CITY OF DAVIS
UNIVERSITY OF CALIFORNIA

BICYCLE CIRCULATION AND SAFETY STUDY

DE LEUW, CATHER & COMPANY · ENGINEERS AND PLANNERS

AD HOC ADVISORY TRAFFIC AND CIRCULATION STUDY COMMITTEE

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University of California, Davis

MR. LOU G. WEISS, Principal Engineer

De Leuw, Cather & Company

MR. DAN SMITH

MR. MIKE KENNEDY

* An additional six citizens appointed to the committee were unable to serve.

DE LEUW, CATHER & COMPANY
ENGINEERS AND PLANNERS
1256 MARKET STREET
SAN FRANCISCO, CALIFORNIA 94102
(415) 861-1302

August 31, 1972

The Honorable Mayor and City Council
City of Davis, California
and
The Office of Architects and Engineers
University of California - Davis

Gentlemen:

Enclosed herewith is the final report of the Davis Bicycle Circulation and Safety Study. This report, along with the companion report of the Davis Traffic Circulation and Safety Study, outlines findings and conclusions of the Study and details alternative improvement programs responding to current and future bike circulation and safety needs.

The City and University have excellent bike safety records and, considering the level of bike travel in the community and the existing system of special bike facilities, is a model for other U. S. cities contemplating bikeway systems. However, at a number of individual locations, physical facilities provided are a contributing factor to poor bike safety records. Long term European experience with facilities for utility-oriented cycling and Traffic Engineering fundamentals are basic resources for physical design solutions to these problems. European experience also provides invaluable background for development of bikeway location and design criteria.

The City and University bikeway system is an impressive network. However, several additions to the network are needed to achieve the objective of providing community-wide bike access equal to or better than that afforded the automobile. Well designed bikeway extensions into new development areas are essential for future bike safety as well as to maintain and emphasize the bicycle's role in community transportation.

We appreciate this opportunity to serve the City and University and wish to express our special thanks to the Ad Hoc Circulation and Safety Committee, to Mr. Lou Weiss, UC Davis Principal Engineer, and to Mr. Dave Pelz, City of Davis Director of Public Works, for their large contributions to the successful completion of this project. We also wish to acknowledge the cooperation and assistance of the City and University Police Departments.

Sincerely,

DE LEUW, CATHER & COMPANY

H. E. Lloyd
Senior Vice President

Daniel T. Smith Jr., P.E. 21,913
Project Manager

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SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

- Considering the level of cycle activity, the bicycle safety record in the City and on the UC campus is excellent in comparison to other California communities. However, at a number of specific locations the physical facilities provided are a factor in bicycle accident experience; at other locations physical facilities could be provided which would reduce incidence of certain types of accidents resulting from elements of characteristic cyclist and motorist behavior.

- The results of years of European experience in dealing with utility oriented and recreational cyclists in urban traffic situations, as documented in numerous reports and papers, and traffic engineering fundamentals provide a sound basis for bike facility physical design specifications and locational and functional design selection criteria. However, further experience in North American urban situations may be required to establish the applicability of certain European design treatments.

- Traffic projections indicate that four motor vehicle lanes will not be needed on Anderson Road. This means that bicycle lanes can be provided south of Rutgers Drive without necessitating removal of parking.

- Bike lanes are desirable in the downtown to increase the accessibility to and safety in that area for cyclists and to reduce the frictional effects of cycle travel on motor vehicle traffic, thereby increasing traffic capacity of downtown city streets. Implementation of an E-F Street one-way couplet would make space available for provision of bike lanes on those streets without necessitating gross removal of on-street parking.

- Special channelizations for bike traffic at on-campus intersections would reduce the bike-bike and bike-pedestrian conflicts which are a major factor in on-campus, bike-involved accidents.

- Reduction in grade profile on the La Rue Road bicycle underpass could improve the poor accident experience at this location. Future bicycle grade separations on campus and in the city area as well should conform to grade profile specifications as outlined in this report.

- Cycle-pedestrian ways provided in each of the alternative plans proposed for Richards Boulevard railroad grade separation reconstruction would be a significant improvement over existing conditions and would be an element of the principal cycleway linkage between South and Central Davis. Cycle facilities incorporated in Schemes B and C are superior to those provided in Scheme A.

- The Davis community has the unique opportunity to create a continuous cycleway completely separated from motor vehicle traffic and some 3.5 miles in length (including existing pathways on the UC campus) in greenbelt area along Putah Creek. This facility would serve primarily as a recreational route. However, the Southern Pacific Transportation Company has plans to replace the existing railroad bridge crossing Putah Creek with a fill-culvert structure. The City must act quickly to arrange for inclusion of a cycle underpass in this design to preserve the opportunity for linkage to the campus area pathways and maintain continuity of the route.

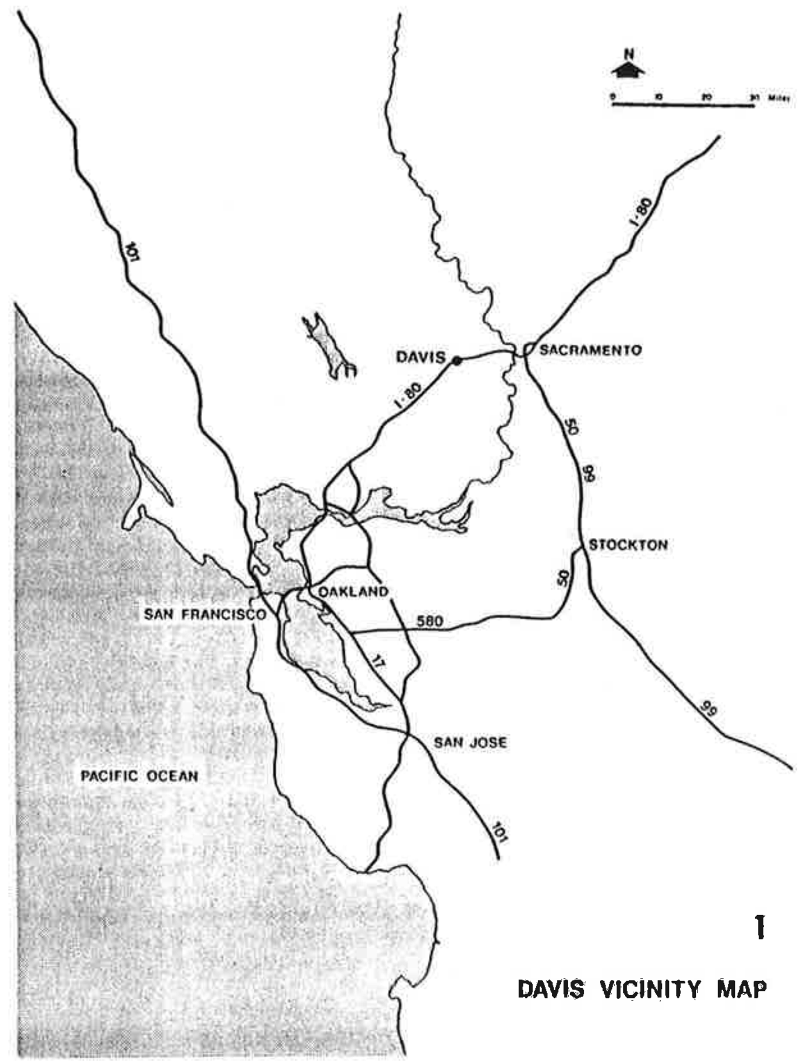
- In addition to providing cycle facilities on a one-third mile grid as an integral part of new developments, the system must be designed to preserve continuity to bike paths and lanes in existing developed areas and to provide corridor linkages to community activity centers such as the campus, the downtown and the schools.

I

INTRODUCTION

BICYCLES IN DAVIS

Davis, California is a small city, 1972 population 27,000, located in the Central California Valley, 14 miles west of Sacramento. An agricultural community over most of its history and site of one of the seven campuses of the University of California, Davis is currently experiencing pressures for transition from a rural campus town to a bedroom community, as suburban development spreads westward from Sacramento. In speaking of Davis the word most commonly used is "unique", perhaps the only accurate portrait of the community as regards its most outstanding characteristic -- the bicycle. "Davis" and "bicycle" are virtually synonymous. Over 20,000 bicycles are kept among a population of 27,000. But more significant than the sheer numbers of cycles or the high proportion of ownership is the way cycles are used.



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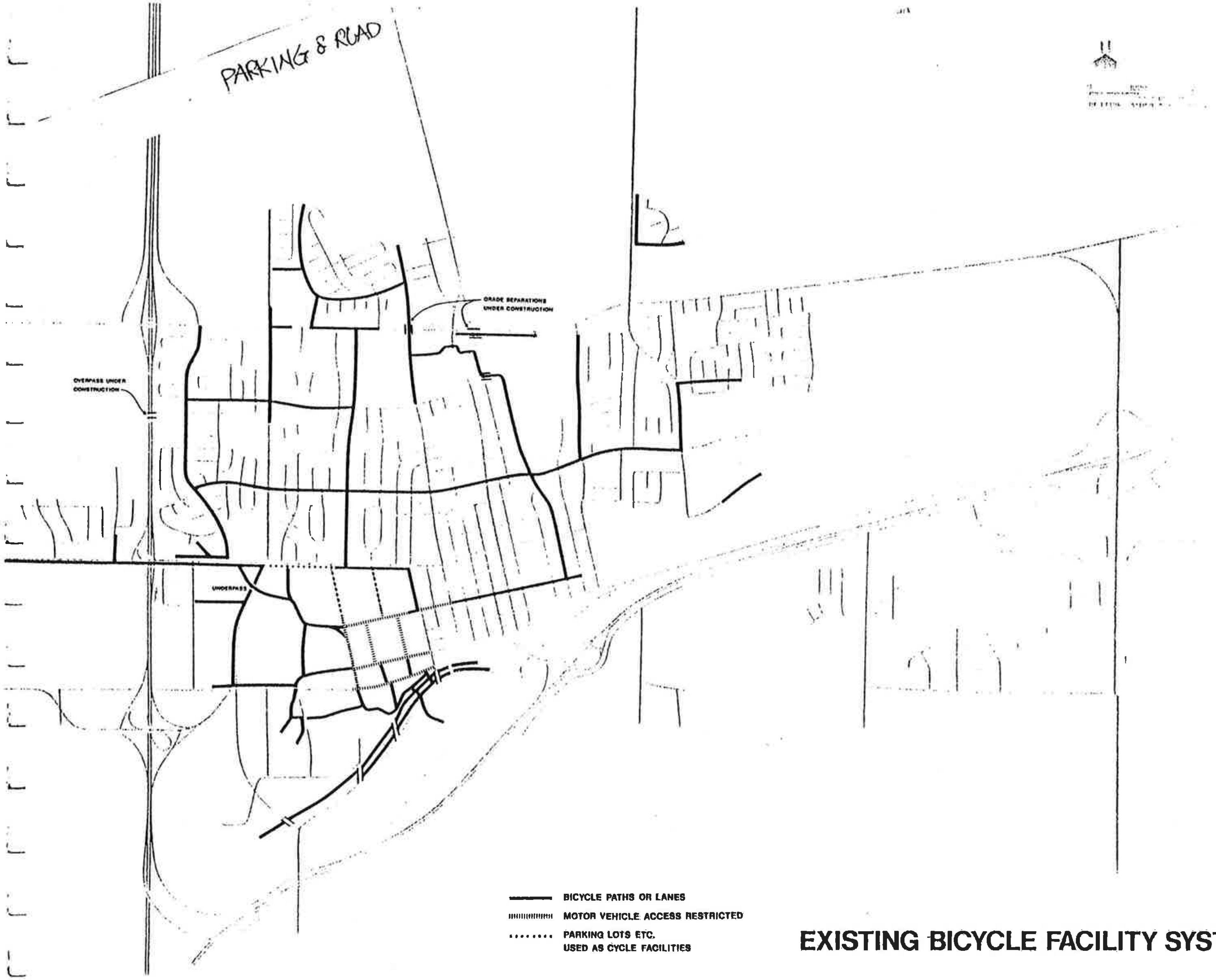
DAVIS VICINITY MAP

