Technical Report Documentation Page

1. Report No. FHWA/TXDOT-96/1394-2F	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle DETECTION AND MITIGATION OF ROADWAY HAZARDS FOR BICYCLISTS	5. Report Date December 1995
	6. Performing Organization Code
7. Author(s) S. A. Ardekani, S. Govind, S. P. Mattingly, A. Demers, H. S. Mahmassani, and D. Taylor	8. Performing Organization Report No. Research Report 1394-2F
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin 3208 Red River, Suite 200 Austin, Texas 78705-2650	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. Research Study 0-1394
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Transfer Office P. O. Box 5080 Austin, Texas 78763-5080	13. Type of Report and Period Covered Final
	14. Sponsoring Agency Code

15. Supplementary Notes

Study conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.
Research study title: "Detection and Mitigation of Roadway Hazards for Bicyclists"

16. Abstract

The principal goal of this study was to identify and compile a list of potential hazards to cyclists, to rank order the hazards in terms of their perceived and actual degree of risk, and propose mitigation actions to address these hazards. Of particular concern are mitigation actions that can be incorporated in an agency's regular maintenance activities; however, in almost all cases, there may be corresponding considerations that are better addressed at the design stage, and these are pointed to as well. This leads to the development of guidelines for detection and mitigation of the principal hazards. Through a literature search, focus groups with cyclists, cyclists' responses to questionnaire surveys, actual field observation, and a review of accident studies, the principal hazardous situations encountered by bicyclists are determined and rank-ordered in this report. Countermeasures have been identified for most of the hazards, and associated cost ranges have been developed based on experience gathered from several sources primarily in Texas, including a special focus group conducted with TxDOT engineers and maintenance professionals.

In general, behavioral factors contribute to most accidents experienced by bicyclists. Responses received to the various surveys described in this report overwhelmingly indicate single bike accidents resulting from loss of control as the primary type of accident experienced by responding bicyclists. Frequently, these crash types, like most, develop from a mixture of behavioral factors, roadway design, and roadway conditions. Many of the hazardous factors found in the roadway or its surrounding environment can be corrected or improved. While many physical elements contribute to the dangers facing cyclists, those with perhaps the greatest impact may be readily remedied through carefully executed maintenance programs, often in conjunction with existing programs and procedures. The main requirement is for maintenance crews to be aware of the hazardous nature of these elements, and of the agency's responsibility and/or intent to remedy conditions that are hazardous to bicyclists even when these may not be of particular concern to automobiles. This report is intended to contribute to this process.

17. Key Words Bicycle hazards, bicycle safety	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 252	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

DETECTION AND MITIGATION OF ROADWAY HAZARDS FOR BICYCLISTS

by

Siamak A. Ardekani
Shekhar Govind
Steven P. Mattingly
The University of Texas at Arlington

and

Alixandra Demers
Hani S. Mahmassani
Dean Taylor
The University of Texas at Austin

Research Report 1394-2F

Research Project 0-1394
Detection and Mitigation of Roadway Hazards for Bicyclists

conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the

U.S. Department of Transportation
Federal Highway Administration

by the

CENTER FOR TRANSPORTATION RESEARCH
Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN
and
THE UNIVERSITY OF TEXAS AT ARLINGTON

December 1995

IMPLEMENTATION STATEMENT

The findings of this study can be used by traffic engineers, planners, and maintenance professionals in the Texas Department of Transportation, cities, and other entities responsible for the safe operation and maintenance of the highway and street system in Texas.

Prepared in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration

DISCLAIMERS

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of either the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation.

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant, which is or may be patentable under the patent laws of the United States of America or any foreign country.

NOT INTENDED FOR CONSTRUCTION,
BIDDING, OR PERMIT PURPOSES

Hani S. Mahmassani, P.E. (Texas No. 57545)
Siamak A. Ardekani, P.E. (Virginia No. 018753)
Research Supervisors

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

The principal goal of this study is to identify and compile a list of potential hazards to cyclists, to rank order the hazards in terms of their perceived and actual degree of risk, and propose mitigation actions to address these hazards. Of particular concern are mitigation actions that can be incorporated in an agency's regular maintenance activities; however, in almost all cases, there may be corresponding considerations that are better addressed at the design stage, and these are pointed to as well. This leads to the development of guidelines for detection and mitigation of the principal hazards. Through literature search, focus groups with cyclists, cyclists' responses to questionnaire surveys, actual field observation, and a review of accident studies, the principal hazardous situations encountered by bicyclists are determined and rank-ordered in this report. Countermeasures have been identified for most of the hazards, and associated cost ranges have been developed based on experience gathered from several sources primarily in Texas, including a special focus group conducted with TxDOT engineers and maintenance professionals.

In general, behavioral factors contribute to most accidents experienced by bicyclists. Responses received to the various surveys described in this report overwhelmingly indicate single bike accidents resulting from loss of control as the primary type of accident experienced by responding bicyclists. Frequently, these crash types, like most, develop from a mixture of behavioral factors, roadway design, and roadway conditions. Many of the hazardous factors found in the roadway or its surrounding environment can be corrected or improved. While many physical elements contribute to the dangers facing cyclists, those with perhaps greatest impact may be readily remedied through carefully executed maintenance programs, often in conjunction with existing programs and procedures. The main requirement is for maintenance crews to be aware of the hazardous nature of these elements, and of the agency's responsibility and/or intent to remedy conditions that are hazardous to bicyclists even when these may not be of particular concern to automobiles. This report is intended to contribute to this process.

To further facilitate the task of the agency's maintenance staff, a special purpose implementation manual has been prepared as a companion to this report. The manual is amply illustrated with examples of things to look for, and specific guidelines to the extent possible with regard to the specifics of size, shape, and location of hazards. In addition, it describes countermeasures, along with estimates of the cost of these actions.

CHAPTER I: BACKGROUND AND OBJECTIVES

PROBLEM DEFINITION AND STUDY OBJECTIVES

The bicycle represents a transportation mode of increasing use on roads today. Bicycles transport both people and goods. However, few roads have been designed to accommodate bicycle requirements when these differ from those of motor vehicles. For example, designers often fail to consider the limiting operational characteristics of bicycles such as wheel stiffness, turning radius, and braking capability. In addition, cyclists of differing ability levels ride a variety of bicycle types. For instance, children tend to ride wide-tired one-speed bikes, touring and racing cyclists tend to ride light, thin-tired multi-speed bikes, and recreational or commuter cyclists often ride sturdy wide-tired mountain bikes. Furthermore, each class of bicycle riders has different opinions on the design attributes of bicycle facilities. Moreover, most cyclists do not consider the same situations hazardous. These differing needs and views make it challenging to satisfy all types of cyclists. Therefore, careful consideration of these variables is important when attempting to design and maintain transportation facilities for vehicle mixes that include bicycles.

