational trips (i.e., trips to work, for shopping, etc.)?								
A. Too much physical effort and sweating	1	2	3	4	5	6	7	NA
B. Personal safety	1	2	3	4	5	6	7	NA
C. Lack of bicycle racks at destination	1	2	3	4	5	6	7	NA
D. Danger of theft	1	2	3	4	5	6	7	NA
E. Bad weather	1	2	3	4	5	6	7	NA
F. Takes too long	1	2	3	4	5	6	7	NA
G. Social pressure (dress, ridicule, etc.)	1	2	3	4	5	6	7	NA
H. Too much starting and stopping	1	2	3	4	5	6	7	NA
I. Cannot carry packages	1	2	3	4	5	6	7	NA
J. Other (specify) ______________	1	2	3	4	5	6	7	NA
20. To what extent do each of the following weather conditions inhibit YOU from riding your bicycle for NON-recreational trips?								
A. Raining	1	2	3	4	5	6	7	NA
B. Smoggy	1	2	3	4	5	6	7	NA
C. Hot	1	2	3	4	5	6	7	NA
D. Cold	1	2	3	4	5	6	7	NA
E. Windy	1	2	3	4	5	6	7	NA
F. Snowy	1	2	3	4	5	6	7	NA
G. Foggy	1	2	3	4	5	6	7	NA

(over)

Figure 4.6.1 The Questionnaire (1st Page)

21. From YOUR experience when riding a bicycle, how dangerous do YOU find the following conditions?

	Not At All						Extremely	
A. Bicyclist making left hand turn	1	2	3	4	5	6	7	NA
B. Car door opening	1	2	3	4	5	6	7	NA
C. Cross traffic	1	2	3	4	5	6	7	NA
D. Being hit from rear	1	2	3	4	5	6	7	NA
E. Car turning abruptly	1	2	3	4	5	6	7	NA
F. Car stopping abruptly	1	2	3	4	5	6	7	NA
G. Riding bicycle against traffic	1	2	3	4	5	6	7	NA
H. Riding bicycle at night	1	2	3	4	5	6	7	NA
I. Drainage ditches	1	2	3	4	5	6	7	NA
J. Bad weather	1	2	3	4	5	6	7	NA
K. Other (specify) ______	1	2	3	4	5	6	7	NA

22. To what extent is each of the following a reason for YOU to ride your bicycle along streets with high automobile traffic?

A. Fewer stop signs	1	2	3	4	5	6	7	NA
B. Less cross traffic	1	2	3	4	5	6	7	NA
C. Shorter distance	1	2	3	4	5	6	7	NA
D. Fewer hills	1	2	3	4	5	6	7	NA
E. Better road surface	1	2	3	4	5	6	7	NA
F. More attractive scenery	1	2	3	4	5	6	7	NA
G. Other (specify) ______	1	2	3	4	5	6	7	NA

23. To what extent would bicycle pathways (i.e., some designated pathway which is generally restricted to bicyclists) increase the number of times YOU use your bicycle if placed in the following places?

A. Pathways in downtown metropolitan areas	1	2	3	4	5	6	7	NA
B. Pathways along major arterial streets	1	2	3	4	5	6	7	NA
C. Pathways along residential or secondary streets	1	2	3	4	5	6	7	NA
D. Pathways through recreation areas or parks	1	2	3	4	5	6	7	NA

24. Please fill in the appropriate response under headings I and II for each of the types of bicycle trips YOU take. Under heading III, check whether MOST of these trips are made on weekdays OR weekends. Under IV, indicate the appropriate hour(s) you would be most likely to make this trip (e.g., a trip to and from work might have under "To" 8:30–9:00 AM and under "From" 5:00–5:30 PM)

Type of Trip	I No. of Round Trips Per Week	II Approx. Oneway Dist. in Miles On Bicycle	III Check One Week-Day (or)	Week-End	IV Indicate Hr(s) of Day To	From
A. Travel to and from work	____	____	____	____	____	____
B. Travel to and from school	____	____	____	____	____	____
C. Shopping trip	____	____	____	____	____	____
D. Recreational trip	____	____	____	____	____	____
E. Other (specify)	____	____	____	____	____	____

25. Please check each of the following ways YOU use your bicycle.
- ☐ A. To get to other means of transportation (e.g., bicycle to bus)
- ☐ B. Transport bicycle close enough to ride bicycle to work (e.g., auto with bicycle rack)
- ☐ C. Transport bicycle close enough to ride bicycle to school.
- ☐ D. Transport bicycle close enough to ride bicycle to shopping area.
- ☐ E. Transport bicycle close enough to ride bicycle to or in recreational area.
- ☐ F. Other (specify) ______

26. If a bicycle pathway were built parallel to the route that you now take for NON-recreational purposes, how many blocks would YOU be willing to go out of YOUR way to ride on the pathway?(Assume 10 blocks = 1 mile)

☐ None at all ______ Number of blocks

27. How many continuous years have YOU used a bicycle regularly for NON-recreational purposes? ______

28. Do you belong to a bicycle club or organization? ☐ Yes ☐ No

29. Do you own a car? ☐ Yes ☐ No A motorcycle? ☐ Yes ☐ No

30. If you have any ideas or comments on how to encourage wider use of bicycles and on how to create bicycle pathways in your area, please indicate below.

(Use an additional page if necessary)

Happy bicycling and thank you!

Figure 4.6.1 The Questionnaire (2nd Page) is non-mandatory. This consideration generally requires a large distribution in order to insure adequate sample sizes.

Another point is that the respondents may represent a sample of persons who have a high propensity for completing questionnaires or may include persons with a vested interest in the problem to which the questionnaire is directed. One standard technique is to make additional efforts to obtain a description of those who did <u>not</u> reply. Second mailings, telephone calls and visits all are useful in this respect to obtain from a sub-sample of non-respondents some basis for deciding how representative the respondent group is of the total population to whom the survey is directed.

These problems indicate that, as with any questionnaire, care must be exercised to insure that adequate sample sizes will be obtained and, that the resultant samples are representative of the populations of concern and that the interpretation of results considers possible biases in the replies.

The questionnaire has purposely been divided into two parts. The first section of the questionnaire entitled "Questions To Be Answered by the Head of the Household," (questions 1-13), examines the socio-economic characteristics of the bicyclist's household. This "hard" data provided by the head of the household will enable a composite description of the bicyclist's family for comparison with census tract data.