In Davis the bike is far more than a recreational toy or exercise vehicle. It is a vital element of the transportation system. Cycles are used for such utility oriented trips as commuting to and from work, school, shopping and other trips to specific community activity centers. Perhaps 30 per cent of the total person travel in Davis is by cycle.

A number of factors appear to contribute in enabling the cycle to play this major transportation role. Among these are mild climate, level terrain and wide streets. Presence of the University of California campus assures a high percentage of the population will be comprised of young adults and the dispersed layout of the campus itself encourages use of the cycle. Also important is the fact that Davis heretofore has been a closely defined and relatively self sustained community. All activity centers in the city are within easy cycling range of the most remote households and with relatively little external travel, the bicycle is a viable mode for almost all trips. But probably the most significant element in maintaining the cycle as a viable form of transportation has been the attitude of Davis residents and city officials and the provisions they have made to insure cycles are not crowded off city streets by growing automobile traffic.

As the City and University underwent a rapid expansion in the early 1960's, increased traffic accentuated the conflict between bikes and motor vehicles. It became apparent that because of their differing physical and operational characteristics, bikes and motor vehicles were not compatible in sharing street space, and, if the unequal competition between the two were not eliminated, the bicycle and with it the unique character of Davis would disappear. In response to this challenge, concerned citizens of Davis introduced to this country the concept of on-street lanes exclusively for bicycles. This concept, adopted and implemented by the City in 1966 has led to the creation in the City and on the UC campus of an areawide system of special bicycle facilities, including on-street lanes, separate pathways, grade separations, streets closed to motor vehicles and greenbelt trails. This system is indicated on Figure 2.



2

EXISTING BICYCLE FACILITY SYSTEM

THE STUDY

The success of the bikeways system is beyond question. However, in 1971 the City of Davis and the University of California, acting jointly, engaged De Leuw, Cather & Company to conduct a study of bicycle circulation and safety in the city and campus area. Objectives of the study were to evaluate Davis cycleway system performance both in terms of overall system effectiveness and effectiveness of individual facility components of the system, identify possible functional or safety deficiencies, prepare criteria or warrants for extending the cycle facilities system and conceptual design treatments for integrating cycle facilities in new developments and for incorporating them in previously developed areas, and to develop specifications and standards for cycle facilities -- grades, widths, curvatures, sight distances, etc.

Conceived as developing a general guideline for bicycle facilities system extensions in Davis as well as for other communities caught up in the current bike boom, the study has also concentrated on specific Davis problems such as increasing the bike-pedestrian orientation of the downtown and reducing bike-bike and bike-pedestrian conflicts in the central campus area.

This project, sponsored jointly by the City of Davis and the University of California, is funded by the National Highway Traffic Safety Program through the State of California Office of Traffic Safety. A study of motor vehicle facilities needs, the Davis Traffic Circulation and Safety Study was undertaken concurrently under the same sponsorship and funding. Though findings of that study are reported separately, motor vehicle traffic and bicycle facilities improvements in many instances are inseparable and several plans presented herein reflect considerations and findings which are more properly the results of the traffic study.

Because of Davis' unique long-term experience with urban, utility-oriented cycling, most basic knowledge of cycle facilities needs and problems lies with local Davis residents. Moreover, for a study of this nature to produce meaningful results and plans and recommendations which are capable of achieving required community consensus, continued input from the community is necessary in the plan formulation and evaluation stage.

To this end a fifteen member Ad Hoc Circulation and Safety Study Committee was appointed, representing a broad spectrum of city and University community interests and including as ex-officio members the City Director of Public Works and Campus Principal Engineer. The Committee worked closely with the consultants, meeting approximately every two weeks between January and June of 1972, and their familiarity with needs and desires of Davis residents and insights to bicycle circulation and safety problems were vital to the successful completion of this study program.

II

CYCLE FACILITIES, PLANNING AND DESIGN

The intent of this chapter is to outline factors affecting cycle facilities planning and the principles of good design practice. Many of the concepts stated here are already understood and practiced explicitly or implicity in Davis. Other material is based on research and observations over the past year in Davis and in several San Francisco Bay Area communities. Another resource has been research reports and national standards published in many northern European countries -- the results of many years' experience in cycle facilities planning.

Increasingly, communities attempting to establish cycle facilities systems are looking to Davis as a model. Thus, the concepts outlined herein are not only intended as guidelines for future cycle facilities planning in Davis and as rationale for specific Davis improvements detailed in the chapters which follow. They are presented with an eye to assisting other communities in developing cycle facilities programs.

TYPES OF CYCLING

Purpose of riding is a major factor affecting cyclist behavior and corresponding facilities needs. Two principal classifications of riding can be distinguished: recreational and utility oriented. Recreational cycling includes all types of cycling done specifically for purposes of pleasure: neighborhood riding, sightseeing -- touring and racing.

Neighborhood

Neighborhood riding is most commonly done by children. It is characterized by a short radius of activity from individual residences, pairs or small groups of riders, play rather than purpose, and unpredictable behavior. While neighborhood riding may comprise a substantial proportion of total cycling activity, the above noted characteristics make it impossible to design special facilities for this usage. However, safety can be enhanced through education, supervision and urban design practices which structure the community to minimize motor vehicle traffic in neighborhood areas.

Sightseeing and Touring

Sightseeing and touring cycling is primarily a fair weather activity with peaks on weekends, holidays and evenings. Riders may be individuals, families, or small or large groups including organized cycling clubs. A broad range of cycling experience and skills is found among touring-sightseeing riders and distances traveled and degree of challenge of routes selected varies similarly. However, cyclists in this category have in common a preference for select, visually interesting and scenic routes including roads and highways with low volumes of automobile and truck traffic as well as paths and trails. As time saving is generally not a consideration, meandering routes and hilly terrain may be positive rather than negative elements. Touring-sightseeing cycling is basically a regional activity but local facilities should also be provided to serve local sightseeing as well as to complete and complement regional systems.

Racing

Racing is practiced by limited numbers of experienced cyclists. Desired characteristics of facilities include loop courses with smooth pavement surfaces, low motor vehicle traffic volumes and hills and scenery to add interest. Special provision of facilities for this group is not usually a priority for local governmental jurisdiction.

Physical Fitness

Physical fitness riding is not a category of cycling to which specific rider characteristics can be attributed. While many persons are motivated to cycle for considerations of health or physical fitness when they do cycle, their trip normally falls into the recreational categories of touring, sightseeing, or racing, or is a utility-oriented trip.

Utility Oriented

While recreational cycling is by nature a daytime, fair-weather activity, a surprising amount of utility cycling continues through night hours and during inclement weather periods. In Davis the vast bulk of cycling is utility oriented. This is not an unusual situation as communities, in awakening to the cycle boom of the 70's and surveying facilities needs, are discovering to their surprise that utility oriented tripmaking is the most extensive form of cycle usage. What is unique in Davis is the level of utility cycling in comparison to total person travel in the community. Bikes comprise 67 per cent of AM peak commute hour traffic on a residential collector street approaching the UC campus, 20 per cent at an arterial intersection north of the downtown and nearly 20 per cent of PM peak traffic at a principal downtown intersection. In surveys conducted in 1971, some 60 per cent of the students and 25 per cent of the faculty and staff at UC Davis indicated the bike as their primary commute transportation mode. Between 40 and 60 per cent of school age children ride bikes to school in fair weather. Considering the above figures in terms of reductions in traffic volumes, congestion and disruptive impacts of motor vehicle traffic as well as reduced need for parking and street facilities, the impact of utility oriented cycling in Davis is staggering.

Bicycle-motor vehicle traffic friction in the downtown.

The principal characteristic of utility oriented cycling is the desire of the rider to reach his destination with a minimum expenditure of energy and time. As a consequence, cyclist generally will not select routes incorporating significant out of direction travel, adverse grades or stops if more favorable routes are available. Desire to avoid facilities heavily traveled by motor vehicles and for aesthetically pleasing surroundings are only secondary considerations. Well designed cycle facilities provided along the cyclist's travel desire lines will as a rule be used but will be deserted in favor of city streets if they stray or imply extra expenditures of energy for stops or grades.

WHY SPECIAL FACILITIES?

As indicated in the preceding discussion, recreational cyclists generally tend to avoid streets and highways with high motor vehicle traffic volumes. Consequently, though recreational cycle facilities are needed to encourage and provide improved opportunities for this type of activity, in terms of safety considerations these needs have low priority.

Due to inherent relationship of land use distribution to transportation network form, "arterial" and "collector" streets are normally the most direct linkages between residential areas and activity centers of a community.