Badgett, Niemeier, and Rutherford (1993) state, "lack of safety while riding a bicycle has been cited in two national studies as a primary bicycle commuting deterrent." Many factors contribute to the threats that bicyclists face daily on roadways. These factors need investigation, particularly since the bicycle's importance as a non-polluting transportation mode is anticipated to increase, encouraged by several federal policy initiatives. For example, the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) mandates that bicycles play an increasing role in urban transportation. The recently released National Bicycling and Walking Study (FHWA, 1994) calls for a doubling of the number of trips made by bicycle. Increasing bicycle usage creates a more diverse transportation system, including infrastructure, control, and vehicle mix. In addition, bicyclists, like motor vehicle operators, have the right to expect the roadway to be free of hazards as established by liability cases involving cycling accidents (Sorton, 1993). This change in vehicle mix requires better understanding of the interactions of vehicles (motorized and non-motorized) with one another and with their surroundings to minimize existing and future hazards. The conditions that represent safety and operational hazards to bicyclists need to be identified and corrected. If these hazards are not mitigated, in a timely fashion, it seems that encouraging more use of the bicycle mode will not be effective. It is therefore imperative that design and maintenance practices be updated for the safety of all current and future road users.

While focusing on both cyclist behavior and physical aspects of transportation facilities, this study ascertains and examines hazards facing cyclists. The hazards can be classified by type into general categories such as behavior, geometric design, and maintenance. Further possible organizations of these hazards includes: frequency of occurrence, severity, and cost of mitigation. Since not all hazards constitute the same level of threat (real or perceived), nor do they occur at the same frequency, each hazard ideally needs to be prioritized according to a ranking that relies upon its severity and frequency. By carefully considering a rank-ordering of hazards (and their associated countermeasures), a comprehensive approach to improving roads for cyclists can be developed.

The principal goal of this study was to identify and compile a comprehensive list of hazards for bicyclists and their respective countermeasures with the intent of developing a priority system of countermeasure implementation and recommendations to identify, manage, and mitigate risk associated with roadway hazards for cyclists. In the first phase of the study, an initial list of hazards were compiled and rank-ordered, countermeasures were identified for most of the hazards, and an initial set of priorities was generated along with some preliminary cost estimates. In the second and final phase, bicyclists' perceptions of and interaction with hazards were analyzed in an attempt to discover links between the physical environment and cyclist behavior.

Lastly for this project, a separate document was compiled from the findings that includes brief discussions of those hazards that are repairable or preventable through maintenance practices. Each of the hazards are described with pointers given for how to detect them in the field, background information on why they are hazards, possible mitigations, and applicable costs of the mitigations (where possible). The hazards were chosen based upon their severity ranking, cost of mitigation, and/or ease of detection (by maintenance crews or bicyclists).

The general approach followed to develop and rank order the list of hazards is described next. Then the process of linking cyclist behavior to physical hazards is discussed. This is followed by an overview of previous studies pertinent to bicycle safety and engineering.

STUDY APPROACH

This study has attempted to recognize both unsafe behaviors and facility dangers for cyclists with an attempt to link the two. First, a number of potential cycling hazards were identified based on a review of previous research, accident data, survey data, and informal discussions with cyclists (86 hazards were identified in the first phase). The seriousness of each identified hazard was then evaluated based upon collected accident studies and two surveys of bicyclists. Next, in conjunction with further analysis of one survey and video footage of cyclists in hazardous situations, the data are examined for potential links between behavior and the environment in an effort to illustrate how a cyclist reacts when confronted with selected hazardous situations. Brief descriptions of the methods follow.

The lot of hazards identified from the literature was categorized into nine groups. A *Hazards for Cycling* questionnaire was developed and administered specifically for the purpose of ranking these hazards in terms of perceived seriousness or severity. The survey responses consisted of severity ratings of the various hazards, which were then used to construct a rank-ordering of hazards. The ranking was further confirmed by comparison to the results of the accident database analyses.

Using the rank and classification of each hazard preliminary guidelines for maintenance and design procedures are proposed to mitigate the hazards. The list of possible mitigation treatments includes temporary solutions to repair the most dangerous locations immediately and permanent solutions for long-term improvements. In addition, costs of the hazard mitigations are evaluated.

A second survey, entitled the *Bicycle Riders Survey*, was distributed with the intent of collecting general information such as bicycle rider characteristics, accident experience, and perceptions of hazards. The survey responses to gain perceptions of hazards consisted of frequency and severity ratings of fourteen selected hazards; this information is compared to the rank-ordered hazards of the previous survey. The hazard list was extended to include those specifically cited by cyclists in their responses. Accidents were classified into seven categories based upon whether the accident involved a collision with another party or not and the type of party (e.g. animal, motorist). These categories were cross-referenced with the hazards cyclists listed as causes of the accidents in an effort to associate accident types with particular hazards.

Finally, bicyclists were filmed traveling through potentially dangerous situations. This data includes characteristics of the cyclists and their riding behavior, with specific attention paid to their maneuvers around or over hazards. Distinct paths related to lane position and position of hazard types were found to exist, so a choice of movement variable was developed. This variable is analyzed in conjunction with the characteristics of the cyclists to further link behavior with physical hazards.

LITERATURE OVERVIEW

Bicycle transportation engineering has been evolving over the past two decades. Bicycle safety has been an important area of research and development aimed at increasing safety for bicyclists. Research in this area can be subdivided into four categories: accident studies, conflict analysis, engineering approaches, and surveys of public opinion. Each category seeks possible solutions by different means of data collection and analysis. Brief descriptions of the four areas of bicyclist safety research are presented in this section with examples of each. Finally, the hazard countermeasure research presented in this paper is discussed in the context of previous bicyclist safety research.

Accident Studies

Accident studies have been a popular approach to study safety issues. They allow the researcher to statistically identify hazards and conflicts using a large amount of data. The researchers rely on previously collected information often found on government accident databases. A drawback of this method is this reliance, because the researcher did not design the database nor train the data collectors. Hence, the data may include potential biases of the data recorders, important variables may be excluded, unnecessary information may be present, and not all of the desired cases may be included. But even with these limitations, the accident study is a powerful method of research based on the analysis of events that actually occurred.

Data can easily be obtained from a variety of state and city databases. For example, in the state of Texas two popular databases are LANCER and TRACER. LANCER is a State Accidents database and TRACER is a database used in most Texas cities that was developed at the Texas Transportation Institute.

Unfortunately, the databases rarely include accidents that did not involve a motor vehicle. It is rare for cyclists to report accidents such as colliding with another cyclist, running into a fixed object, or losing control and falling. Such accidents may be serious and require medical attention, but unless the accident involves a motor vehicle they are rarely reported. Therefore, the data obtained for bicycle accidents are primarily bicycle-motor vehicle accidents.

The definitive bicycle-motor vehicle accident study was performed by K. Cross and G. Fisher in 1977. The significance of this study was that data is obtained from four different communities yet showed strong similarities. This led Cross and Fisher to organize the various accidents into seven classes encompassing thirty-six types. Since then, many cities have used this typing system for their databases - enabling them to easily pinpoint accident types of concern. Cross and Fisher's results are compared to the accident data analyzed for this study. Other significant car-bike studies include Thom and Clayton's (1992), who attempted to link accidents to behavior, and Williams (1976), who related age to primary responsibility for car-bike accidents.

Some accident studies have attempted using data from hospitals (Stutts, 1986) leading to surprising results concerning the under-representation of bicycle accidents in common accident databases.