In Part II of the questionnaire, entitled "Questions to Be Answered by the Bicycle User," questions 14-23 are designed to examine the preferences and attitudes of bicyclists and the modes of travel available to them. Part II is specifically intended for bicycle users that are 18 years of age or older. Restricting the surveyed population to an over-18 age group provides some insurance that the users will have alternative means of transportation available to them. Secondly, this insures that the analysis will not be biased towards the very young users whose tastes and values have a high propensity for change. In order to get at the full range of reactions involved in expressing attitudinal responses, questions 17-23 incorporate a semantic differential scale. The scale is structured to enable the respondent to select his position between two numeric extremes.

Questions 24-25 specifically investigate the number and types of bicycle trips that are made by users of bicycles, the distance covered and the trip time to various destinations, and the usage of mixed modes of transportation.

Question 26 provides preliminary information on the distance a bicyclist is willing to travel out of his way to use a bikeway if one were available.

Questions 27-29 were designed to allow stratification of the sample. Finally question 30 allows the respondent to give qualitative replies outside of the structure of the questionnaire.

To summarize, the questionnaire provides a framework for analyzing the socio-economic characteristics, values, preferences, and attitudes of bicycle users with respect to the roadways they use, the trips they take, their reasons for using their bicycle, their personal evaluation of safety and comfort, and their propensity for using bikeways if such were provided. However, it should be emphasized that while the use of the questionnaire provides several dimensions of bikeway demand it does not provide the whole of the picture. Studies of bicycle registration, sales, maintenance, accidents, mixed-mode travel, and origin and destination patterns are equally important in assessing the current and future demand for bikeways in a given region. Finally, before actual bikeways are constructed or designed in response to a demonstrated current or future demand, the impacts and externalities accruing to residents, businessmen, and motorists in the region should be ascertained. If properly executed and interpreted these adjuncts to the planning process should insure the orderly incorporation and interfacing of the bikeway route system with other modes of travel and types of land use within the community.

4.6.4 SELECTION OF A SAMPLE TO TEST THE FINAL VERSION OF THE QUESTIONNAIRE

In order to obtain a mailing list for the questionnaire a request was made to the City of Los Angeles Police Chief, Edward Davis, for access to bicycle registration information. Upon referral to Commander Noel A. McQuown, Commanding Officer, Technical Services Bureau, access was allowed to the files.[1]

Carbon copies of the bicycle registrations are filed by year numerically by the last 5 significant digits of the manufacturer's frame number and also by the registration copy number.

The Los Angeles City Police Department makes these registration forms available to the public by distributing them to all bicycle shops in Los Angeles as well as to local LAPD police stations. For sampling purposes the registrations filed by the registration copy number were used. Carbon copies of these registrations are sent into the LAPD Bicycle Registration Department whenever the local bicycle shop or police station feel they have an adequate number of completed registrations.

The information on the forms contains the registrant's name and address. Often only "L.A." was entered as the city, and the zip code was rarely entered. The person's date of birth should also have been filled in, although many times it was not included. Furthermore, the

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[1] A preliminary version of the questionnaire was mailed to the Los Angeles and Orange County Wheelmen Bicycle Club via their November, 1971 monthly newsletter. Selected tabulations of the responses are given in Appendix C. From an analysis of the results many improvements to the earlier questionnaire were made and incorporated in the final version of the questionnaire shown in Figure 4.6.1.

owner of the bicycle was supposed to sign his name; in this way it was possible to make sure the person registering the bicycle was also the owner.

The LAPD maintains these files for bicycles registered over the last five years. The problem was to select registrants from the files who were at least 18 years old. It was decided to sample only from those registrants who filed during the calendar years 1969 and 1970 because it was felt this would guarantee that the respondent had had an opportunity to ride the bicycle at least one year. Thereby, the respondent would have established definite use patterns and, secondly, the respondent would have developed more explicit opinions concerning the factors that influence his bicycling habits.

It was decided that approximately 2,000 questionnaires, given the anticipated return rate, would be an adequate number to send out for this pilot study. Since about 50,000 bicycles were registered in 1969 and also in 1970, this sample constitutes approximately one adult out of every 50 people who registered during 1969-1970.

4.6.5 RESPONSE RATE OF THE QUESTIONNAIRE MAILING

On February 8, 1972, 1,886 questionnaires as described in the previous section were mailed to randomly selected registrants in Los Angeles County over the age of 18. As of February 23, 200 unclaimed questionnaires were returned by the postoffice, and 515 completed questionnaire forms were returned in the postage paid envelopes provided with the questionnaire. Considering the length and complexity of the questionnaire the response rate of 30.5% is excellent and aside from providing valuable information, points up the timely nature of the research called for in this study.

Owing to time constraints, the questionnaire has not as yet been analyzed, and can be considered as one excellent area for future investigation.

CHAPTER FIVE

CONCLUDING DISCUSSION AND RECOMMENDATIONS FOR FUTURE WORK

In Chapter Three design criteria, specifications, and guidelines were presented for Class I, Class II, and Class III bicycle facilities. Design guidelines for Class I facilities were presented and feasible locations were specified.

Likely locations for both urban and rural Class I bikeways include continuous linear spaces such as electrical transmission line rights-of-way, river banks, dry beds, beach fronts, flood control channel levees, irrigation canal embankments, and railroad rights-of-way. In addition to the various linear rights-of-way, Class I facilities may be located in public parks, urban redevelopment projects, "new towns," and open space. It should be emphasized that a Class I bikeway need not be primarily a recreational facility; depending upon the location, it may be feasible to incorporate a Class I bikeway portion of a bikeway route linking transportational traffic generators in already built up urban areas.

In Section 3.7 several alternatives for incorporating Class II and Class III bikeways on existing street rights-of-way were presented and discussed in terms of traffic factors and land use. The alternatives were then specified in terms of minimum width requirements, types of barriers, and minimum road right-of-way necessary for their incorporation on existing streets. From the presentation it should be possible for communities to evaluate the physical feasibility of locating the various Class II and Class III alternatives on candidate streets. It is recommended that two-way Class II bikeways on one side of a street be avoided; rather, the Class II alternatives should be provided in one-way fashion, preferably but not necessarily, in a symmetrical alignment. The practice of providing

Class III bikeways on existing streets should be avoided except in the most ideal circumstances, since such provision does not provide a tangible level of safety to cyclists, and may, in fact "lull" them into a sense of false security.