As a result, utility oriented cyclist travel desire lines tend to be along city streets most heavily traveled by motor vehicles. Bikes and motor vehicles in high volumes do not mix compatibly. The basic problem seems to lie in differences in physical and operating characteristics.

Most obvious contrast is physical. Automobiles are large and sturdy. Bikes are, in relation, small and frail and their riders are unprotected from impacts. Auto-bike collisions are almost inevitably injury accidents. Normal operating speeds of motor vehicles on city streets range to more than four times the average travel speed of bikes on level terrain. The speed differential of itself causes specific safety problems as well as producing driver irritation and impatience when delayed by a bike. The combination of greater speed potential and mass tends to produce a driver arrogance in which the roadway is assumed to inherently belong to the auto, while the bike, as an inferior vehicle, is expected to yield. On the other hand the cyclist, motivated by the desire to maintain the momentum developed through his own physical exertions, is reluctant to yield street space or right-of-way if yielding will cost that momentum. Aggressive driver behavior resulting from arrogance or impatience plus cyclist willingness to place himself in compromising situations to maintain momentum produces confrontations and accidents.

Differences in regulation and discipline in operations is another element of the bike-auto compatibility problem. Safe and expeditious flow of vehicular traffic depends on an organized system of behavior, a system which produces regularity and predictability in the movement of vehicles in traffic. To this end an extensive body of operating codes and a system of signs, signals and markings has been developed over time. Driver understanding of operating codes, signs, signals and markings is insured through formal driver education and required licensing with regular testing incorporated in the licensing procedure. All auto drivers are adults or near adults of whom mature and rational behavior is expected. Strict enforcement by law officers results in general compliance with codes and controls.

Cycles are bound by the provisions of the vehicle code and other local ordinances but there is no cyclist licensing-testing procedures and cyclist education normally begins and ends with the single lesson of mastering the art of balancing on a two-wheeler. Thus, the cyclist, even if he generally understands the provisions of the vehicle code, may not feel that it applies directly to him. This feeling is reinforced by inconsistent and lax enforcement of codes and ordinances with respect to cycles and by the fact that in many cases prescribed procedures run against the natural rational inclination of the cyclist. To the motorist a "STOP" sign has a single clear message "Come to a complete stop." For the cyclist, blind obedience to such a sign conflicts with the overriding desire to maintain momentum. He regards the "STOP" sign as a warning of inherent danger at the intersection but in most cases will obey it only if cross traffic is visible. Cyclists may understand that hand signals provide desirable informational exchange and may know the correct procedures for signaling. However, the act of hand signaling makes maintaining balance and executing turning movements difficult, even dangerous. Thus, cyclists will give turn signals only when they perceive clear danger to themselves and perhaps not even then. Bike left turns are themselves another example of unpredictable behavior. Instead of regularly following a prescribed left turn path, the cyclist will select the route which, according to the instantaneous perceived traffic situation, will allow maintenance of momentum through the intersection. Wrong way (opposed to motor vehicle traffic) riding is another common violation of code. At times this is done for shorter travel distance considerations but in other instances it is due to a physical characteristic of the bike: most have no rear view mirrors. Wrong way riding allows the cyclist to see traffic which will pass closest to him. Added to the frequent non-observance of code are the facts that the bicycle is a basically unstable vehicle of which even a skillful rider may lose control and a considerable segment of the riding public is comprised of children who may not have fully mastered necessary physical skills.

As Eighth Street traffic becomes congested, encroachments on the bike lanes increase.

The result when one mixes motor vehicle traffic, dependent on and anticipating orderly and predictable behavior, with bicycles, the traffic stream behavior of which is dominated by other considerations, is conflict. The need for separate facilities or facilities which result in predictable patterns of travel and resolve conflicts is clear.

BIKE IMPACT ON TRAFFIC SAFETY

Recent experience in Davis and the results of studies conducted in European countries generally substantiate the conclusion that special bicycle facilities make a positive contribution to traffic safety.

Davis experience is difficult to quantify in a meaningful statistical way. Because mechanical or electronic bike traffic counting devices are not generally available, bike traffic volume measurements must be conducted manually. And since bike traffic volumes in Davis change sharply over very short segments of individual streets, the level of effort required to provide inputs for accurate determination of accident rates per bike-mile makes such computation impractical. Moreover, the substantial population growth in the community with attendant increases in bike and motor vehicle traffic brings question to the validity of comparing current bike accident totals to totals prior to the implementation of the bike facilities system. However, a number of factors point to the effectiveness of special facilities in reducing cycle accident occurrences.

- Davis' record of only 31 reported cycle-involved accidents in the past year is outstanding for a community of this size notwithstanding the extraordinary level of bicycle travel in Davis.
- Over the two-year period for which accident records were studied in detail only two of 74 reported bike-involved accidents occurred in the bike lanes. In fact, in the more than five years since bike lanes were first introduced in Davis, only a handful of mid-block accidents have taken place in the lanes.
- Of the three Davis street segments having highest rates of bike accidents per mile, two have no bike facilities and the third only partial provisions for bikes. These streets serve significantly lower bike traffic volumes than streets having lower accident rates which do have bike lanes or paths. If sufficient volume data were available to compute the accident rates per bike-mile, rates on the three accident-prone, no-bike-facility streets would be several times the rate on the most accident-prone streets which have bike facilities.
- Both motorists and cyclists in Davis indicate feelings of general uneasiness and apprehension in mixed traffic situations and feelings of increased security in areas where cycle facilities are provided.

European accident studies generally indicate safety benefits of bike facilities. The most recent of these, reported by the Danish Council of Road Safety Research (1), presented results of a three-year study concluding that bicycle lanes have a clear influence on the number of bicycle accidents and their distribution between road sections and intersections. The study reviewed three year accident experience on four 4- to 5-mile roadway segments with roughly equal numbers of cross streets, two of the segments having bike lanes and two having no special bicycle facilities. Principal findings were:

- On roadway sections with bike lanes, the rate of bike accidents per bike-mile is significantly lower than on sections without bike lanes. Bike lanes appear to produce a 40 per cent reduction in bike accidents per bike-mile overall.

- The bike lanes reduced midblock accident rates by 60 per cent but intersection accident rates were marginally higher with bike lanes provided (the latter difference is not statistically significant).

- While accident rates at intersections did not differ significantly, bike lanes produced substantial changes in the pattern of accidents, with right-turning motor vehicles striking cycles moving straight through the intersection increased.

The Danish study findings are supported by results of accident research in England (2), France (3), and The Netherlands (4, 5). However, the complete relevance of the latter two studies is of some question as moped (motor assisted bicycle) traffic is permitted in the bike lanes. In any case, the European literature substantiates that bike lanes do produce significant reductions in overall bike accident rates primarily by reducing mid-block accidents. The European accident research also indicates certain accident hazards inherent in two-way sidewalk pathways (3). This problem is discussed in detail in a subsequent section.

DEFINITIONS

Considerable ambiguity, overlapping and conflict exists in current usage of terminology describing bike facilities. The following definitions are presented to clarify terminology which is used consistently in this report and to propose this terminology for general usage.

- <u>Mixed Use</u>: Bikes and motor vehicles sharing street space with no provisions for segregation of traffic.

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

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

- Bike Lane: An on-street treatment in which separate auto and bike travel lanes are designated visually by signs and street markings.

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

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

- Sidewalk Path or Wide Sidewalk Treatment: A bike path within the roadway right-of-way which may be used by pedestrians as well as cyclists.

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

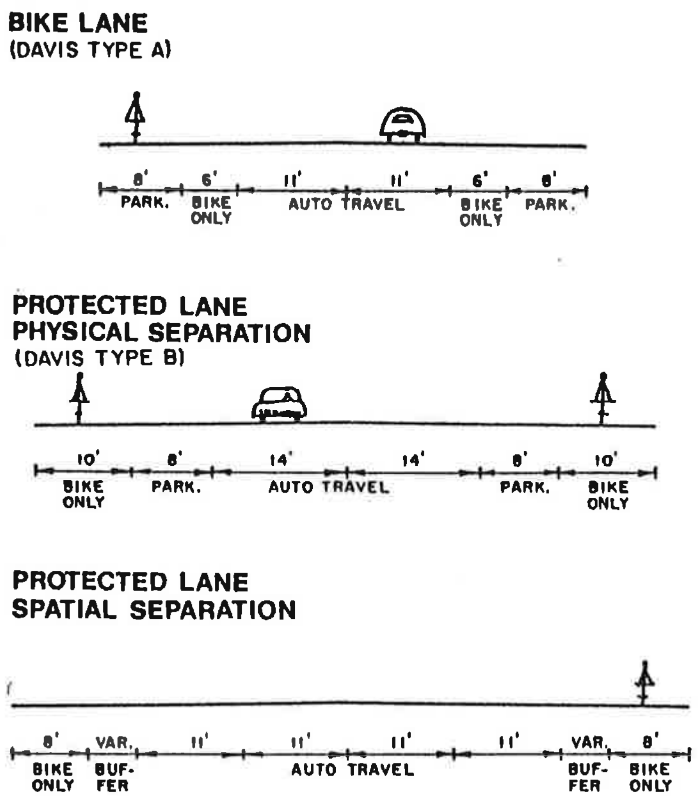
- Mall Treatment: A block or blocks of city streets closed to motor vehicle traffic with the exception of emergency and possibly service and public transit vehicles.

Typical examples of several of these treatments are illustrated on Figure 3.

OPERATIONAL CHARACTERISTICS OF BICYCLE FACILITIES

Mixed Use

Characteristics of the mixed use situation have been generally described in the foregoing section on the need for special bicycle facilities. Mixed use of streets is desirable only when traffic volumes and speeds are low as on local residential streets.