The applications of accident study research are quite varied. One common use is to guide bicycle safety programs, "...allowing educational objectives to be targeted to the age group most affected," (Stutts et al., 1992). Another application, in departments of transportation, could be to pinpoint locations that may need to be redesigned because of the number of serious accidents occurring at those spots. Hence, accident studies yield information applicable to several areas of safety.

Conflict Analysis

Closely related and often stemming from accident studies is conflict analysis. It is a method of systematically trying to predict and locate hazards. For example, John Forester in his book *Bicycle Transportation* examines the relationships of cars and bicycles in traffic. He states, "Car-bike collisions are not produced by the failure of separation, but by the relationships during traffic maneuvers that cannot be eliminated by building bikeways. Crossing and turning relationships are involved in over 95% of car-bike collisions." Because crossing and turning create conflicts, Forester analyzes several bicycle-motor vehicle collisions. He examines the behavior of each vehicle operator to point out what each is concentrating on -- from this perspective the conflicts are easy to understand and countermeasures can be developed.

Engineering Judgment Approaches

Due to the lack of quantitative studies on most bicycling hazards, current practice relies primarily on engineering judgment when it comes to identifying, prioritizing, and mitigating these hazards. Most of the design standards published (North Carolina Bicycle Facilities Planning and Design Guidelines, January, 1994, North Carolina DOT, Raleigh, NC; State of Oregon Bicycle Master Plan, May 1988, Oregon DOT, Salem, OR; and Florida Bicycle Facilities Planning and Design Manual, 1982, Florida DOT, Tallahassee, FL) rely heavily on engineering judgment. In addition, many popular publications (Williams, John "Improving Local Conditions for Bicycling," Bike Centennial, Missoula, MT) and bicycle engineering courses (Sorton, 1993) base their "good practice" recommendations on engineering judgment. In Chapter II of this report, the list of hazards is developed based primarily on a synthesis of these published engineering judgments. These are also used to suggest countermeasures for each hazard.

Surveys and Public Opinion

Finally, bicyclist safety research includes studies based on public opinion, yielding information on the perceptions and attitudes of the population of bicyclists and motor vehicle users. Surveys allow researchers to target specific populations of interest.

An application of public opinion studies is the identification of hazards for facility improvement. Public comments obtained through the use of postcards or other survey methods are a good source of information to identify hazards and their location. These programs enable the public to notify maintenance teams of new problems not detected by regular maintenance. Such programs are in existence in Seattle, Washington, San Diego, California, and Boulder, Colorado.

Another use of surveys is to obtain information on the characteristics of bicycle users in a given area, as an input to community planning and design activities.

CLOSURE

The present study relies on all four types of safety research in developing the list of hazards to cyclists. In addition to a synthesis of published results, accident databases are analyzed and surveys of bicyclists are conducted in developing and prioritizing this list of hazards. Moreover, the survey data and video footage collected are used to add systematic quantitative studies to this body of knowledge, thereby addressing an important gap identified in our review.

The next chapter presents a more extensive review and discussion of previous bicycle-safety related studies, with particular focus on identifying a list of hazards in various key categories. Chapter III describes all of the data collection methods for this study and entails analysis of relationships between the actions of cyclists and surrounding physical infrastructure. Chapter IV details the methodology to refine and prioritize the list of hazards. It includes an analysis of responses to two surveys conducted in the Dallas-Fort Worth area and in Austin. Chapter V focuses on countermeasures and cost estimates for the maintenance-related hazards that primarily rank high in severity based upon the results in Chapter IV. Chapter VI presents the conclusions and recommendations derived from the study.

CHAPTER II: HAZARDS TO CYCLING

In this chapter, a comprehensive list of cycling hazards is developed, based on a review of pertinent literature, discussions with cyclists and cycling groups, and survey comments. To place this list in proper context, general studies about bicycle facility design and use are highlighted, followed by a review of pertinent accident studies.

CYCLIST TYPES AND DESIGN GUIDELINES

Betz, Dustrude, and Walker (1993) state, "current road and highway systems are designed specifically to accommodate the automobile. Until effective support mechanisms for the bicycle are in place, bicycle use will not be able to reach its full potential." Accordingly, designers need to develop design approaches that consider the needs of all cyclists. A Federal Highway Administration (FHWA) report by Wilkinson, Clarke, Epperson, and Knoblauch (1994) creates the following classifications to identify multiple "design bicyclists":

1. Group A.- advanced bicyclists: experienced riders who operate under most traffic conditions
2. Group B - basic bicyclists: casual or new adult and teenage riders who are less confident of their ability to operate in traffic without specific provisions for bicycles
3. Group C - children: pre-teen riders whose roadway use is initially monitored by their parents; eventually they are granted independence to bike to all areas in the network

Group A cyclists prefer to use the existing road network, especially streets with wide curb lanes or shoulders while group B/C cyclists prefer facilities that provide a feeling of security, such as separate facilities or bike lanes. This study discusses three types of bicycle facilities since an effective bicycle network requires a blending of all three facilities.

1. Bike route: shared motor vehicle/bicycle use of the existing roadway network
2. Bike lane: designation of a portion of a roadway for exclusive bicycle use
3. Bike path: a separate facility for bicycle use not located on the roadway

Bike routes include shared lanes, wide outside lanes, and shoulders. According to Wilkinson et al. six factors affect bicycle use:

1. Traffic volume
2. Average motor vehicle operating speed
3. Traffic mix
4. On-street parking
5. Sight distance
6. Number of intersections

Wilkinson et al. used these factors to develop a series of tables that provide guidelines for design approaches which customize bicycle facilities for the expected users. Group A cyclists receive one treatment while Group B/C cyclists receive another. The tables recommend an easily implemented design treatment (Wilkinson et al.). A sample table from the FHWA report (Table 2.1) is included, providing guidelines for the widths and types of facilities intended to serve Group A cyclists in urban streets with no parking. According to these guidelines for high (automobile) volume conditions (AADT>10,000), only a wide curb lane is recommended for speeds under 64 km/h whereas the use of a shoulder is recommended for speeds higher than 80.5 km/h. While these tables provide design guidelines and standards for new construction and reconstruction projects, many other elements of the roadway environment, particularly with regard to potential hazards, are outside the scope of these guidelines. These considerations are discussed in the remainder of the chapter, following the discussion of accident characteristics.

ACCIDENTS

Thom and Clayton (1993) state, "information about bicycle accident frequencies, travel, and accident rates is useful for determining and justifying the need for countermeasures." Ferrara (1980) reveals that the most common bicycle accident types are: multi-bike, bike-pedestrian, and single bike accidents. Cross (1980) supports this when noting that only five percent of all bicycle injuries result from collisions with motor vehicles. However, most governments only collect bicycle accident data for motor vehicle-bicycle accidents. A survey of League of American Wheelmen (LAW) members quantifies, as summarized in Table 2.2, the percentage of all accidents and the percentage of serious accidents that fit into certain accident classifications (Thom and Clayton, 1993). These data may be biased towards group A cyclists' experiences, since LAW members typically represent group A cyclists. The latter travel in traffic more often than other types of cyclists; therefore, they encounter more motor vehicles. Nonetheless, motor vehicle-bicycle crashes account for a large portion of serious accidents.