Intersections pose particularly difficult problems from the standpoint of design to cope with bicycle traffic. Several intersection designs were presented in Section 3.8. From these various designs, most types of intersections can be analyzed and several alternative treatments conceived and evaluated with respect to the existing intersections through which a proposed bikeway is to be routed.

Safety is a primary factor in providing bikeways that will be used. It is clear that United States bicycle accidents are on the increase and, if European experience is any indication, can be reduced by proper design of the bikeways. Section 3.5 contains a discussion of the effect of separated Class II bikeways on accident rates.

Nighttime use of bikeways will require adequate illumination but generally no more than is usual for urban streets. Traffic signs and pavement markings should be standard in compliance with the MUTCD and placed so as clearly to inform motorists that a pathway is provided for the use of bicyclists. Other, smaller, standard signs and markings are appropriate for guiding the bicyclists and warning them of various hazards. It should be emphasized that the enactment and enforcement of laws and ordinances governing bikeway operation, motor vehicle parking and intrusion onto the bikeway, and in some cases bicycle use of sidewalks, is a necessary adjunct to insure the efficient and safe operation of bikeways.

Chapter Four contained topics relating to the more global aspects of providing bikeways and routes in a community. These included short and long range planning considerations, community participation in the planning process, assessing land use impacts, mixed mode travel, bicycle parking facilities, theft prevention, techniques for assessing demand, and the design of a bicycle-user questionnaire. The questionnaire provides a framework for collecting data on the socio-economic characteristics, preferences, and attitudes of bicycle users with respect to the roadways they use, the type of trips they take, their reasons for using their bicycle, their personal evaluation of safety and comfort, and their propensity for using bikeways if such were provided. As such, the questionnaire provides a valuable tool for use by communities in planning facilities for bicycle travel.

Several areas of future work are clearly indicated. These are:

1. Analysis of responses from the user questionnaire study: This will disclose information valuable in design and location of bikeways that reflect the needs and characteristics of the ultimate users of proposed bikeway systems.
2. Use of urban bikeways as experimental laboratories: much relevant information can be collected on safety, accidents, bicyclist behavior, bikeway useage, and design by providing bikeways and conducting controlled experiments on them. While European countries have had wide experience with bikeways, well controlled and statistically designed experiments to compare the marginal safety of various design configurations appear to be lacking. Such studies

would provide the initial framework for cost effectiveness evaluations of alternative bikeway facilities. The City of Davis is one example of an already existing "laboratory" for studying bikeway development under ideal topographical, climatic, and land use conditions.

3. Development of rational volume warrants for provision of separated bikeways on urban streets: Warrants would have to reflect tradeoffs between motor vehicle and bicycle level of service if a portion of the road right-of-way were allocated for a bicycle facility.

4. Study of the environmental effects of bikeway location upon the cyclist: Initial studies performed as a part of this work indicated the need for more research to determine the effects of air pollution upon cyclist performance when the proposed bikeway route closely parallels a major line source of pollution (i.e., a major urban freeway).

5. Though outside of the scope of this report, a study of methods of financing bikeways is definitely in order. Determination of bases for equitable sharing of costs will provide important and valuable information to local agencies contemplating providing bikeways in their communities.

In conclusion, each community will have to assay its own potential demand for bikeways. The overall demand is apparently still growing but certainly is subject to rapid change and likely to have quite different time and spatial characteristics for each urban area. More or less standard origin-destination techniques can be used together with registration, sales, and maintenance records, among others, to aid in assessing demand. Accident statistics also can be used to reflect amount and type of bicycle usage.

It would appear that especially for short trips the modern multi-speed bicycle constitutes a potentially viable alternative mode of transportation for urban adults. This study shows how bikeways can be created, but does not attempt to answer to what extent they will be used in any given community.

It is clear that community representation is important in considering bikeways and their locations, just as it is in the location of highways. This report can help engineers and community representatives to reach more reasoned conclusions regarding provision of bikeways than heretofore has been possible. In a similar fashion it can prove a source of unbiased information for legislative debate, and to the extent that it does, it will have met its initial purpose.

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APPENDIX A

COST ESTIMATES (AVERAGE VALUES) GIVEN FOR CONTRACT (INCLUDING MATERIALS, CONSTRUCTION AND INSTALLATION) AND MAINTENANCE.[1,2]

[1] Cost estimates were supplied by Richard H. Kermode, District Design Coordinator, Design B, State of California, Division of Highways, District 7, Los Angeles. Estimated costs for specific projects could run either higher or lower depending on the design, location, topography, and size of project.

[2] Notation: LF= linear foot, SF= square foot, CY= cubic yard.

I. STRUCTURAL SECTION

a.	2" Surface (Type B Asphalt Concrete)	$ 8.00/Ton
b.	4" Aggregate Base	$ 4.00/CY

II. GRADING

a.	Roadway Excavation	$ 2.00/CY
b.	Imported Borrow	$ 2.00/CY

III. DRAINAGE

a.	Graded Ditch (Ditch Excavation) 1' Wide Vee ditch 2 to 1 side slopes or	 $ 2.50/CY $ 0.06/LF
b.	Cross Drains 6" Asbestos - cement drain pipe	 $ 6.00/LF
c.	Modify existing catch basin grates (welded cross bars to prevent bicycle wheels from dropping-in) Note: Hydraulic design should be considered.	$ 10.00 EA

IV. LANDSCAPING

a. Plant shrubs to form a screen or barrier - 10 foot on center, including a one year maintenance period:

With irrigation $4.50 to $6.00/LF

Without irrigation $1.50 to $3.00/LF

b. Other landscaping including irrigation $8,000 to $20,000/Acre

Cost varies with location, size of project, type of planting, size of plants and availability of water.