3

TYPICAL BIKE FACILITY TREATMENTS

Bike Lanes

With proper education as to their use, bike lanes have proven effective in separating flows of motor vehicle and bike traffic and in reducing midblock car-bike accidents. The defined space eliminates the tendency for cyclists to distribute themselves over the roadway cross-section and gives the cyclist a sense of security. Furthermore, presence of the bike lane itself serves as a reminder to the cyclist of his responsibilities to observe traffic regulations. For the motorist, the bike lanes provide a predictability and sense of security and the removal of the slower bikes from the motor vehicle lanes results in improved operations and capacity. However, the lanes do not physically prevent motor vehicles or bikes from encroaching on the territory of the other and encroachment, some deliberate, some inadvertent, does occur. Inadvertent encroachments are relatively rare ... the car which strays from its normal lane, loses control or makes a panic maneuver in an emergency situation, the cycle which veers out of the bike lane to avoid a parking or de-parking car or to avoid the open door of a parked car all are examples. Deliberate encroachments are more common...the right turning car which makes its approach to the intersection in the bike lane, the car which enters the bike lane to avoid another car which is blocking the motor vehicle lane while awaiting the opportunity to execute a left turn to a driveway at midblock or to a cross street, the bike which suddenly leaves the lane and crosses the street at midblock to reach a destination on the other side or the cycle which leaves the lane approaching an intersection in order to execute an unauthorized form of left turn which will allow it to maintain momentum...are some of the common forms of deliberate encroachments. Encroachments are partially an element of the intersection problem which is discussed subsequently. However, encroachments tend to increase with increased motor vehicle volumes (particularly as capacity is approached) and speeds, thus on high speed-high volume streets more positive physical separation is desirable.

Protected Lanes

Protected lanes in varying degrees provide elements of positive physical separation between cycles and motor vehicles. Lanes protected by visually delineated buffer areas are very similar in operation to unprotected on-street lanes with the exception that the width of the buffer area tends to reduce the level of encroachment and frictional effects of traffic. Lanes protected by raised buffers more completely reduce encroachments and frictional effects. Protected lanes located between the parking shoulder and curb line have most positive separation. However, the parked cars create sight distance problems at driveways and intersections. Inability for cyclists to cross streets at midblock in this type of treatment results in two-way usage which, in turn, leads to intersection problems described subsequently. Protected lane treatments are most appropriate for very specialized situations; typically in cases where parking turnover produces high frictional effect in the bike lanes, on rural secondary highways where high speed traffic makes protection desirable, where wide pavement and shoulder width is available but parallel pathways are unfeasible, and in very specialized circumstances when a buffer between motor vehicle traffic and abutting land uses is desirable.

Sidewalk and Independent Paths

Sidewalk pathways eliminate midblock bike-motor vehicle friction. However, frictional interference of pedestrians may discourage usage of these facilities as does frequent interruption by cross streets and driveways or meandering of the path. An additional problem is establishment of a visual relationship between motor vehicles and cycles on the sidewalk path on approaches to intersections. Sidewalk paths are most effective on long stretches uninterrupted by cross streets where there is no frontage development or where frontage development is oriented to internal streets. Independent paths provide the most desirable environment for cycling. However, care must be taken to avoid compromising the primary objective of serving origins and destinations without necessitating significant out of direction travel. Additionally, independent paths tend to intersect roadways at isolated locations away from regular street intersections and thus may result in poor accident experience as discussed subsequently.

WARRANTS

Criteria for locating bicycle facilities and for specifying their conceptual design treatment depend on public policy determinations, physical constraints and operational considerations. In Davis as in most European countries the overall rationale in providing the facilities has been to afford the cyclist safe and convenient community-wide accessibility equal to or better than that afforded the auto (6, 7). With this rationale, facility specification proceeds on the basis of physical, functional and network service continuity criteria. Other communities may have more limited objectives such as improving conditions in accident prone locations, serving high bike traffic generators such as schools, or providing essential recreational facilities. Again, functional criteria relate most closely to achievement of these objectives. Cost-benefit evaluations have not been a major determinant in planning cycle facilities. Many inputs are elements normally costed to quantified in typical highway and transit analyses...cost of physical facilities, value of reduced accidents, savings in transportation costs, value of reduced traffic congestion, savings in costs for provision of parking and other auto-oriented facilities, reduction in air pollution, etc. But quantifications on the micro-scale necessary for cycle facilities decision-making is impractical if not impossible. Moreover, non-quantifiable factors...the sense of security afforded, the fact of having the viable choice of safely using the bicycle as a regular transportation mode, the community image and character elements, to cite a few...appear to be as important to decision-making as costable or quantifiable criteria.

System Criteria

Warrants for special cycle treatments in European countries are generally based upon threshold levels of motor vehicle and bicycle traffic volumes taken singly or in combination. Volume specifications are grossly inconsistent from country to country with some including mopeds in the cycle volume count. Most do not take into consideration relevant conditions such as traffic speed, pavement and right-of-way width, presence of heavy trucks in traffic, previous accident experience or abutting land use. German specifications, which have achieved the most general acceptance, are presented on Table 1 (8). They indicate provision of cycle facilities at volume levels which reflect collector street function or higher type facilities.

Placement of cycle facilities along all collector and arterial streets as implied by the German standards relates well to new town planning practice in The Netherlands (7). There it has been determined that to achieve the objective of community-wide cycle accessibility, a one-third mile spacing of the cycle facility grid is necessary. In the United States, one-third mile is the average arterial-collector street grid spacing in low-medium density residential areas. This is roughly the spacing of the Davis arterial-collector street grid. Thus, grid spacing of streets where traffic volumes reach levels which make provision of cycle facilities desirable from a safety standpoint is roughly equal to the grid spacing desirable to facilitate community-wide cycle accessibility.

Table 1
BIKE FACILITY CRITERIA - GERMANY

Motor Vehicle Volume	Bicycle Volume	Conditions	Type
2000 ADT	500 cycles/day	Urban	Lane or Pathway
3000 ADT	200 cycles/day	Urban	Lane or Pathway
2500 ADT	200 cycles/day	Rural	Lane or Mixed Use
2800 ADT	30 cycles/hr.	Rural	Lane or Mixed Use
2500 ADT	200 cycles/day	Rural	Lane or Pathway
2500 ADT	30 cycles/hr.	Rural	Lane or Pathway

Source: 8

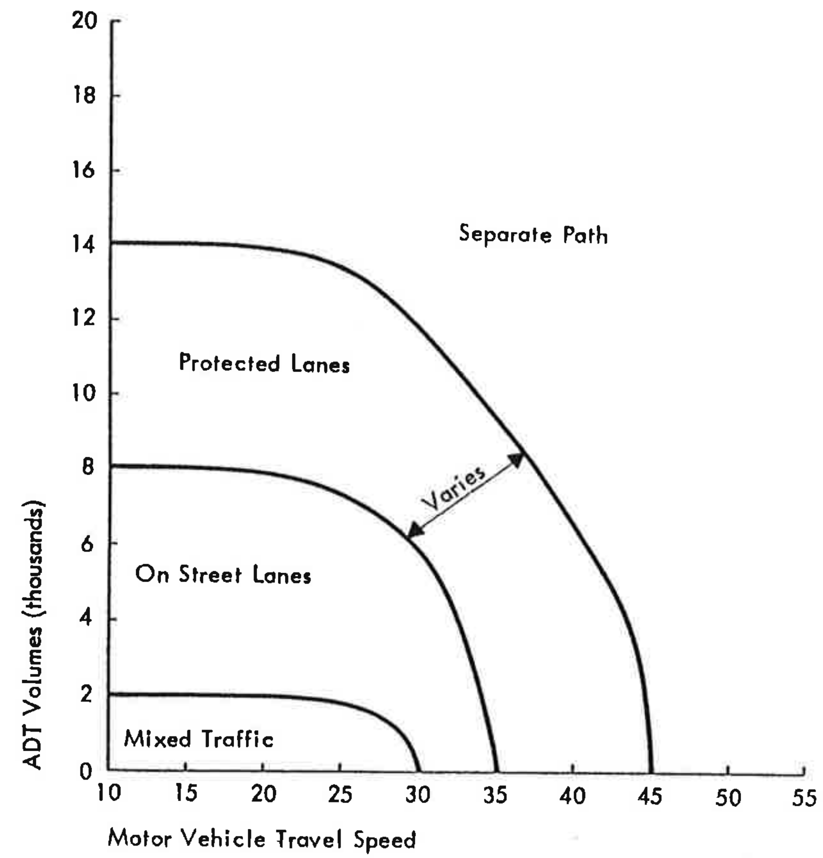
For this reason and for the fact that community activity centers, which are the primary destinations of utility-oriented cyclists, tend to be located along the arterial-collector street system, it is recommended that cycle facilities be placed along all arterial and collector streets. Other cycleways should be provided as necessary to achieve a network grid with spacing at least as fine as one-third mile and to serve any major cycle traffic generators located off the arterial-collector system. Facilities along streets could be replaced by parallel independent paths in greenbelt areas and other available rights-of-way if essential network continuity and direct service to cyclists' destinations could be maintained. Otherwise, these independent pathways should be regarded only as supplements to the major grid system or recreational route options.

Design Selection Criteria

The foregoing indicates generalized areawide system criteria but does not provide guidelines for selection of specific design treatments for individual facilities. Design selection should be based upon the functional characteristics of the various bikeway types as outlined previously and the relevant character and constraints of the individual corridor in question. These include traffic volume and speed, truck traffic volume, accident experience, existence of bus routes and bus stops, pavement width and right-of-way availability, abutting land use and grade profile. To date no comprehensive methodology for bringing together these elements in a design selection process has been detailed. The following guidelines are set forth on the basis of individual established criteria, empirical observations and engineering-planning judgment and should be regarded as a first step in developing a comprehensive design selection methodology.

Figure 4 presents a scheme for specification of bike facility treatment on the basis of motor vehicle volume and speed. Once volume-speed limits of a given type of treatment are exceeded, a higher type treatment is mandated. However, a higher type treatment may be substituted at any time on the basis of other considerations even if volume-speed limits of a lower type treatment are not exceeded.

In the figure, mixed use is indicated only where exposure levels are low; volume-speed standards are set at the upper limits of local street function. On-street lane limits are defined first by the traffic volume level at which deliberate motor vehicle encroachment on the bike lanes could be expected due to congestion and second the speed limit at a level at which the lanes become psychologically ineffective and the wind and road debris stirred up by motor vehicles become a factor. Tolerable volume level obviously depends on the individual street section and would be defined as the nomi-



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RELATIONSHIP OF MOTOR VEHICLE SPEED VOLUMES TO BICYCLE FACILITIES REQUIREMENTS

nal ADT volume at which level of service "D" operations are incipient. Operating limits for protected lanes and sidewalk paths are difficult to define since in most instances these treatments will be utilized under special circumstances; a protected lane where parking turnover is high or a sidewalk path where insufficient pavement width is available for an on-street lane are examples. However, there is a limited volume-speed range between the upper limit of applicability of on-street lanes and the level at which independent pathways become desirable. In this range the protected lane properties of eliminating motor vehicle encroachments and wind blast effects are significant. The upper limit of this level or threshold level at which independent pathways are mandated occurs where the motor vehicle volume-speed profile becomes such that complete separation of bike and motor vehicle movements, particularly at intersection or interchange areas, becomes necessary.