Agencies and researchers need more complete bicycle accident data than is typically available from accident reports. Cross and Fisher (1977) estimate police only receive reports on a third of all bicycle-motor vehicle crashes. Motor vehicle-bicycle crashes account for ninety to ninety-two percent of bicyclist deaths and twelve percent of bicyclist injuries (Baker, et al 1993). Hudson (1982) illustrates some common types of motor vehicle-bicycle accidents:

1. Cyclists turning across the traffic flow into a side road and colliding with a vehicle either following or approaching
2. Cyclists emerging from a side road into the path of a motor vehicle

Table 2.1 Group A Bicyclists, Urban Section, with No Parking (FHWA, 1994)

	Average Annual Daily Traffic (AADT) Volume											
	Less than 2,000				2,000-10,000				Over 10,000			
Average Motor Vehicle Operating Speed	Adequate Sight Distance		Inadequate Sight Distance		Adequate Sight Distance		Inadequate Sight Distance		Adequate Sight Distance		Inadequate Sight Distance	
	Truck, bus, rv				Truck, bus, rv				Truck, bus, rv			
Less than 30 mi/h	sl 12	sl 12	wc 14	wc 14	sl 12	wc 14	wc 14	wc 14	wc 14	wc 14	wc 14	wc 14
30-40 mi/h	wc 14	wc 14	wc 15	wc 15	wc 14	wc 15	wc 15	wc 15	wc 14	wc 15	wc 15	wc 15
41-50 mi/h	wc 15	wc 15	wc 15	wc 15	wc 15	wc 15	sh 6	sh 6	wc 15	wc 15	sh 6	sh 6
Over 50 mi/h	sh 6	sh 6	sh 6	sh 6	sh 6	sh 6	sh 6	sh 6	sh 6	sh 6	sh 6	sh 6

1 mi/ h = 1.61 km/h

Key: wc = wide curb lane* sh = shoulder sl = shared lane bl = bike lane
*WC numbers represent "usable widths" of outer travel lanes, measured from the left edge of the parking space (8 to 10 ft [2.4 to 3.0m] minimum from the curb face) to the left stripe of the travel lane.

3. Motorist overtaking a cyclist
4. Cyclist emerging from a footway or alleyway into the path of a motor vehicle
5. Motorist emerging from a side road and hitting a cyclist

The cyclist is apparently at fault in approximately eighty percent of all bicycle-motor vehicle crashes (Gårder, 1994). Gårder believes many reasons exist for the cyclists' failure to obey traffic laws, including lack of knowledge, young age/ inexperience, lack of enforcement of rules for cyclists, and disrespect for regulations. According to Gårder, failure to yield right-of-way and bicyclist inattention represent the most common cyclist behaviors contributing to collisions.

Motor vehicle speed, road classification, and cyclist experience/ training affect the likelihood of accidents and their severity. Bicycle-motor vehicle accidents occur frequently near intersections because there are more points of conflict in an intersection than the rest of the roadway. According to Thom and Clayton (1993), eighty percent of bicycle-motor vehicle crashes occur at intersections. Table 2.3 provides accident and near miss rates for bicyclists in the Philadelphia , PA region (Noland, 1994). Over seventy-five percent of the accidents identified in Table 2.3 resulted in no injuries, and near misses represent a subjective evaluation of conflicts. This information identifies the frequency of motor vehicle-bicycle conflicts. Once again, these data demonstrate that experienced cyclists are involved in fewer near misses and dangerous conflicts than general bicyclists. "One third of bicyclist fatalities occur on roads with speed limits of 55 mph [88 km/h] or higher." (Baker, et al 1993). After investigating bicycle accident data, some of the more hazardous situations can be improved, such as prohibiting bicycle use on freeways while providing them a suitable alternative route.

In the next chapter, accident databases and studies are used along with cyclist survey responses and video footage of cyclists to identify and characterize ties between the behaviors of cyclists and their physical riding environments. Then, in the fourth chapter, cyclist survey responses are used in the process of ranking hazards that confront cyclists. Prior to this ranking process, hazards are first identified, as described in the next section.

HAZARD CATEGORIES

The hazards identified through the literature review and focus group discussions were grouped into nine categories to facilitate their evaluation and the design of survey instruments for this study. These categories are:

Table 2.2 Accident Types and Frequencies, LAW Members (Thom and Clayton, 1993)

Type	Percentage of all Accidents	Percentage of Serious Accidents
Fall	44	38
Collision with moving motor vehicle	18	26
Collision with moving bicycle	17	13
Collision with moving dog	8	10
Collision with parked car	4	2
Bicycle defect	3	3
Collision with pedestrian	1	1
Other	5	7

Table 2.3 Accident and Near Miss Rates for Bicyclists (Noland, 1994)

	Falls, Collisions, and Accidents (per million miles)	Near Miss Incidents (per million miles)
Total sample	415.9	3315.83
General random sample	1229.96	7343.43
Bicycle club sample	406.4	3271.72

1 mi. = 1.61 km

1. Cyclist behavior
2. Motorist behavior
3. Geometric design
4. Other design elements
5. Pavement conditions
6. Roadway maintenance and upkeep
7. Traffic control and conditions
8. Policy and enforcement
9. Bicycle characteristics

Following the analysis of survey returns, some further hazards were identified and added to the appropriate categories, and one additional category was defined, namely:

10. Environmental conditions

These categories and the specific hazards that comprise them are described in this chapter, accompanied by a discussion of related studies.

The first category concerns *cyclist behaviors,* many of which create dangerous situations. Some of these behaviors can be corrected or modified through cyclist education and enforcement, and the degree to which these behaviors impact the transportation system can in many cases be lessened with thoughtful design. In order to reduce such hazards, bike network design should consider and attempt to provide for anticipated dangerous actions, if applicable. Bike path and bike route design can improve conditions for cyclists and reduce the number of conflict errors and unsafe behavior.

The *behavior of motorists* also has an impact on the safety of a cyclist (as well as that of the motorist). Again, this category suffers from the difficulties associated with correcting behavioral problems. Some useful design approaches help reduce the amount of conflicts caused by motorists' actions. Additionally, motorist education improves driver recognition of cyclists' needs. These possible mitigation techniques represent long-term improvements.

The *geometric design* category covers not only geometric design but also network planning and layout considerations. Once again, most of the design difficulties encountered are attributed to physical constraints. Some design problems cost considerably more than pavement problems to mitigate since they affect a greater area of the roadway or network and require more extensive materials and labor. The obstructions associated with network design usually require a different design approach, however the correction of minor geometric design problems could result in considerable improvement in the safety and usability of the bike network.

A few design elements need a separate classification; therefore, this study groups them as *other design elements.* Some of the items here cannot be easily avoided; however, their designs can be more bike "friendly." Proper approaches to these potential dangers must be considered prior to construction because retrofitting these hazards requires large expenditures. Standardized design policies that provide bicycle prudent design approaches assist designers to develop safe bicycle networks.

The category of *pavement conditions* includes hazards that develop in the roadway surface itself. In general, most of the pavement problems are physical in nature and can be readily corrected; however, some of the possible corrections can be expensive. Many of these situations occur because of wear and tear on the roadway, but a few of the hazards relate primarily to design difficulties, and could be more effectively avoided at the design stage.