V. BRIDGES AND RETAINING WALLS

a.	Pedestrian Overcrossing including ramps 8' width, max. 100' span.	$ 280/LF
b.	Pedestrian Undercrossing Min. 18' wide x 14' high required for freeways. Cost does not include traffic detour.	$1250/LF
c.	Cantilevered bikeway attached to existing bridge. 10' width including wire mesh railing	$ 155/LF
d.	Retaining Walls: 4' height	$ 25/LF
	6' height	$ 35/LF
	8' height	$ 50/LF

VI. BARRIERS AND FENCES

a.	Concrete Median Barrier	$ 12.00/LF
b.	Single Metal Beam Barrier	$ 8.00/LF
c.	Cable Barrier (with mesh)	$ 3.50/LF
d.	Cable Barrier (without mesh)	$ 3.00/LF
e.	0.5' Asphalt Dike	$ 0.70/LF
f.	Type B3 Dowelled Curb (Parking Bumper) Class B Concrete at $45.00/CY	$ 0.50/LF
g.	72" Chain Link Fence "CL-6"	$ 2.50/LF
h.	48" Chain Link Fence "CL-4"	$ 2.00/LF

VII. MODIFICATIONS OF EXISTING STREETS

a.	Remove Concrete Curb	$ 0.60/LF
b.	Remove Concrete Curb and Gutter	$ 1.60/LF
c.	Remove Concrete Sidewalk (4" depth)	$ 0.50/LF
d.	Construct Concrete Sidewalk (4" depth) Class B Concrete at $45.00/CY	$ 0.55/SF
e.	Construct Type A2-8 Curb & Gutter Class B Concrete at $45.00/CY	$ 3.00/LF
f.	Construct Concrete Bikeway Ramp (including curb removal, sidewalk removal and roadway excavation):	
	4' width 4' length 4" depth	$ 24.00 EA
	6' width 4' length 4" depth	$ 36.00 EA
	8' width 4' length 4" depth	$ 48.00 EA

VIII. SIGNS

a.	Regulatory Signs 3' x 3' enamel painted sign mounted on wooden post	$ 25.00 EA
b.	Bikeway Sign (enamel painted) mounted on wooden post	$ 15.00 EA

IX. STRIPING

		Cost Per One Lane Mile
a.[1]	Single 3" solid white or green line (paint)	$ 500/Mi
b.[2]	Single 3" solid white or green line (thermoplastic)	$2000/Mi
c.[3]	Single 4" dashed white lane line (paint)	$ 500/Mi
d.[3]	Single 4" dashed white lane line (thermoplastic)	$2000/Mi
e.[3]	Double 4" solid yellow center line (paint)	$ 700/Mi
f.[3]	Double 4" solid yellow center line (thermoplastic)	$2800/Mi
g.	Cross walk stripe (12" white thermoplastic)	$ 1.00/LF
h.[3]	Remove traffic stripe (paint)	$ 0.20/LF
i.[3]	Remove traffic stripe (thermoplastic)	$ 0.50/LF

X. PAVEMENT MARKINGS - STENCIL

a.	Pavement markings (paint)	$ 0.50/SF
b.	Pavement markings (thermoplastic)	$ 2.00/SF
c.	Remove pavement markings (paint)	$ 0.60/SF
d.	Remove pavement markings (thermoplastic)	$ 1.50/SF

XI. PAVEMENT MARKERS

a.	Type G one-way clear Reflective Marker	$ 2.00 EA
b.	Type A non-reflective marker	$ 0.75 EA

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[1] white stripe is standard, green stripe may be considered for bikeway
[2] use of thermoplastic lines may pose hazards to bicyclist when pavement is wet
[3] these items are for striping or removal of traffic lanes

XII. SIGNAL MODIFICATIONS

Modify signal heads and controllers	$10,000/Intersection

XIII. LIGHTING

Light standard and conduit. Utilization of existing street lighting facilities may reduce this item cost.	$1000 EA

APPENDIX B

TOWARDS ESTABLISHING BIKEWAY GRADE LIMITATIONS BASED ON CYCLIST ENERGY EXPENDITURES

The grade that one can adequately ride is a function of many variables which include the rider's age, sex, weight and surface area, the bike's weight, gear ratios and tire pressure, how hard the cyclist wants to work, and the velocity of travel up the grade. A study of the available literature gives no direct relationships for these factors. Grades ranging from zero to ten percent are considered feasible but no basis for these criteria are explicitly stated. An effort to develop a more rational measure of the effect of grade is presented below. Simple examples are included to illustrate the manner in which this data can be used to design grades for various bikeway situations.[1]

Consider the bicycle shown in Figure B-1 ascending a grade which makes an angle ϕ with the horizontal. The forces shown include the weight of the rider (W), the weight of the bike (W_b), the normal reactions from the ground (N_1 and N_2), the wind resistance (F_w), the friction force (F_f) and the torque applied to the rear wheels (T).

The rate of work done by the cyclist (W_b) to ride up the hill at constant velocity v can be equated to the external mechanical rate of work to give

$$E W_o = v\left[F_w + F_f + (W + W_b)\sin\phi\right] , \qquad (1)$$

where E is the gross mechanical efficiency of the rider. Considering small values of the angle ϕ and assuming clam air conditions, Equation 1 may be solved for the grade:

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[1] Notation and references are given at the end of this Appendix.

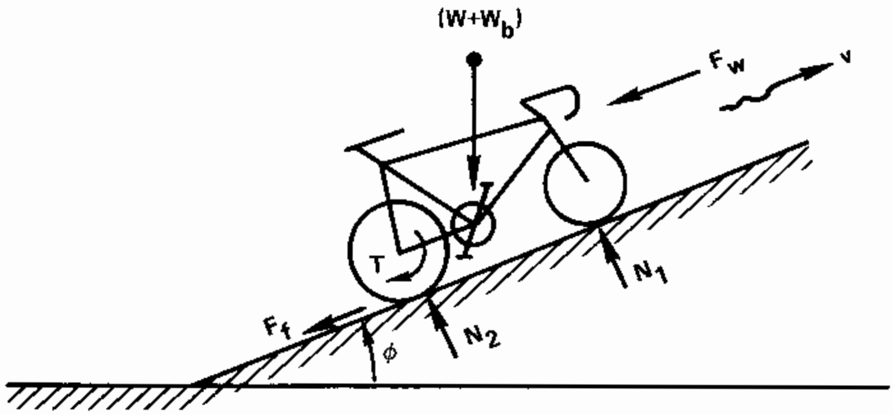

Figure B-I

$$\phi = \left(E W_o - F_w v - F_f v \right) \frac{1}{(W + W_b)v} \quad . \qquad (2)$$

The terms of Equation (2) may now be evaluated using published data, generally for an average population of riders.