Other Considerations:

- Provide protected lanes or sidewalk paths over on-street lanes where parking turnover is high, on low headway bus routes, or where truck volumes are heavy.

- Provide sidewalk or independent paths where insufficient pavement width is available for on-street facilities.

- Provide independent paths where short block spacing, frequent driveways and incompatible land use frontage would interfere with operation of sidewalk paths or protected lanes.

- Where available greenbelt or other available rights-of-way offer the opportunity to provide direct service independent of motor vehicle rights-of-way, provide independent paths.

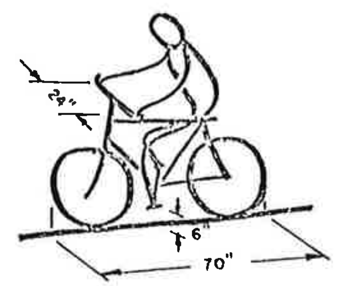
BIKE FACILITY DIMENSIONAL REQUIREMENTS

Figure 5 illustrates the basic elements of bike facility space requirements: the area occupied by the cyle and rider, the maneuvering room required since the cyclist is incapable of traveling in a perfectly straight line, and the additional clearance required for shy distance from horizontal and vertical obstructions. The dimensions are conversions to the nearest inch of German standards which have nearly worldwide acceptance (8). As indicated in the figure the basic lane width is 40 inches (1 meter), not including shy distance to obstructions beyond the edge of pavement. In the case of multi-lane pathways, it is permissible for the external maneuvering allowance to overhang the edge of pavement.

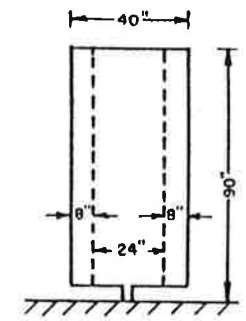
BIKE DIMENSIONS

According to these standards the minimum width for a single on-street bike lane would be slightly over 4 feet including right-hand shy distance between the bike and curb or parked auto but with left-hand shy distance assumed to be included in the width of the motor vehicle traffic lane. However, it appears desirable as a general practice to provide two-lane widths for all on-street bike lanes as well as for any bike pathway. This practice is recommended in almost all national standards and is particularly important in the case of on-street lanes as it allows one bike to pass another or to avoid a parked car's open door without encroaching on the motor vehicle traffic lane. The Davis "Type A" on-street lanes are only 6 feet wide, less than the 80 inches required for two-lane maneuvering allowance alone with no shy clearance. However, most parked cars do not utilize the full 8 foot reservation of the standard curb parking strip and shy distance can be assumed to be supplied within the parking lane allocations. The Davis "Type A" lanes (see Figure 3) in practice function as two-lane facilities but this width must be considered the lower limit of effective two-lane function. Where street width is available, 7 or 8 foot bike lane width is desirable.

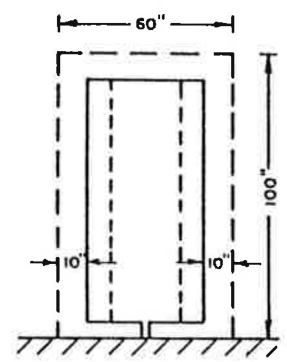
Table 2 indicates basic minimum widths for vehicle travel lanes by street functional classification. Based on this and the preceding information, minimum collector or local street pavement width for provision of a



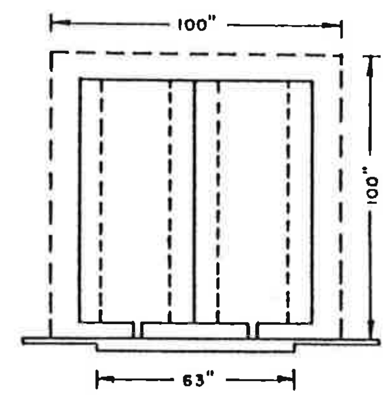
TYPICAL BICYCLE DIMENSIONS



BICYCLE OPERATING SPACE



OPERATING SPACE PLUS MINIMUM CLEARANCES



TYPICAL BICYCLE PATH DIMENSIONS

5

BASIC DIMENSIONS

single on-street bike lane in each direction would be 44 feet with parking allowed on both sides, 28 feet if parking is prohibited on both sides. Minimum width for provision of the more desirable two-lane bike lanes in each direction is 50 feet with parking permitted, 34 feet if parking is prohibited.

Figure 6 presents capacity of level bikeways as a function of width as interpolated from various European standards (4,8,10,11,12). Definitive research on bikeway capacity has not been completed and the European source material is not fully consistent. However, as can be seen from the figure, hourly capacity of the basic 40-inch lane is over 1,000 bikes per hour and relatively limited pathway widths afford capacity in excess of that which might be required even in the most heavily traveled areas. Thus, basic maneuvering space, level of service and other considerations will determine bikeway width rather than capacity.

Table 2
MINIMUM MOTOR VEHICLE TRAVEL LANE WIDTHS

Type	Width in Feet
Expressway	12
Arterial	11
Collector	
San Francisco Residential	10
Other	11
Local	
San Francisco Residential	10
Other	11

Source: Traffic Engineering Handbook

DESIGN SPEED AND CURVATURE

Possible bike travel speed on level terrain ranges to more than 30 miles per hour. Individual cyclist speed is affected by numerous factors including weather (wind, temperature, wet or dry roadway surface), type of bicycle (weight, gearing), roadway conditions and the cyclist himself (physical condition and motivation). Average travel speeds on level pavement as observed both in Davis and in Europe fall in the 10-11 mile per hour range and 10 mph appears an appropriate design speed for bikeways (8,13). Minimum curve radii on bikeways should permit unbraked turns at design speed. German standards call for a minimum radius of 16.4 feet (5 meters) for a 10 mph curve. Recent experimental work in the U. S. indicates a radius of 14 feet would be satisfactory for 10 mph design speed and has postulated the following equation for determining required radius as a function of speed (14).

$$R = 1.25\,V + 1.4 \quad \text{where}$$
V = speed in mph
R = curve radius in feet

While most bike facilities are on the alignment of roadways designed to accommodate the greater turning radius requirements of motor vehicles and will not be of concern, the above equation enables evaluation of critical curves at the foot of downgrades where high cycle speeds can be anticipated and greater turning radii are desirable.

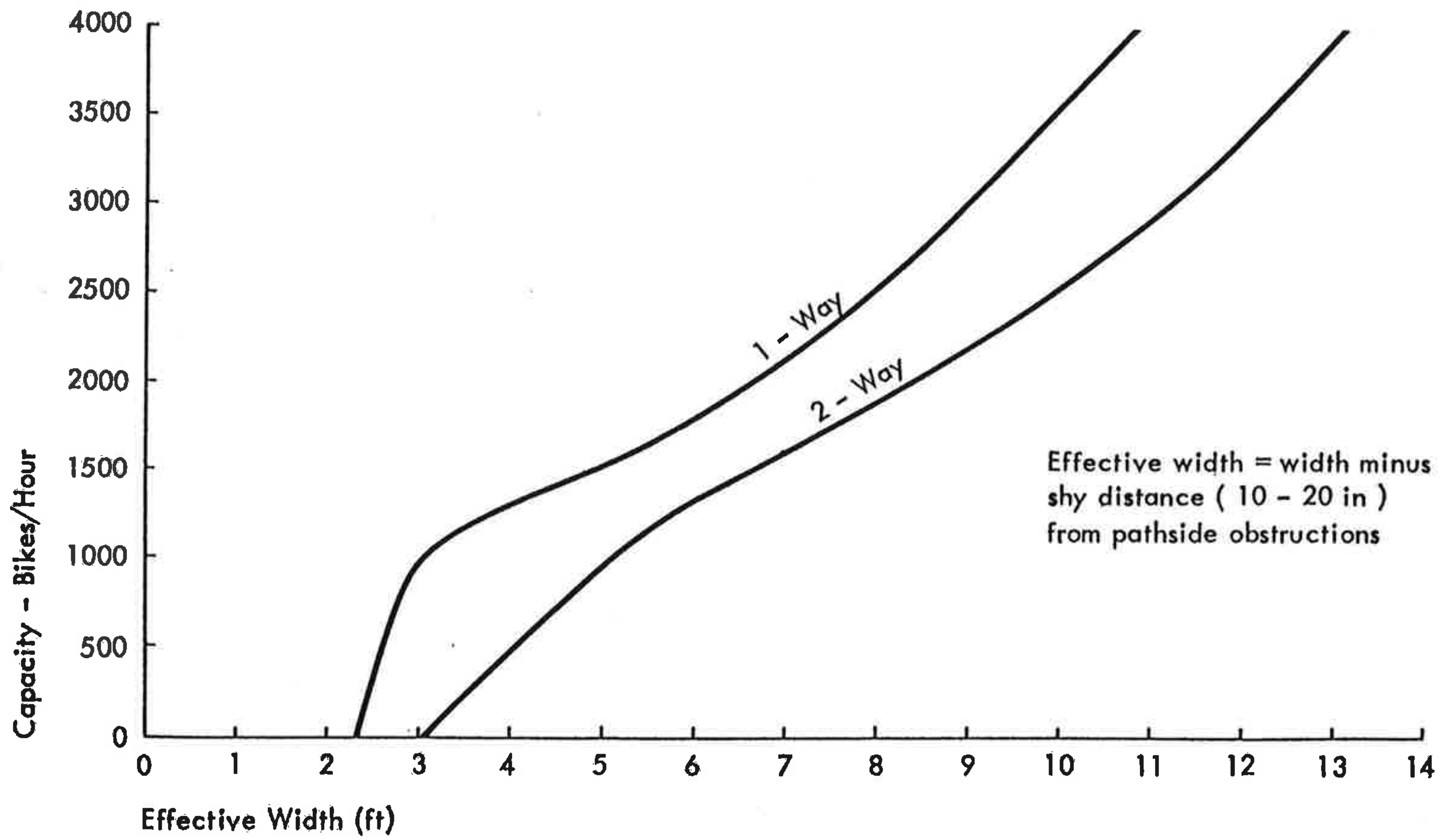
GRADES

Grade profiles permissible under several European standards are presented on Figure 7. Since grade climbing ability varies with the physical characteristics of the individual cyclist and the characteristics of his bicycle, the various profiles are based on assumption of an average "design cyclist" plus "design bicycle" and an acceptable level of effort the cyclist might expend in climbing the grade. Background data and assumptions used in determining the various grade profile curves is not well documented. But from the composite standards in the figure it is clear that there is a sharp drop in the length of grade which can be tolerated if gradients exceed 5 per cent (4,8,10,11,12). It is also clear that the European standards recommend significantly shorter and less steep grade profiles than those on existing bikeway grade separations in Davis. Minimized adverse grade and length of grade is essential on facilities designed to divert cycle traffic away from motor vehicle roadways, especially in the case of bikeway grade separations. It is recommended that the profile be adopted as a standard for grade separation approaches. For facilities paralleling roadways, application of the grade standards would be less stringent, the principal criteria being that steepness and total change in elevation along the bikeway should be no greater than that along the roadway.