Roadway maintenance and upkeep crews need a regular pattern and checklist to insure that all bicycle hazards receive attention. Maintenance and upkeep include both physical and environmental concerns. Regular maintenance along bike routes and bike paths helps maintain their integrity and identify impending problems. Maintenance along these routes and paths must be frequent because bicycles are more susceptible than motorized vehicles to changing conditions. The hazards identified in this classification concern primarily immediate maintenance problems.

Small improvements to either *traffic control* or *traffic conditions* along bike routes could increase the safety of bicyclists. Many hazard mitigation measures in this category require relatively small expenditures.

The *Policy and enforcement* category addresses shorter-term enforcement issues and longer-term government policy issues. The development and the enforcement of governmental policies that pertain to cyclists can improve the safety and decrease the health risks of cyclists. For example, enforcement officers can be specifically directed toward bicycle-motor vehicle interactions to improve safety. Another example is restricting motor vehicle use in certain areas (e.g. traffic calming, transit/pedestrian malls) to reduce pollution and improve safety. By creating bike "friendly" policies, governments both encourage cycling, and help protect cyclists.

Some cycling hazards are related to the operational *characteristics of bicycles.* These dangers seem to stem from both design and operational problems. Some of these obstacles cannot be easily corrected since they represent dangerous situations found in all networks. Bicycle characteristics that contribute to dangerous situations must be addressed during the design process, especially when the designer or planner begins to layout potential bike routes. Although these hazards cannot be corrected easily, they play an important role in making roadways bike "friendly."

Environmental conditions represents the final classification group. These conditions, such as rain or the sun setting, cannot be prevented but the problems associated with them may be reduced through a combination of transportation-related practices and behavior modifications.

Hazards in the above ten categories are listed in Appendix A and described in the sections that follow, along with a summary of findings from related studies.

CYCLIST BEHAVIOR

Cyclists' behavior could compromise their safety and the safety of other road users. Some dangerous behaviors are directly related to the operational characteristics of bicycles, while others reflect irresponsible attitudes or simply the lack of sufficient experience of the rider. Certain design approaches encourage cyclists to avoid dangerous behaviors. Cyclist safety could also be enhanced through education. If cyclists use the roadway correctly, then their level of safety could be substantially improved.

Unexpected cyclist behavior promotes conflict with motorists and other roadway users. When a rider fails to yield the right-of-way, motorists either lack the time to react or can react in an aggressive manner. A common cause of failure to yield the right-of-way is the cyclist's reluctance to decelerate or stop at crossings, because he/she expends most of his/her energy during acceleration (Hope, 1992). Another example is when a biker turns right from the lane to the left of an exclusive bus lane, he or she may enter the buses' path from an unexpected direction. When bicyclists turn left from the right lane, they cross the paths of other road users, obviously not a safe behavior.

Inexperienced cyclists and those avoiding pavement problems fail to maintain straight, predictable paths which create conflicts with other vehicles (Lucero, 1975). When cyclists ride against traffic, they develop conflicts with motor vehicles by behaving in an unpredictable manner. When motorists pull out of a driveway, they do not expect traffic from their right in the near lane. Riding against traffic is a common yet particularly dangerous cyclist maneuver (AASHTO, 1991).

Even when cyclists avoid conflicts, they endanger themselves through other unsafe behaviors. For example, it is not uncommon for a cyclist to exceed the design speed of the roadway on a downhill grade. Attempting to carry large, heavy, or bulky packages or wide trailers reduces a biker's ability to maintain control of the bicycle (Ferraro, 1980). When cyclists fail to use safety equipment, such as a helmet, bright clothing, lights and reflectors, they seriously compromise their safety (Daecher, 1975). Obviously, riding under the influence of alcohol or drugs greatly reduces the ability of the rider to control the bicycle. Baker, et al. (1993) state, "two-thirds of fatally injured bicyclists are tested for alcohol; 32% of those tested have been drinking."

By avoiding these hazardous behaviors, a cyclist increases the level of safety for the entire traffic mix. When cyclists understand and follow the law, other users treat them like traffic (Adams, 1994). By reducing unexpected actions, and observing better riding techniques, a cyclist limits his or her potential conflicts.

Little is available in the literature on the interaction of cyclist behavior with the elements of the roadway infrastructure, especially those elements that may be construed as "anomolies" to be corrected through maintenance activities. Characterization of such behavior is essential to the development of maintenance countermeasures, and an assessment of their effectiveness. The importance of their interaction provide the motivation for the observational study and analysis performed in chapter 3.

MOTORIST BEHAVIOR

Motorists also operate their vehicles in manners that endanger cyclists who share the road network. In thirty-five percent of bicycle-motor vehicle crashes, motorist behavior contributes to the crash (Thom and Clayton, 1992). Hudson (1982) cites common causes of bicycle-automobile accidents, such as motorists failing to yield the right of way and driving under the influence of drugs or alcohol. Hope (1992) and Hudson agree that motorists need to accept and respect the traffic laws regarding cyclists' right to use the roadway. Driving under the influence presents a serious danger to all roadway users. Bicyclists seem particularly vulnerable to drunk drivers since their vehicle affords them no protection.

In addition, some design practices increase the likelihood of motor vehicle-bicycle conflicts, especially when coupled with lack of enforcement. For example, when a bike lane is continued to the intersection line, right-turning automobiles are forced to cross the lane, thus creating a serious conflict with the straight-through cyclists. Ying (1987) and AASHTO (1991) believe this action causes many intersection accidents. Parking to the right of a bike lane also forces conflicts between cars and bikes. After crossing through the bike lane to park, the motorist opens his/her door into the cycle lane in front of incoming cyclists (Wortman, 1975).

To prevent some hazardous behaviors, designers must strive to create a safer roadway environment. When cycle lanes continue forward through a junction, McClintock (1992) advocates using a broken white line or a thermoplastic blue line to identify the bike lane, however this treatment is not in the MUTCD. In addition, he suggests placing straight-through bike lanes to the left of right-turn only traffic lanes; however, Ferrara (1980) believes discontinuing bike lanes at intersections altogether is an effective means of reducing conflicts with right-turning vehicles. At junctions where the bike lane or bike path turns right, the lane or path continues around the corner behind the traffic signals (McClintock and Figure 2.17).

Prevention of other hazardous actions by motorists requires understanding and following the law. Increased efforts to educate motorists, coupled with improved designs will help reduce conflicts.

GEOMETRIC DESIGN

Geometric design problems typically increase the likelihood of a motor vehicle-bicycle conflict. McClintock (1992) proposes many ideas for improving geometric design. Narrow right lanes (Figure 2.1), narrow cycle paths, and narrow, unmarked shoulders may not provide enough safe clearance from other vehicles and pedestrians. Roadway bottlenecks where the cross-section of the roadway decreases, particularly at intersections and bridges, force bikes and motor vehicles into insufficient space, thereby, engendering more frequent conflicts. To avoid such bottlenecks with mixed traffic, separate facilities may be called for to cross major barriers such as rivers, canals, major roads and railways. At-grade railroad crossings that appear harmless by motorists can be deadly when biking. When the rails and the roadway are uneven, the rails can damage bike tires and create a fall. Railroad crossings need special treatment to be made more bike "friendly" according to Ferrara (1980), AASHTO (1991), and Hudson (1982). Since not all bikes have strong braking systems, some horizontal curves have an insufficient radius at the base of a steep grade. Bike path designers need to consider the characteristics of the bicycle when using ramps, which can have sharp turns at the top or bottom of a ramp as well as inadequate sight distance. Poorly designed ramps discourage use of bike paths (Caine and Siegel, 1975).