(a) <u>Gross Mechanical Efficiency - E</u>

The maximum gross mechanical efficiency of a person performing a work task has been found to be slightly less than 20 percent (1). Studies on the efficiency of bicycle riding have shown however, that the efficiency is a function of the pedal frequency α, with the maximum occurring at a pedal frequency of approximately 50 to 60 rpm (2, 3). An equation relating the mechanical efficiency of a muscular movement was given by Hill (7) and shown by Dickinson (4) to provide a reasonable estimate of the efficiency of bicycle pedalling. This expression, relating the efficiency to the time of a muscular contraction, is given as

$$E' = \frac{1 - \beta/t}{a(1 + bt)} \qquad (3)$$

where t is the time for one muscular contraction (in this case 1/2 a revolution of the pedal crank), E' is the efficiency related to this movement, and a, b, and β are constants. Tests indicate that the maximum efficiency occurs when $t \simeq 0.6$ seconds (3). When this value of t is used in Equation (3) with $\beta = 0.16$ and with the efficiency E' set to $E'_{max} = 0.218$[1] as shown by Dickinson (4), the

[1] E'_{max} used in Dickinson's work was the value obtained after a correction for the energy required to merely sit on the ergometer without pedalling (work-position basal). Other researches show the gross efficiency is approximately 14% lower. This, however, does not change Equation (4).

constants a and b are calculated to be 2.14 and 0.954, respectively. Conversion of the time t to pedal frequency α and normalizing Equation (3) by division by E'_{max}, the normalized efficiency $f(\alpha)$ as a function of the pedal frequency is given by:

$$f(\alpha) = \frac{30\alpha - 0.16\alpha^2}{14\alpha + 400} \tag{4}$$

Thus, Equation (4) may be used to obtain the gross efficiency as a function of pedal frequency:

$$E = E_{max} f(\alpha) , \tag{5}$$

where E_{max} is the maximum gross efficiency that is expected from the cyclist.

(b) Energy Expenditure of the Cyclist - W_o

The rate of energy expenditure of a cyclist can be determined from his rate of oxygen uptake ($\dot{V}o_2$). This will vary depending on the age and weight of the rider as well as the level of work at which he desires to ride. Åstrand (2, pg. 311) shows curves for the maximal $\dot{V}o_2$ uptake for an average group of people ranging in age from 4 years to 75 years. In the present development these curves were approximated as shown in Figure B-2 for males. For females the values shown can be reduced by 15 to 20 percent after 10-12 years of age. Taking the ordinate of the curve as g(A), the maximum rate of oxygen uptake (or the maximum rate of energy expenditure) may be expressed as

$$W'_o = W\, g(A) , \tag{6}$$

where W'_o is the maximum rate of energy expenditure.

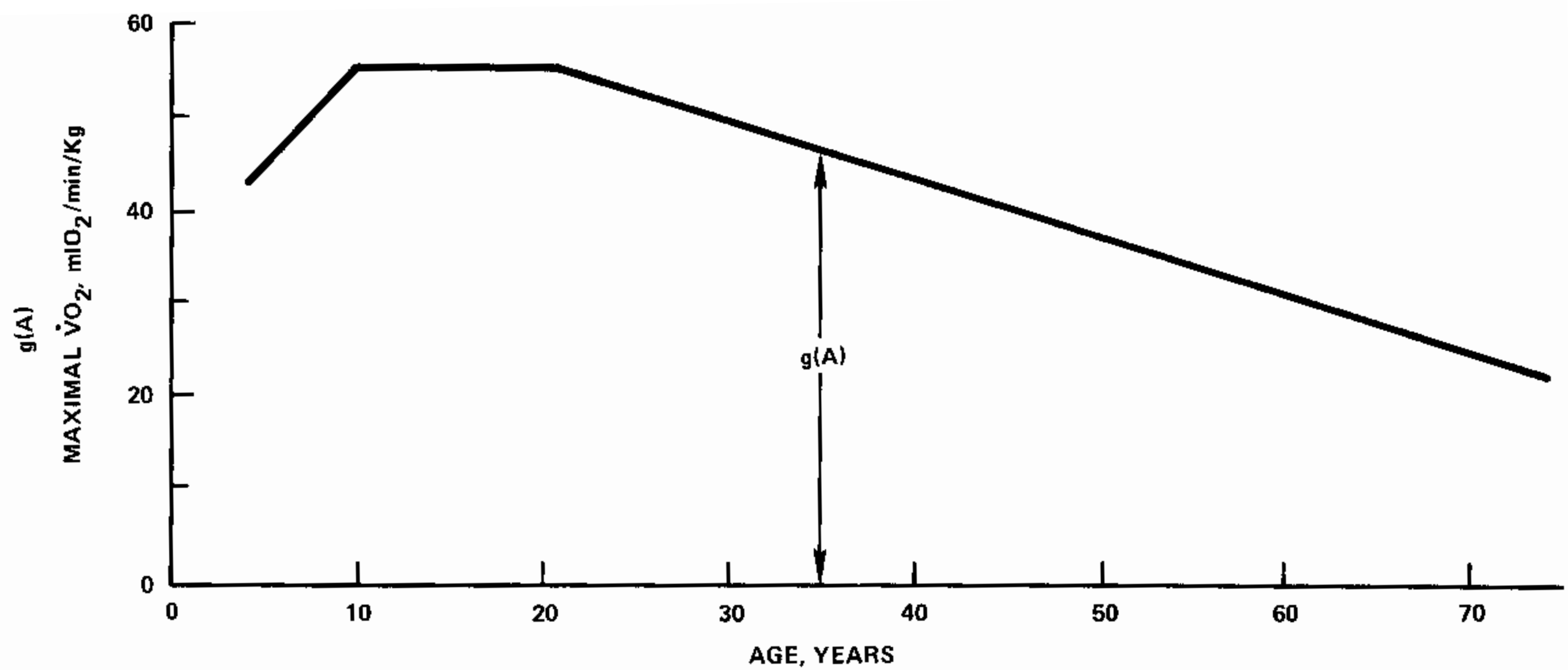

Figure B-2. Maximal Rate of Oxygen Uptake as a Function of Age (Based on Ref. 2)

The average rider rarely performs at a maximum work level, but usually at some fraction k of the maximum level. Table B-1 indicates typical classifications of various work levels as it relates to industrial tasks (8). Thus by multiplying W'_o by the work level k the rate of energy expenditure is:

$$W_o = k\ W\ g(A) \tag{7}$$

(c) Rate of Energy Expenditure as a Function of Air Resistance - $F_w v$

From studies of runners, the additional rate of oxygen uptake ($\Delta \dot{V}o_2$) required to do work against the air velocity is given by Pugh (5) to be

$$\Delta\ \dot{V}o_2 = 0.00418\ A_p\ v^3$$

where v is in units of m/sec^2, A_p is the projected frontal area in units of m^2 and $\Delta \dot{V}o_2$ is in units of ℓo_2/min. The rate of work may therefore be expressed as:

$$F_w\ v = 0.00418\ C_w\ A_p\ v^3\ , \tag{8}$$

where C_w is a constant that converts the expression to the units used in Equation (2).