Where terrain makes steep gradients inevitable it is at times possible to reduce the effective grade along the bikeway. The Dutch (4) recommend provision of grade breaks (horizontal sections at least 330 feet in length) if maximum length-steepness relationships would be exceeded. Where ample right-of-way is available, a "switchback curved" path would reduce the effective steepness.

Overpass vs. Underpass

Acceptability of a grade separated bikeway crossing of a motor vehicle roadway to utility oriented cyclists is closely related to the convenience of using the overcrossing as compared to attempting to find a gap in traffic sufficient to make a safe at-grade crossing. In addi-



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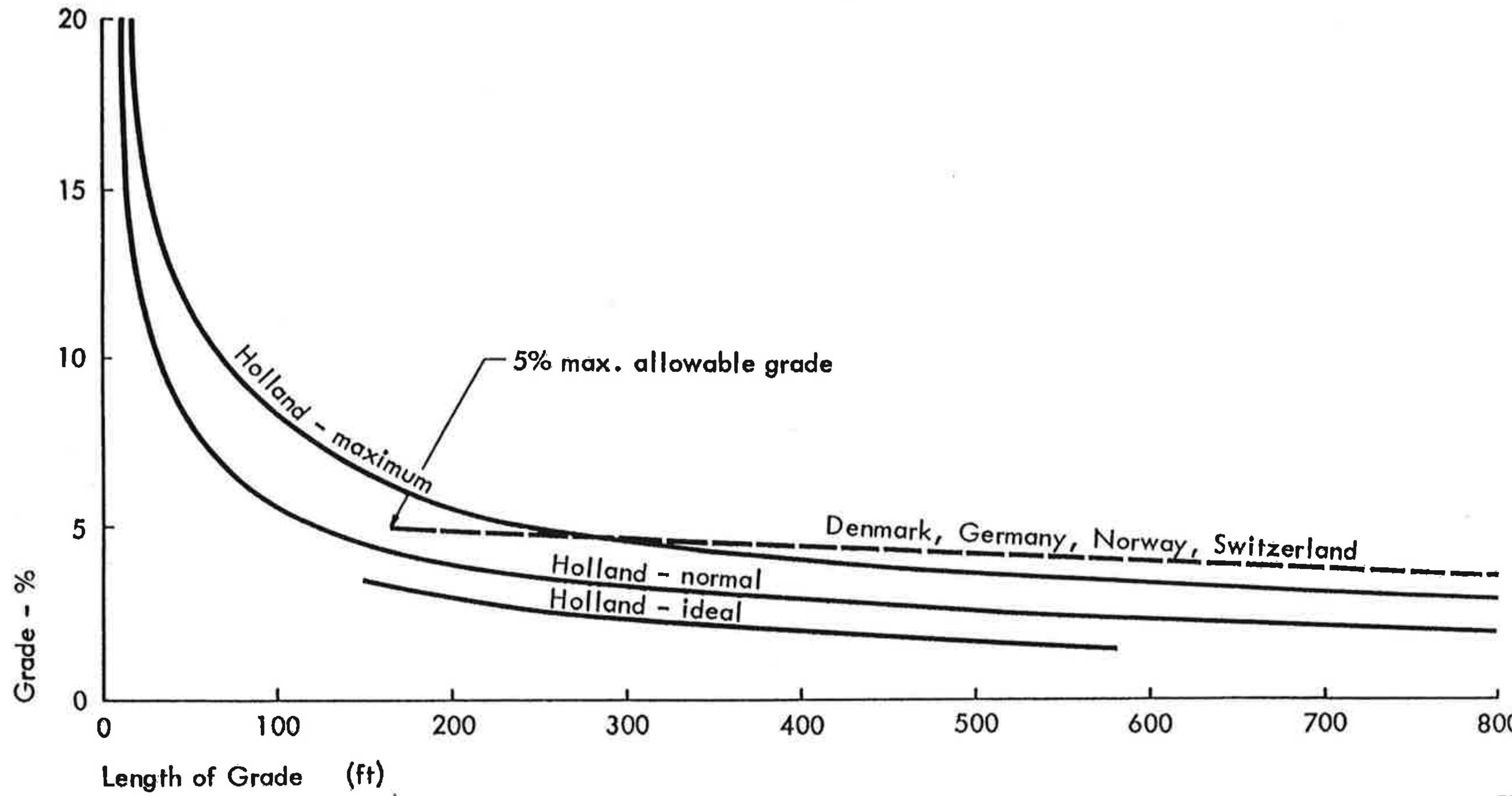
BICYCLE LANE AND PATH CAPACITY



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RELATIONSHIP OF GRADE TO ALLOWABLE LENGTH OF GRADE
EUROPEAN NATIONAL STANDARDS

tion to location of the crossing along bike travel desire lines and proper alignment of its approaches, grade profile is a key factor in determining the attractiveness of the crossing.

Ideally, bikeways would remain at grade with motor vehicle roadways depressed to pass beneath or elevated to pass over them. This is often possible in the case of separations with freeways as freeways are generally depressed or elevated through most urban areas. However, full depression or elevation or urban arterial roadways for purposes of bikeway grade separation is not practical as this might interfere with provision of access to abutting property or complicate connection to cross streets. In addition, costs for depression or elevation of the roadway section exceed by orders of magnitude the cost to depress or elevate the bikeway. Thus, the planner of a bikeway grade separation with an urban surface-street is faced with the choice of imposing a grade change on the cycleway by placing it on overpass or in underpass.

Required overhead clearance of motor vehicle roadways is 15 feet; with allowance for structure, the surface of a bikeway must be 16.5 or 17 feet above roadway surface elevation. Required overhead clearance for a bikeway is 8 feet 4 inches. With allowance for structural depth, bikeway surface elevation in an underpass must be at least 10.5 feet below that of the roadway surface. The difference in overhead clearance requirements favors the underpass. Another advantage is the fact that in the underpass the cyclist rides first on the downgrade, building momentum which eases his ascent on the other side. On the overpass the cyclist must himself supply all the momentum for the climb as the climb occurs before the descent. Given level terrain, an underpass might be easier to integrate in an urban area because of less visual impact and less right-of-way requirements due to the shorter approach length needed to maintain a good grade profile.

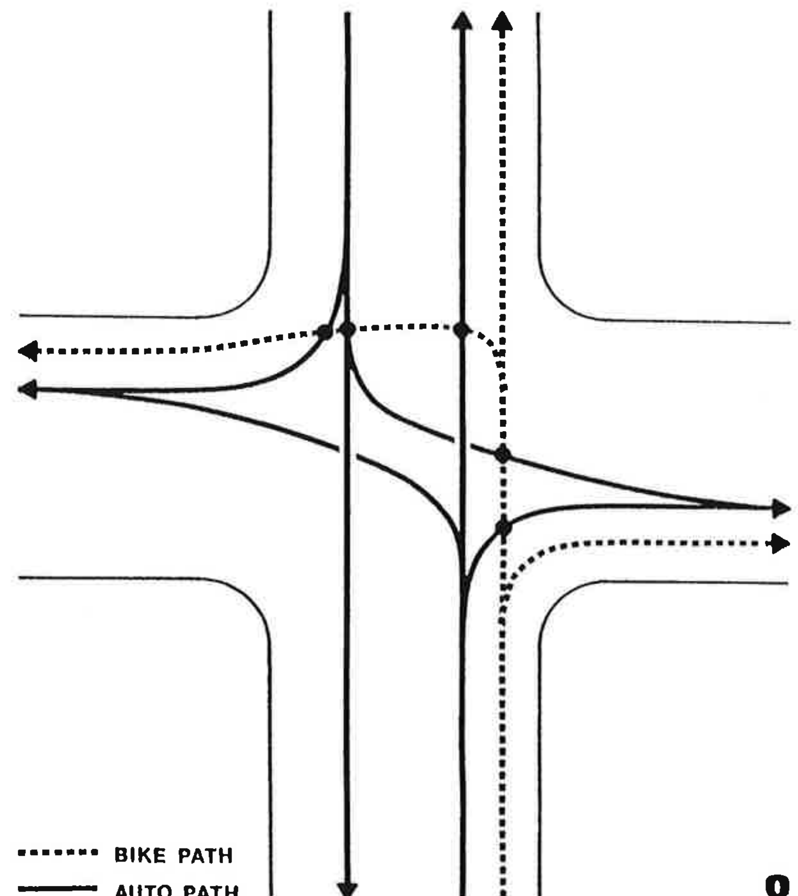
But determination of whether an underpass or overpass should be provided in the individual situation depends largely on site characteristics. For instance, if the roadway were in a swale area, an overpass might provide the most favorable grade profile. Cost-wise, width of the roadway to be spanned is a key consideration for overpasses while presence of ground water and underground utilities affects underpasses.

INTERSECTION TREATMENTS

As detailed subsequently in this report, nearly three-fourths of all auto-bike collisions in Davis for which police reports were filed over the past two years took place at intersections. This pattern is typical of that noted in European bike-accident studies. Predominance of intersection accidents reflects the higher overall traffic activity levels there, increased decision options and the fact that motor vehicle and cycle paths must necessarily cross of conflict at the intersections.