Circumventing hazards due primarily to facility design considerations may require a variety of approaches. Ferrara (1980) provides eight possible solutions to help negotiate major bicycle barriers and improve bike paths:

1. Signing curb ramps
2. Bike ramps on sidewalks (where applicable)
3. Bike paths on bridges separated from the roadway by a barrier
4. Creek bikeways under bridges
5. Underpasses at railroad crossings
6. Bike bridges over creeks, canals, or rivers
7. Bike - pedestrian bridges
8. Bridge sidewalks for bikes at peak hour (where applicable)

According to Lowe (1989) and McClintock (1992), cyclists may bypass dangerous intersections and main roads using underpasses and bridges (Figure 2.2). Ferrara includes some ideas for improving at-grade railroad crossings; for instance, he recommends using signing and pavement marking as a first step to improving the crossing. He also advocates building up of the road surface to track level, and making the roadway approach both at the same level and at right angles to the rails. AASHTO (1991) also recommends this practice. McClintock recommends the installation of rubberized crossing pads (Figure 2.3), but rubberized mats and flanges should not be installed for crossings with high speed train movements. As an ultimate improvement for railroad crossings, Ferrara suggests the construction of under crossings.

Proper design approaches prevent some hazards altogether. Ferrara (1980), Hudson (1982), and AASHTO (1991) agree on improving all right lanes with substandard widths. All roads need to maintain consistent curb-to-curb widths without any sudden narrowing according to both AASHTO and Hudson. Ferrara (1980) and Lowe (1989) encourage the use of wide, well-marked shoulders to help prevent bicycle accidents in rural locations. Sorton (1993) states,

> "studies in Texas and Wisconsin have shown that 3 to 8 foot [1 to 2.4 meter] shoulders are cost effective for volumes as low as 1,000 to 2,000 vehicles per day. ...Paved shoulders reduce run off the road motor vehicle accidents and also reduce maintenance costs because [the] edge of the road will not be raveling and ruts won't form."

In China, load-carrying bicycles receive an allotment of separate space (Lowe, 1989). McClintock (1992) recommends avoiding large roundabouts (traffic circles) since they are a source of too many conflict points. Bikes and buses have numerous locations for conflict, for example when buses cross the bike lane to get to the bus stop. Ying (1987) encourages improving bus stop design to accommodate bicyclists by limiting bus stops and spreading them out to minimize conflicts with cyclists and by marking with white diagonal lines the locations where buses enter and leave a bike lane. By carefully planning and by addressing each of the bicycle's special concerns, designers eliminate most of the hazards created during roadway design. Furthermore, a design that considers the cyclist early in the design process can avoid many costly corrections. Some designers overlook including ramps as part of a bike path and discontinue them with curbs. Often, small adjustments to the original design may satisfy the cyclists' needs.

Safe geometric design for bicycles requires designers to think like a bicyclist in addition to a motorist and to use concepts that make roadways safer for all users. Geometric conditions cost considerably more to retrofit than to properly construct the first time. By considering cyclists in all aspects of design, the entire roadway becomes friendlier and safer for all users.

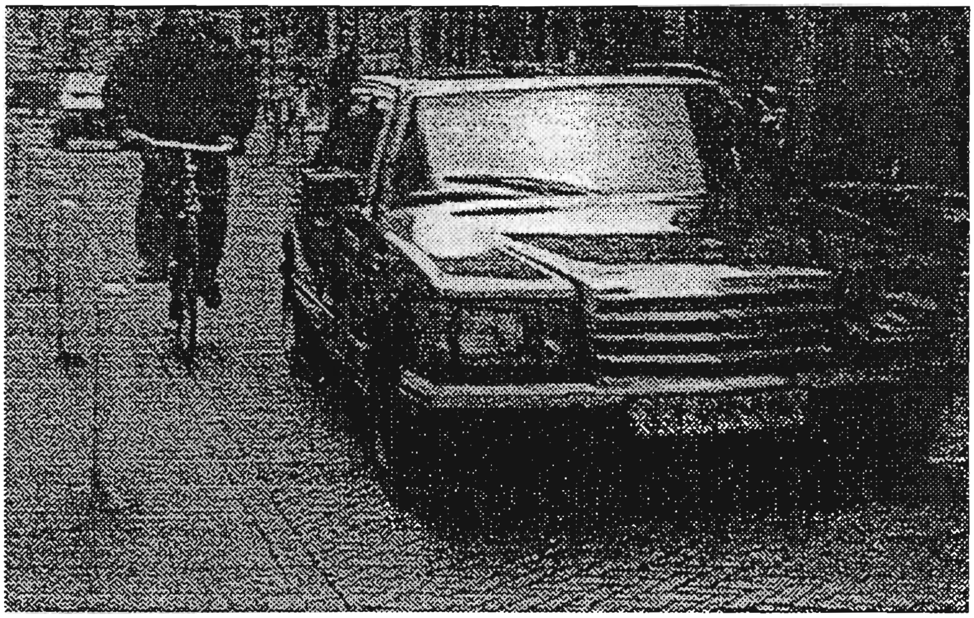


Figure 2.1 Narrow-width Right Lane (CROW, 1993)

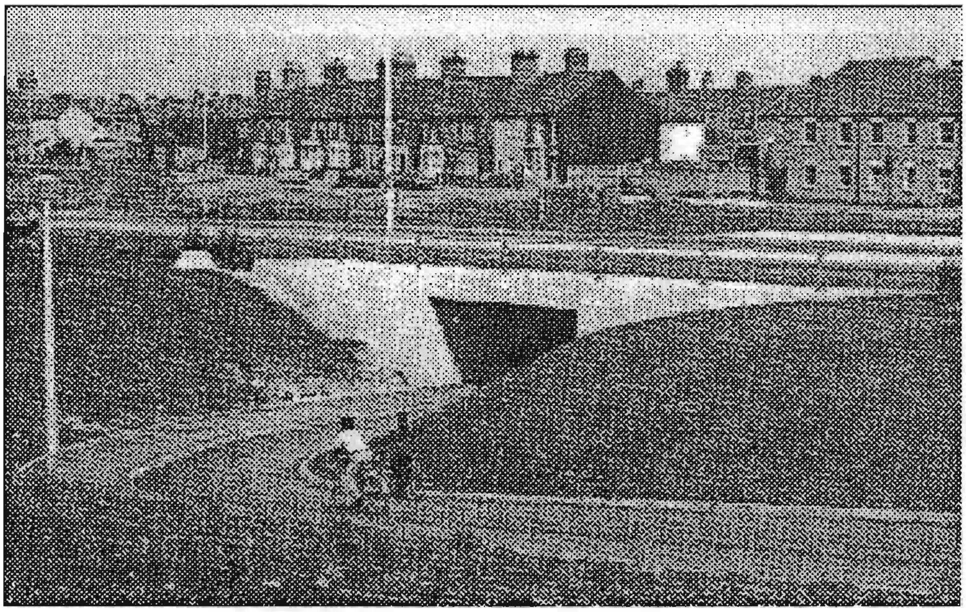


Figure 2.2 Effective Segregation of Bicycles and Pedestrians (Hudson, 1982) The sharp curve at the bottom of the hill constitutes a bicycle hazard.