(d) Rate of Energy Expenditure Against Ground Friction - $F_f v$

A recent paper by Whitt (6) showed that the friction force acting on a bicycle can be taken as

$$F_f = 0.005 + \frac{0.15}{T}$$

where F_f is in units of lbs force/lb weight and the tire pressure T is in psi. Thus multiplication by the velocity and the bike and rider weights gives the rate of work that must be done against friction

TABLE B-1 EQUIVALENT WORK LEVELS FOR VARIOUS TASKS[1]

Sports Equivalent	Work Level: Fraction of Maximum Oxygen Uptake (k)	Classification
Long Distance Running	1.0	Unduly Heavy less than 1 hr. duration
Handball	0.8	Very Heavy short duration (1-2 hours)
Tennis	0.6	Heavy 8 hr. duration with frequent long rests
Level Bicycling	0.4	Moderate 8 hr. duration with occasional 5-10 min. rests
Billiards	≤ 0.2	Light Desired occupational level. Causes no physical disturbances

[1] Based upon Exercise Physiology, H. B. Falls, ed., Academic Press, N. Y., 1968.

$$F_f v = C_f \left(0.005 + \frac{0.15}{T}\right)(W + W_b) v , \qquad (9)$$

where C_f is a constant that converts the expression to the desired units.

Equations (5, 7, 8 and 9) may now be substituted into Equation (2) to obtain:

$$\phi = \Big[(E_{max})(f(\alpha))(k)(g(A))(W)C_o - 0.00418\ C_w A_p v^3 - C_f v(.005 + \frac{.15}{T})(W + W_b) \Big] \frac{1}{(W + W_b) v} \qquad (10)$$

where C_o, C_f and C_w are constants necessary to put all terms in the proper units.

The solution of Equation (10) for various combinations of the parameters yields the maximum theoretical grade which may be used for bikeway grade planning. Figure B-3 shows the variation of grade as a function of the velocity and work level for three cases having the following fixed parameters:

$E_{max} = 18\%$

$W_b = 35$ lbs

$A_p = 0.5\ m^2$

T = 50 psi

sex = male

wheel diameter = 26 inches

The gear ratio was taken to be 2.42 which is considered a "normal" ratio for many bicycles. For a given velocity, this ratio fixes the pedal frequency α. The other parameters, which varied, were

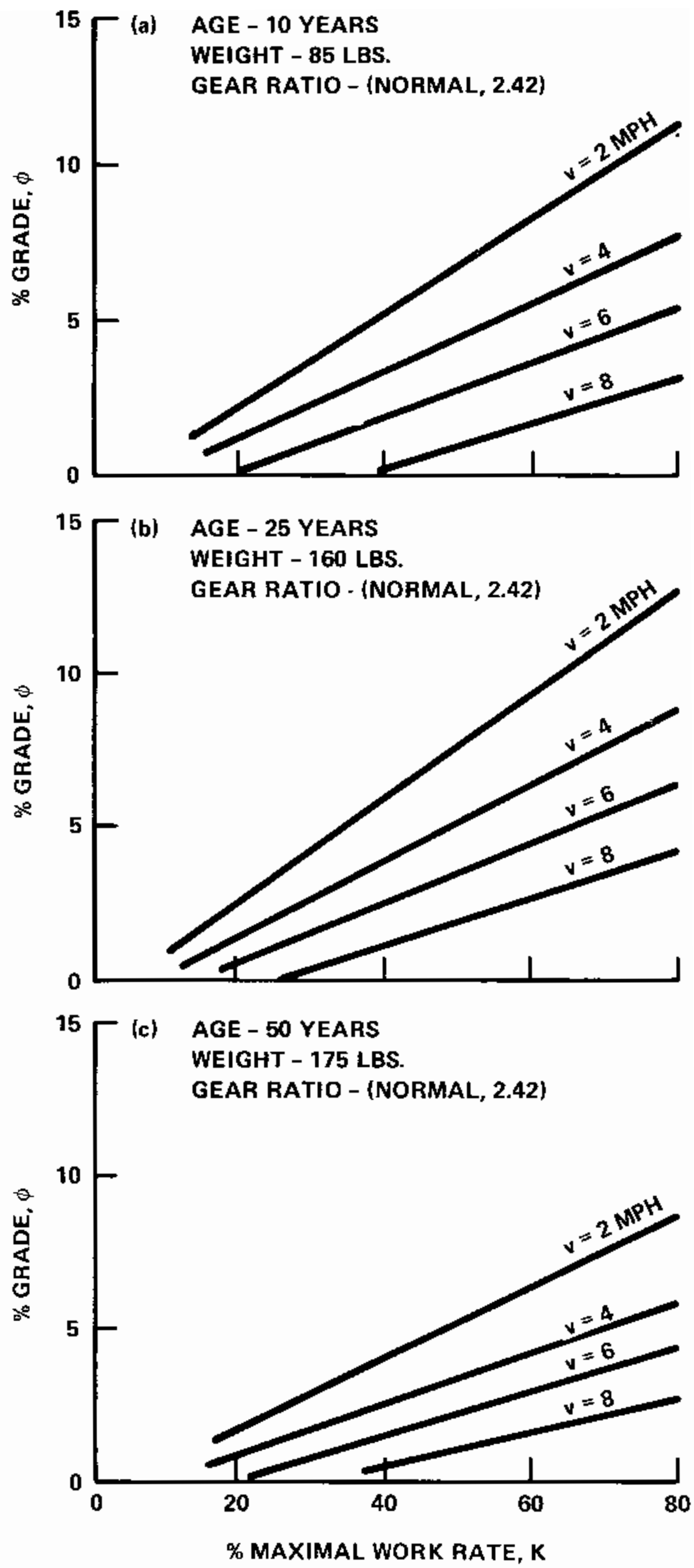

Figure B-3. Examples of Maximum Grades

Age - 10, 25, 50 years; and

Weight (W) - 50, 160, 175 lbs corresponding to the three ages.