Figure 8 illustrates auto-bike turning movement conflicts. Principal conflicts involve straight-through cycles with right-turning motor vehicles from the same direction of approach and with left-turning cars from the opposite approach direction. Davis traffic code prescribes that left-turning bicycles must follow the pattern indicated on Figure 9 if cycle lanes are provided. As shown in the figures, bikes executing the left turn according to the ordinance conflict with all same or opposite approach movements except the right turn from the opposite approach. Because this level of conflict, particularly with straight-through movements, generally requires the left-turning cyclist to wait through almost two cycle phases, cyclists typically execute a number of illegal forms of left turns which allow them to maintain momentum through the intersection. Safety hazards inherent in these maneuvers, some of which are illustrated on Figure 10, can be inferred.

Two basic forms of design are utilized in Europe to alleviate intersection conflict problems. One involves offsetting the bikeway crossings from the intersection area; the other relies on striping of special bike turning and through lanes.



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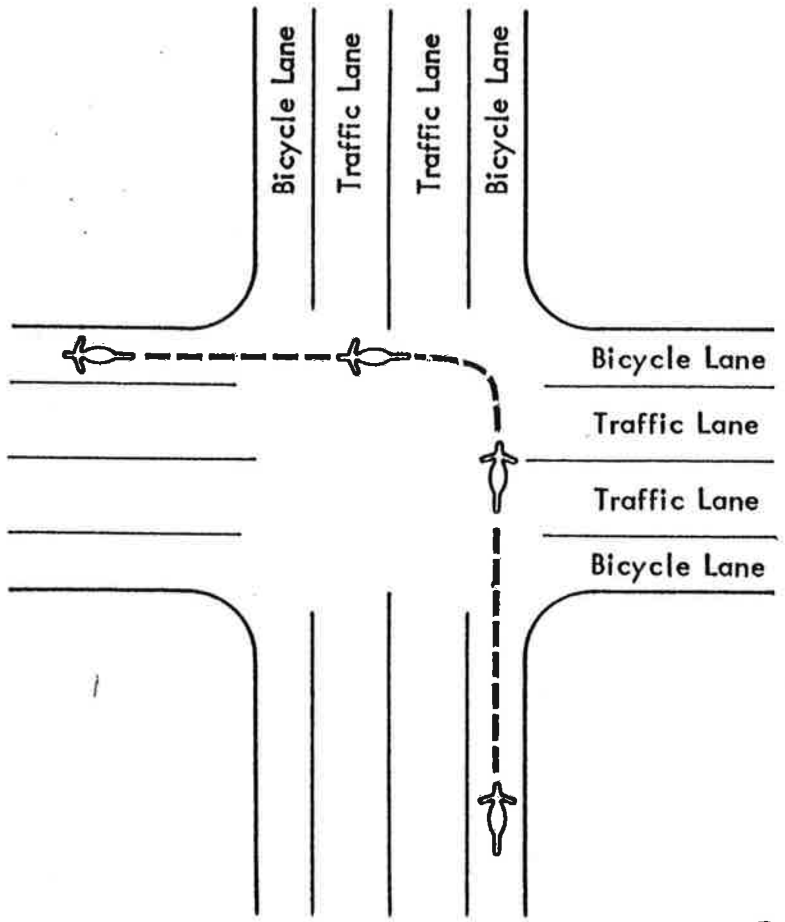
MOTOR VEHICLE · BICYCLE INTERSECTION CONFLICT



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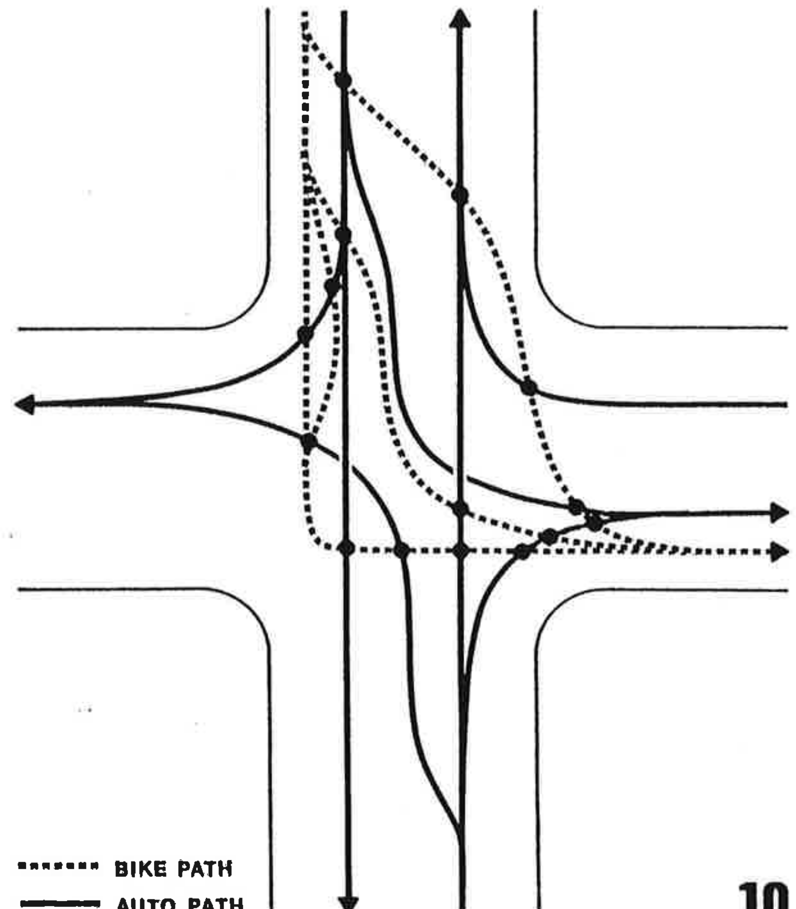
PRESCRIBED BIKE LEFT TURN ROUTE



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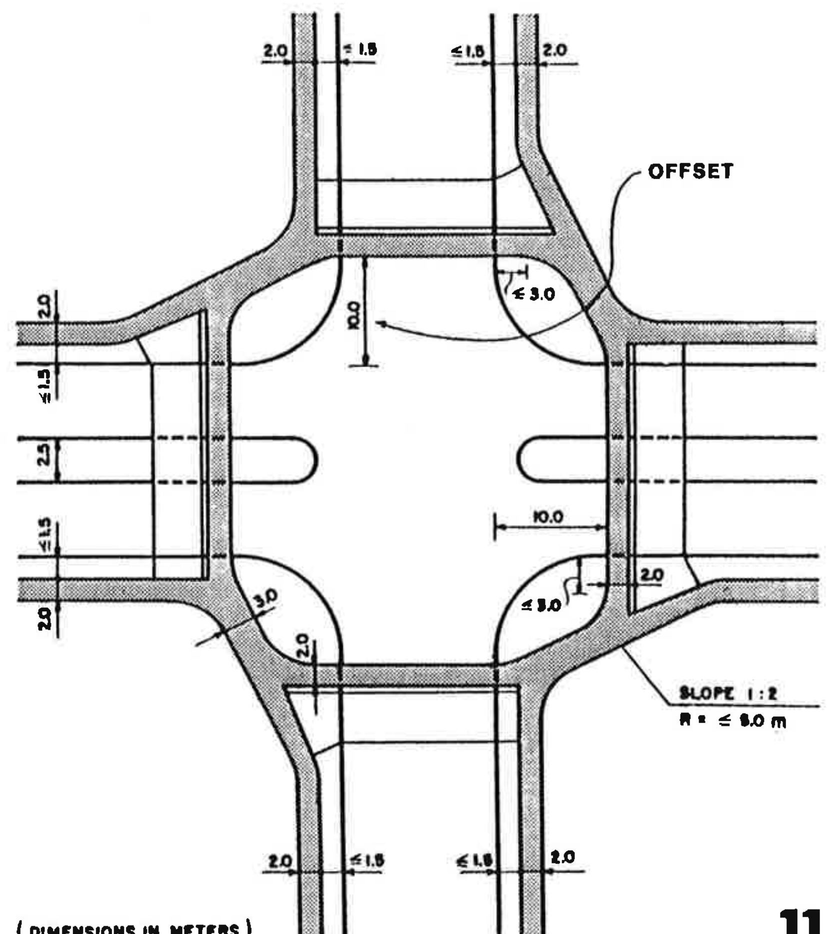
TYPICAL BICYCLE LEFT TURN PATHS AND CONFLICTS WITH AUTOS

Figure 11 illustrates the German (8) concept of offsetting the bikeway crossings from the intersection, effectively providing a bikeway loop around the intersection. The offset crossings improve the angle of incidence between straight-through cyclists and right-turning motorists so that each will appear in the other's forward field of vision. The bike queuing space in the sidewalk area eliminates conflicts between queued bikes and motor vehicles making right turns on red. Principal deficiency of this scheme is that left-turning bikes must still wait through two signal phases. Straight-through bikes are led somewhat out of direction as well and there is serious question whether American cyclists, by nature less order-dominated than Germans, would use this type facility. However, a modification of this concept, indicated on Figure 12 which retains curbside queuing areas and a reduced crossing setback might have some merit in downtown areas where available right-of-way is limited but where elimination of bike queue interference with motor vehicles turning right on the red signal phase is desirable

Figure 13 illustrates the concept of providing directionally designated turn lanes for bikes within the motor vehicle traffic stream (11). This legitimizes and provides an established pattern for some of the illegal forms of left turns which cyclists often find preferable to the form prescribed in existing traffic code and replaces intersection area conflicts with weaving movements on intersection approaches. This shifting of the area of auto-bike inter-