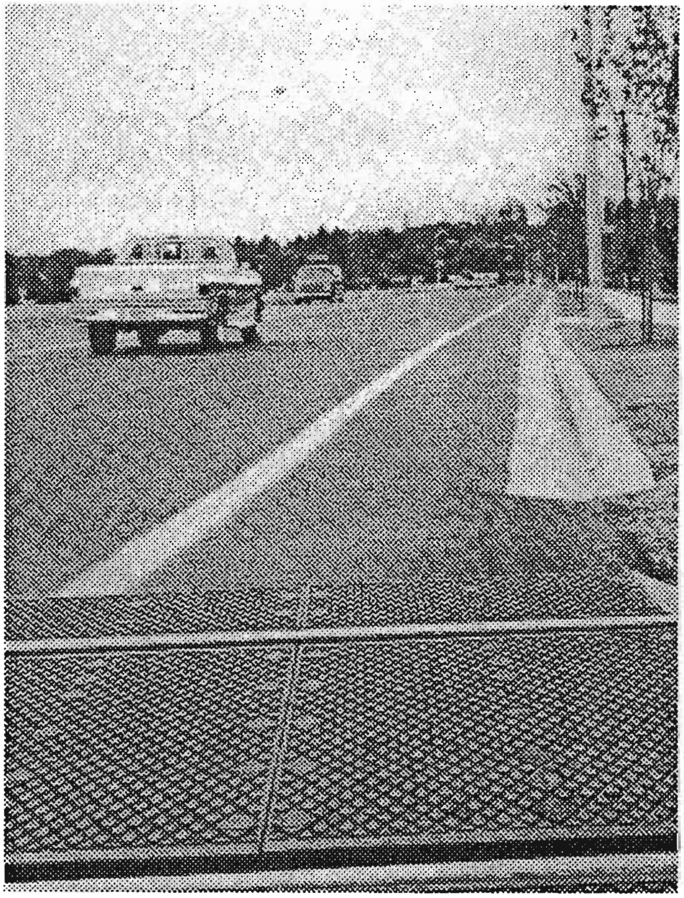


Figure 2.3 Rubberized Railroad Crossings Offer a Good Combination of Smoothness and Traction (Oregon DOT, 1992)

OTHER DESIGN ELEMENTS

Certain design factors impact cyclists' safety, but they do not fit under any other classification. This category addresses the hazards that they pose to cyclists. As in most other cases, these pose difficult trade-offs among the conflicting interests of the cyclist and those of other road users (pedestrians, automobile drivers).

The designer needs to avoid certain hazards at bridges even when adequate roadway cross-section width is provided. Metal grate bridge decks exhibit a few hazardous characteristics (AASHTO, 1991). The bridge deck has a low coefficient of friction during a rainfall if the construction uses a smooth metal. A rougher metal could be used to avoid this problem, but rougher metals damage bike tires easily. The metal slots and grooves found on the deck make controlling a bike difficult for the rider. Some bridge expansion joint designs damage bicycle tires. The use of joints with large gaps and sharp edges (Adams, 1994) is particularly hazardous to cyclists. The choice of a bridge railing height also presents a problem. The railing needs to be high enough to prevent a cyclist from flipping over the railing, but short enough to prevent any restriction of a cyclist's or motorist's sight distance. The railing height recommended by Forester (1983) and the U. S. DOT (1994) is 1.37 meters. It is crucial, Forester states, that

> "railings should have rub rails 42 inches and 54 inches [1.07 meters and 1.37 meters] in height, so that the cyclist rubs against the horizontal rails instead of getting his hands or handlebars caught by vertical stanchions."

Bridges possess many unusual design elements that merit attention to avoid creating bicycle hazards.

Other areas in the road and cycle network require special attention. Ferrara (1980), AASHTO (1991), and Hudson (1982), all agree that both drainage grates and catch-basins could trap bicycle tires. When a wheel-trapping catch-basin (Figure 2.4) has a steep entry slope that extends into the roadway, it could act as a bicycle trap. Catch basins covered with parallel bar grates (Figure 2.5) also tend to trap bike tires. The North Carolina DOT approves the use of one of three bicycle-safe drainage grates as shown in Figure 2.6. Stairways in pedestrian/bike mall areas, such as a college campus, obstruct the cyclist's path (McClintock, 1992). Insufficient lighting on roadways and on paths endanger bicyclists because bicycle lights do not fully illuminate potential obstacles. Additional lighting makes conflicts easier to avoid by providing motorists and cyclists greater opportunities to see each other at night (McClintock, 1992; Hudson, 1982).

Possible solutions to these problems have been proposed; for example, AASHTO (1991) reminds designers to keep grates out of the cyclist's expected path and flush with the roadway surface. In addition, AASHTO encourages designers to avoid parallel bar grates altogether, despite their hydraulic efficiency, since these grates trap bike tires. Areas with high bicycle usage, such as college campuses, need to consider cyclists when designing the entire environment. For example, McClintock (1992) suggests using troughs on flights of stairs to make it easier for cyclists to push bicycles up or down them (Figure 2.7), especially when stairs present potential obstacles to through travel. Only safe designs eliminate the hazards created by bridge railings, bridge expansion joints, and metal grate bridge decks; therefore, proper designing the first time remains essential.

Retrofitting these design elements may prove cost prohibitive; therefore, a safe design approach needs to be used during the initial construction. In order to develop safe bicycle networks, design policies need to provide bicycle prudent design approaches to assist designers. And as new design elements are introduced, their potential impacts on cycling need to be evaluated to avoid the need for costly retrofits in the future.

PAVEMENT CONDITIONS

Dangerous pavement conditions reduce bicyclists' control. According to American Association of State Highway and Transportation Officials (AASHTO, 1991) guidelines, pavement surfaces should be free of irregularities and rough patches. Wortman (1975) describes many such problems for bicycles.

When tires lose contact with the road surface, the rider no longer maintains control of his or her bike. Many obstacles force bike tires to be lifted from the road surface; such as, potholes (Figure 2.8), ruts, and wide pavement cracks that restrict tire movement causing the cyclist to lose his or her balance, damage bike tires, or stop the bicycle's movement thereby sending the cyclist over the handlebars. Wortman (1975) and Hudson (1982) discuss potholes and the damage they inflict on bicycle tires. Any portion of the pavement that is not smooth or raised higher than the rest of the pavement can cause the biker to lose control. Uneven manhole covers pose serious problems for cyclists. According to Hudson (1982) and AASHTO (1991), all manhole covers should be located away from the areas that cyclists ride since manholes tend to be uneven and gradually settle at different rates than the road surface. Wide longitudinal pavement joints that run in the direction of bike travel, especially joints between roadways and gutters, trap bike tires, directly causing crashes (Figure 2.9). Participants in various focus groups all considered wide, longitudinal pavement joints to be extremely dangerous. Drop-offs at pavement overlays parallel to the direction of travel can knock riders off balance as they cross the boundary in either direction. Differential pavement settlement produces dangers similar to uneven manhole covers; in such cases, cyclists experience a sudden elevation change without the benefits of shock absorption.