In each case Equation (10) was solved for four different work levels corresponding to $k = 0.2, 0.4, 0.6$ and 0.8.

As expected for a given work level, the attainable velocity decreases as the grade increases and for a given grade the velocity increases with the work level. In Figure B-3(c), the 50 year old performs at lower levels than both the 10 and 25 year olds which points out that age may be one determining factor in the design of the bikeway grade. Such a decision should be taken into account when the "design cyclist" is chosen.[1]

Curves like those of Figure B-3 can be used to determine permissible bikeway grades. For example, if the designer specifies a 6 mph design speed and a work level of 50% of the maximum rate of energy expenditure, grades of 2.9, 3.5 and 2.2 percent could be tolerated for the 10, 25 and 50 year old, respectively. Or alternatively if the grade on a given bikeway route is given as 5 percent and again a 50% rate of energy expenditure is specified by the designer, speeds of 3.8, 4 and 2 mph, respectively, could be negotiated by the three cyclists.

In the design of steep grades such as occur on overpass facilities, the length of the grade is an important design consideration. Curves

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[1] It is recognized that in this example the 10 year old is riding the same bicycle and has the same projected frontal area as the others. Normally this is not the case but for the purpose of the example many parameters were kept constant for simplicity.

such as those of Figure B-3 can be used to determine the design grade length once the designer has decided on the length of time that the "design cyclist" should perform at a specified work rate. For example, if it were desired to have a 6 percent approach grade and the designer felt that the cyclists could tolerate riding at 60% of their maximal energy expenditure short periods of time, say 1 minute, the three riders of Figure B-3 could proceed at 3.8, 4.5 and 2.3 mph, respectively. The length of the grade based on the 50 year rider in this case would then be 202 ft. Similarly, for the 25 year old the length of the grade would be 400 ft. Naturally if the riders have a sufficient approach velocity they will be able to surmount the grade with less effort or, for the same effort, at a faster rate.

The above curves are presented merely as examples to illustrate how such data can be used in design. In all cases the gear ratio was fixed which affected the results at the lower velocities. For slower speeds a reduced gear would improve the grade climbing capability of the rider. For example when a gear ratio of 1.92 is used, the velocities for the 6 percent grade of the previous example increase to 4.4, 5, and 3.0 mph, respectively.

NOTATION

ϕ - the grade

W - weight of the cyclist (lbs)

W_b - weight of the bicycle (lbs)

N_1, N_2 - Normal ground reactions (lbs)

F_W - Wind resistance

F_f - friction force (lbs)

v - velocity of the bicycle (mph)

E - Gross mechanical efficiency of the cyclist

W_o - rate of work done by the cyclist (or rate of energy expenditure)

α - pedal frequency (rpm)

a, b, β - constants in Hill's efficiency equation

t - time for one muscular contraction (sec)

E' - efficiency calculated after the work-position basal energy has been deducted

f(α) - An expression for the normalized efficiency as a function of pedal frequency

E_{max} - Maximum gross mechanical efficiency expected from the cyclist

$\dot{V}o_2$ - rate of oxygen uptake (mlo_2/min/kg)

W'_o - maximum rate of energy expenditure $\frac{(kg\text{-}m)}{min}$

g(A) - ordinate of the curve which relates one's age to the maximal rate of oxygen uptake (mlo_2/min/kg)

k - fraction of the maximal rate of oxygen uptake

$\Delta \dot{V}o_2$ - additional rate of oxygen uptake required to do work against air resistance. (lo_2/min)

A_p - projected frontal area (m^2)

T - tire inflation pressure (psi)

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APPENDIX C

TABULATED RESULTS OF SELECTED RESPONSES TO A PRELIMINARY VERSION OF THE QUESTIONNAIRE

Approximately 700 preliminary questionnaires (an early version of the questionnaire in Figure 4.6.1) were sent to the membership of the Los Angeles County and Orange County Wheelmen Bicycle Club via their November, 1971 monthly newsletter. Realizing that the wheelmen represent a select group of dedicated bicyclists, the study was not made to determine elements of the demand for bikeways for the general bicycling population. Rather, the study afforded an excellent opportunity to gain valuable insights into how dedicated bicycling enthusiasts are now using their bicycles and on how they estimate separated bikeways would affect their own bicycle riding habits. Furthermore, the trial of the preliminary questionnaire resulted in several important improvements which were incorporated into the final version of the questionnaire.

The response rate of the Wheelmen to the questionnaire was exceptionally high. In fact, this response rate of approximately 50% is an indication of the Wheelmen's zealous enthusiasm towards cycling and efforts to improve cycling conditions. Some 372 questionnaires were returned, of which 15 were answered by more than one respondent by such innovative methods as using different colored inks, etc. The 15 multiple questionnaires were not included in the tabulations, however, because in contrast to the single respondents, the multiple respondents all appeared to answer only those select questions which appealed to them.

The replies of the Wheelmen were illuminating and interesting, especially when club members added their own supplementary remarks.

When asked to check the reasons for using their bicycles (among five choices) and to rate each reason in importance, the responses indicated that the respondents placed a high importance upon bicycling as a form of exercise and companionship. The tabulations are shown in Figure C-1.

When citing other reasons why they rode their bicycles, 13 specified for "fun", 14 for "pleasure", and 17 for "enjoyment". Other interesting replies included: for "mental release and good feeling", "ride to beat traffic jams in parking lot", and "to combat isolationist syndrome of autos."

A high percentage, 64%, of the respondents indicated that they travelled on streets with high auto traffic when making a typical trip. Many of them felt it necessary to make known their feelings in regard to the dangers of present riding conditions and what steps could be made to minimize these dangers. The following comments are a sampling of some of the feelings expressed:

"Need actual bike path."
"Routes should be completely separate from autos."
"Don't like riding bike to work because of traffic."
"Too dangerous to travel on congested streets."
"Wilshire (boulevard in Los Angeles) is a death trap."