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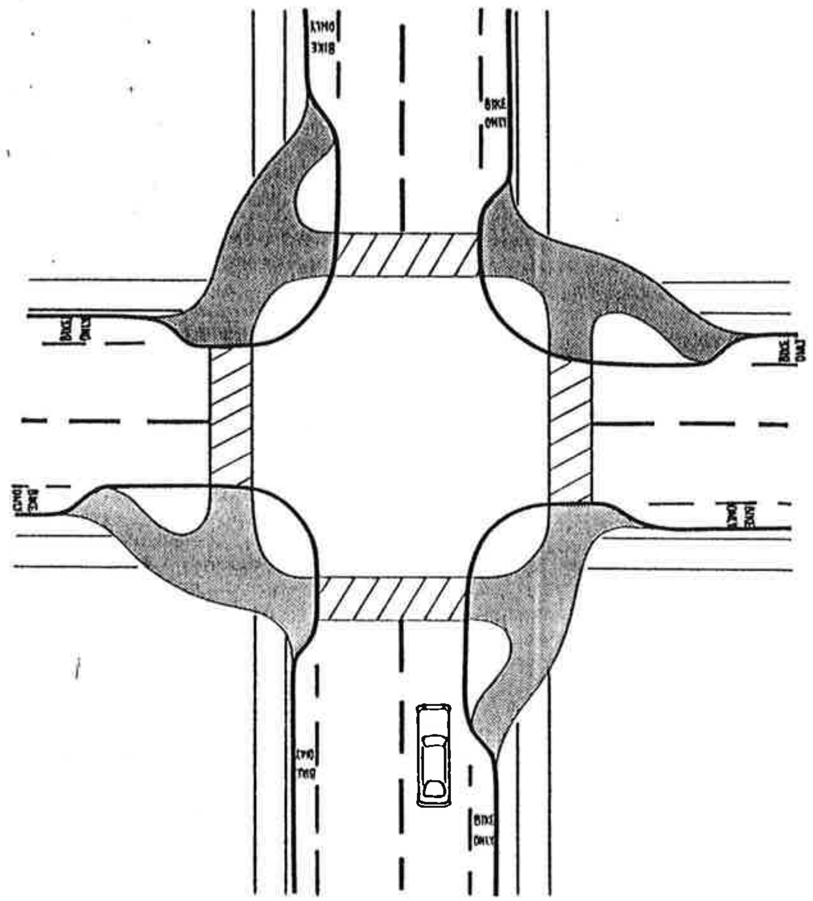
OFFSET PATHWAY CROSSING



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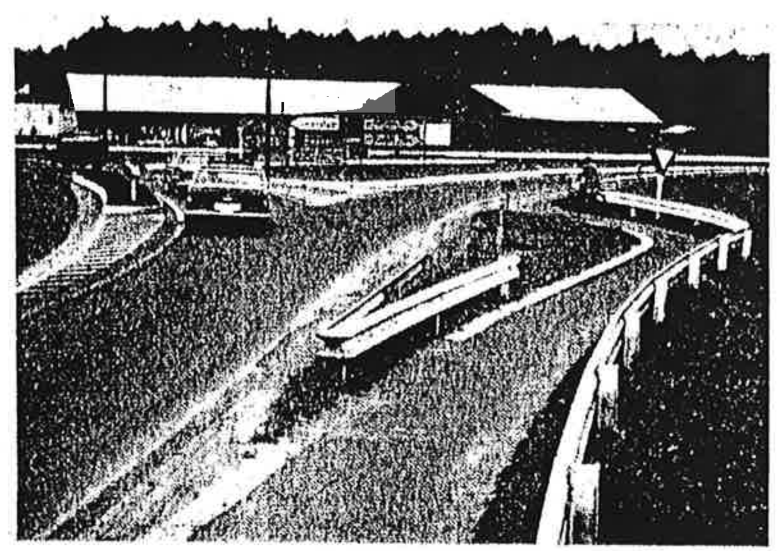
MODIFIED OFFSET PATHWAY CROSSING

action away from the area of intense activity at the intersection appears desirable but because of the poor rear view characteristics of bicycles (bikes are generally unequipped with rear view mirrors; cyclists must turn to look over their shoulder or beneath their arm) overall safety of the weaving movements necessary to enter the designated lanes is in doubt. There is also some question as to whether all cycle riders are sufficiently skilled and judgmentally experienced to execute the weaves.

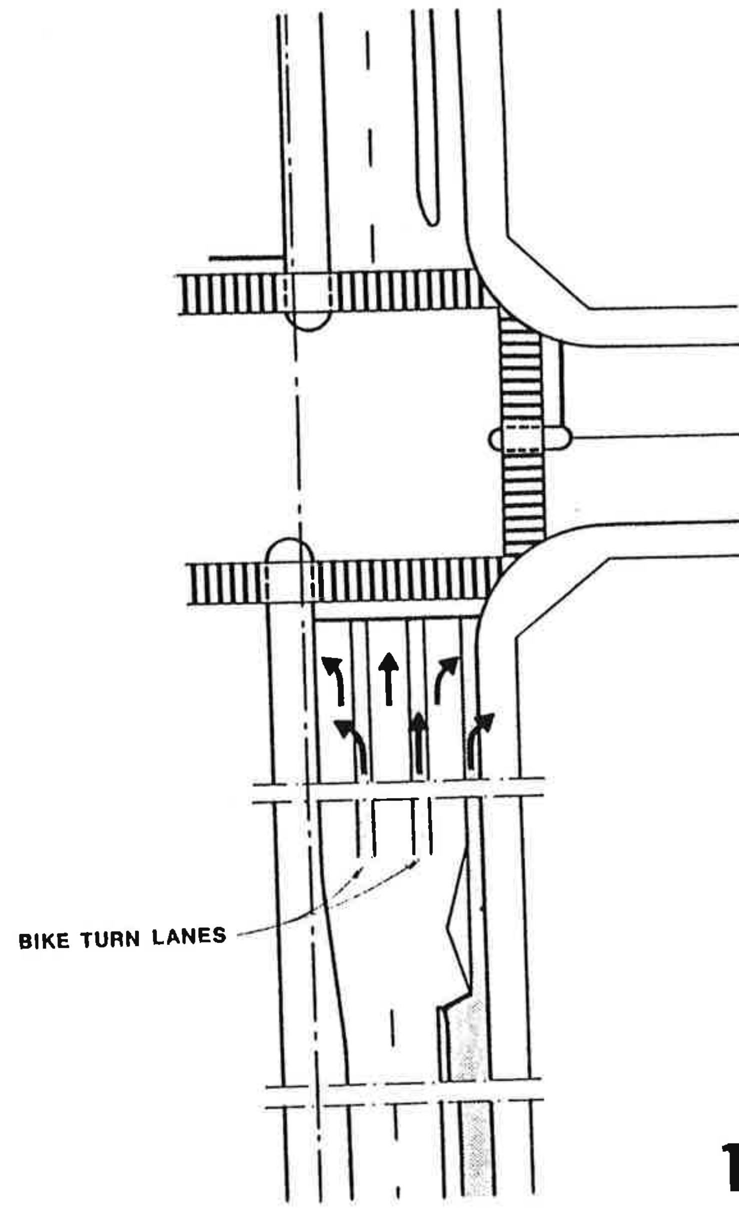


Offset, right-angle crossing of bikeway and free right turn lane.

In conclusion, the first type of design involves some inconvenience for the cyclist and it is questionable whether the offset crossing design would achieve success without strong enforcement. The design involving designated turning lanes is more convenient for the cyclist but involves an element of hazard in weaving movements on the approaches. Experimentation with these designs is necessary to determine their safety-effectiveness under North American traffic conditions.

SPECIAL SIGNALIZATION

Special signal phasing and separate signal heads to control bike movements at intersections are frequently provided in European countries, particularly The Netherlands. These offer the possibility of increased bike safety at the intersection and enable correction of problem conditions such as inadequate bike-clearance interval currently provided at many intersections where the amber phase is set to motor vehicle clearance requirements. Other signalization possibilities include "all red" phases and "scramble cycles." However, special allocation of portions of the signal cycle to bikes may compromise motor vehicle traffic service at busy intersections and in these situations bikeway grade separations may be indicated. Another consideration is that in the absence of strict enforcement, cyclists might be inclined to travel on motor vehicle travel phases as well as on the phases provided exclusively for the cycles.



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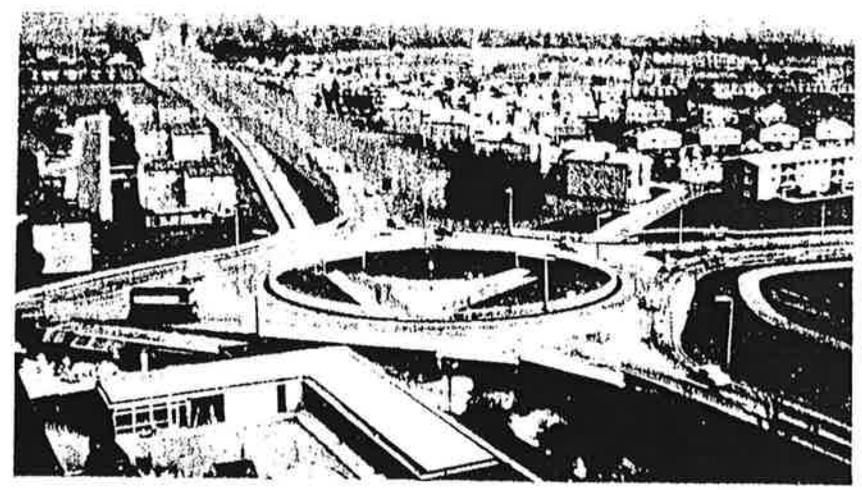
DESIGNATED BIKE TURNING LANES

For minor street crossings of major roadways, bicycle actuation of semi-actuated traffic signals with sensitive magnetic detectors and specialized induction loop patterns, is claimed possible by several signal equipment manufacturers. The advance detectors offer improved convenience and decreased delay to cyclists but until such time as these installations have been proven operationally feasible, pedestrian type actuators placed within convenient reach of the cyclist, such as the existing installation at Third and B Streets in Davis, are recommended for these situations.

GRADE SEPARATION CRITERIA

Specific criteria for grade separation of bike facilities from arterial streets are not established in European sources or in U.S. literature. Most guidelines are quite vague, as when crossing bike and motor vehicle flows are heavy, or where bike traffic interferes with expeditious motor vehicle traffic flows and conversely. A more specific criteria might be high accident experience coupled with an inability, due to motor vehicle traffic capacity requirements, to set signal phasing to provide opportunity for safe and convenient bike movements. Figure 14 illustrates European techniques for providing grade separations at such intersections.

At isolated midblock bikepath-roadway crossings, European experience and limited experience on the UCD campus has indicated a high accident potential. Theoretical work in Germany has attempted to relate safe bike crossing time interval, frequency of motor vehicle traffic gaps of such a size, and bike arrival-delay functions to determine when traffic control devices should be placed at the isolated crossing loca-



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BICYCLE · MOTOR VEHICLE
GRADE SEPARATION AT INTERSECTION
STEVENAGE, ENGLAND