Mixed mode travel was apparently quite important to the respondents. Of the 357 respondents, 59% indicated that they had automobiles with bike racks or some similar device to carry their bicycles to a riding area.

Several of the respondents from the Wheelmen do not limit themselves to weekend activities but take rather extensive trips as evidenced by the following written comments:

"Ride bikes on vacations."
"Fly to area for tours by bike."
"Extended trips because we vacation by bike."

Of some interest, 18% of the respondents indicated that when determining a place of residence their decision was influenced by

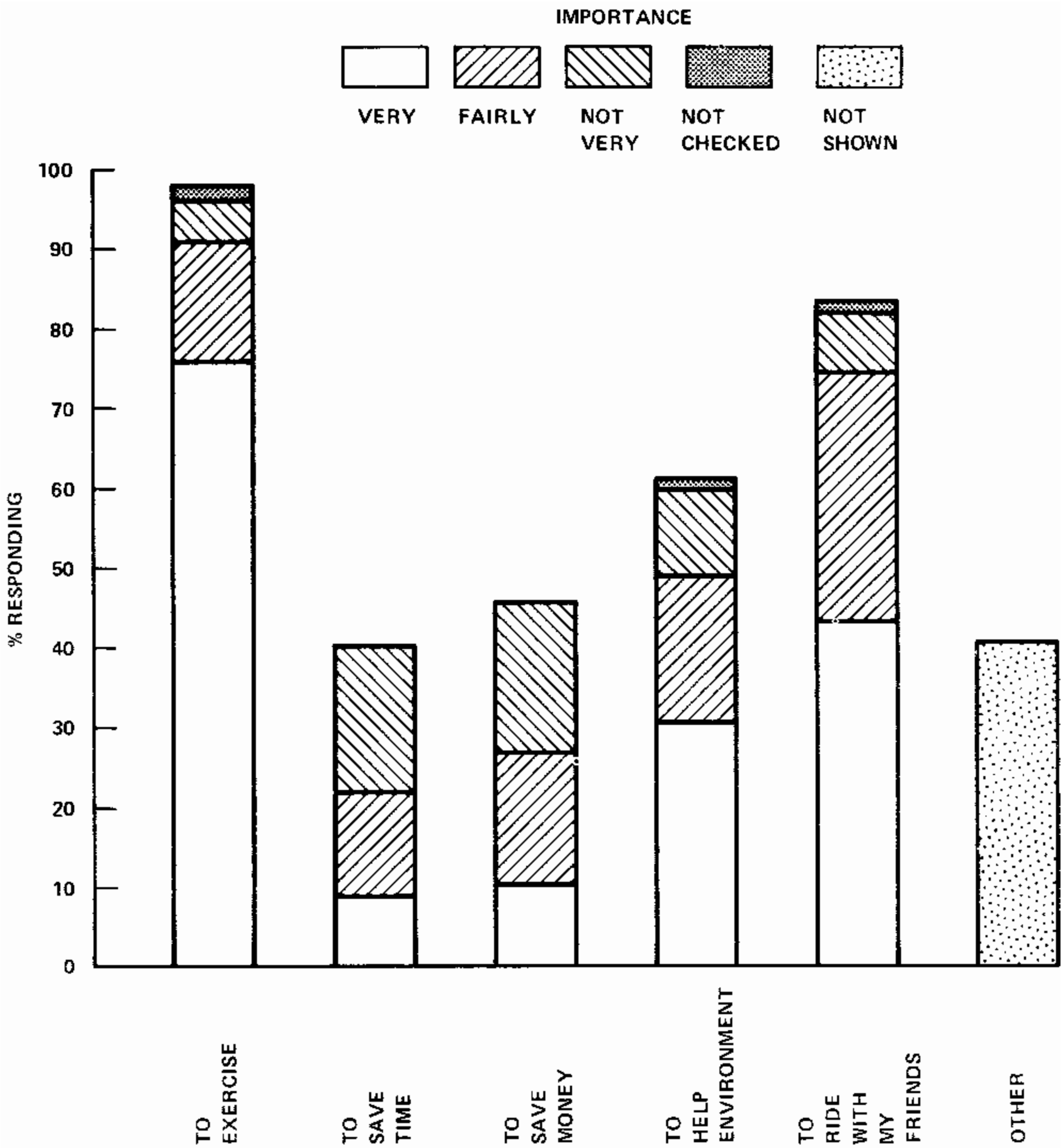

Figure C-1. Wheelmen Responses: Reasons and Importance Given for Bicycle Riding.

the favorability of the area for bicycle riding. If favorability of bicycle riding in an area enters into the residential location decision of less select groups than the Wheelmen, (just as proximity to schools, shopping and churches may motivate residential selection among the general population), it would appear that providing bikeways could form a positive benefit in community development. It remains for the future to determine whether bikeways in an area - once provided - would influence the make-up of a community, and its desirability to prospective residents.

One question specifically related to the types of trips (work, shopping, school, recreation) that the Wheelmen made by bicycle. Of the responses, 86.6% indicated recreation, 49.3% indicated shopping, 48.5% indicated work, and 30.5% indicated school.

The Wheelmen were questioned as to whether provision of bikeways along the sides of major arterial streets and along the sides of residential or collector streets would increase the number of times that they would use their bicycles on these roads.

It was initially hypothesized that for dedicated bicyclists, the provision of bikeways on major arterials would increase the useage of these arterials over similarly provided bikeways on residential collector streets. This hypothesis is subjectively supported by the contention that dedicated cyclists who use residential collector streets probably view them as adequately safe under low traffic volume; but on major arterials with heavy flow conditions, the provision of Class II bikeways would decrease their perceived risk and thus make the arterial more attractive for bicycle use.

Tabulated percentages are shown below for those who replied "yes" and "no".

Would providing bikeways at the sides of. . . . increase the number of times you would use your bike?	YES	NO
Major Arterial Streets	87.9%	12.1%
Residential (Collector) Streets	67.7%	32.3%

A Chi-square test was performed to test the null hypothesis that there is no difference in the proportion who replied yes for major arterial streets and the proportion yes for residential (collector) streets, against the alternative hypothesis that the proportion is greater for arterial streets. The null hypothesis was strongly rejected at the 1% level in favor of the alternative hypothesis.

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