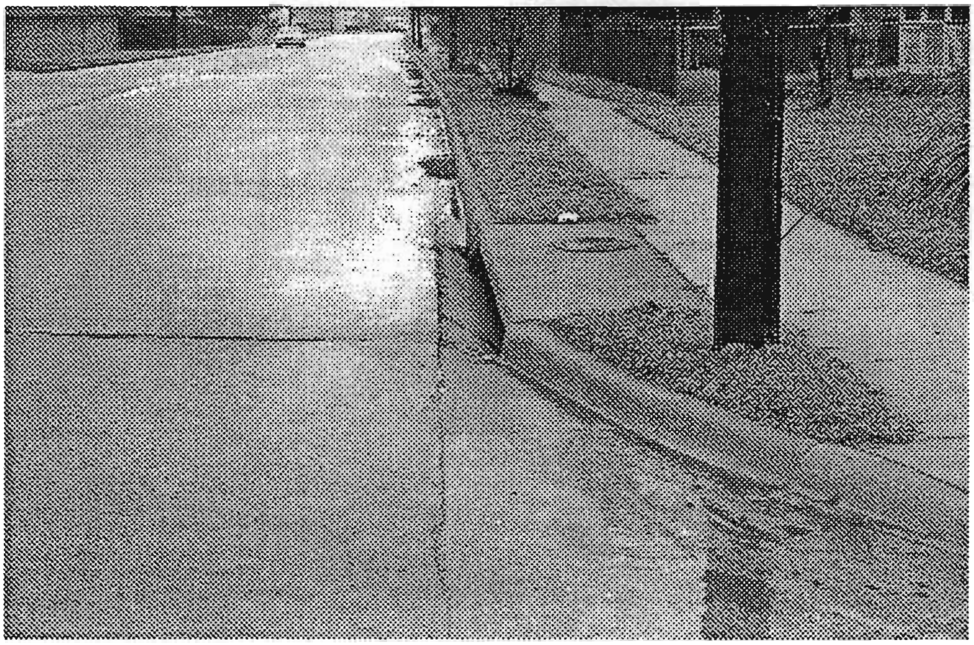


Figure 2.4 A Bicycle-catching Catch Basin

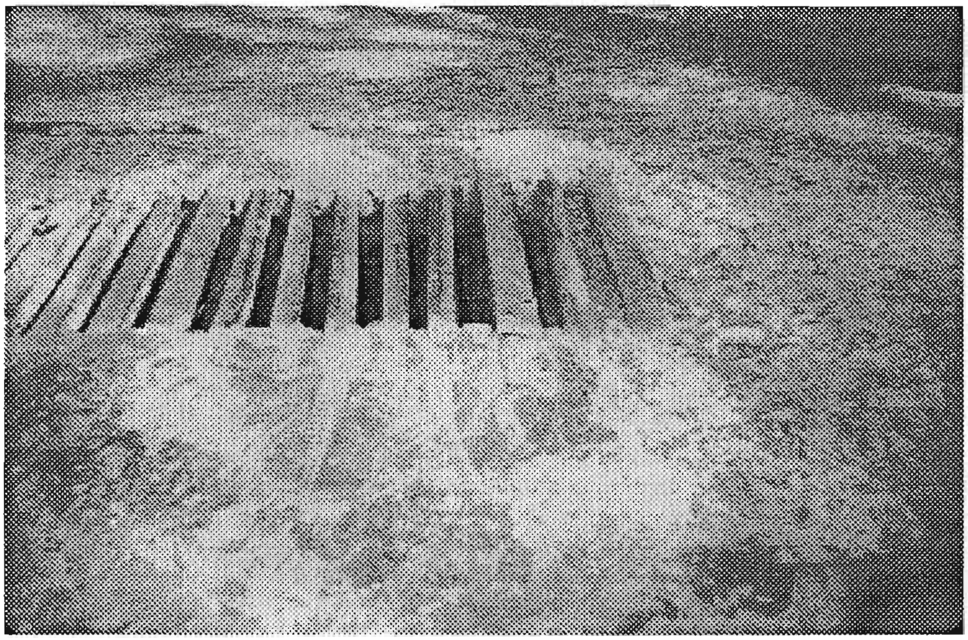
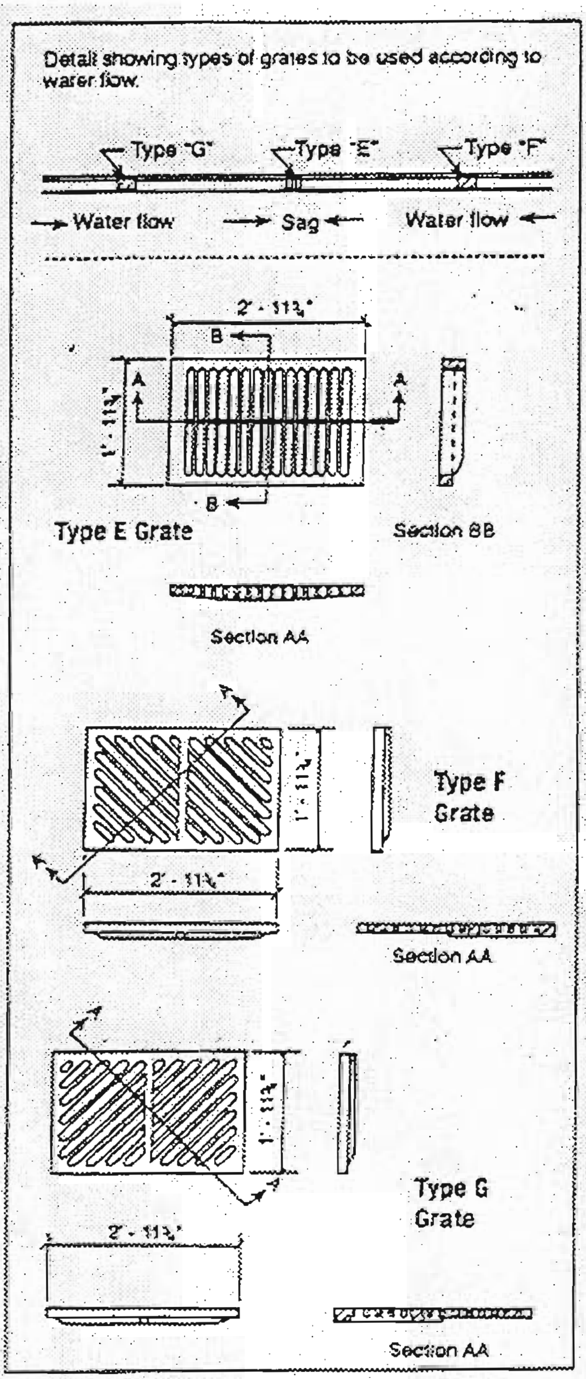


Figure 2.5 A Wheel-Trapping Parallel Bar Grate



Source: NORTH CAROLINA PLANNING AND DESIGN GUIDELINES

Figure 2.6 Bicycle-Safe Drainage Grates Approved by NCDOT (U. S. DOT, 1994)

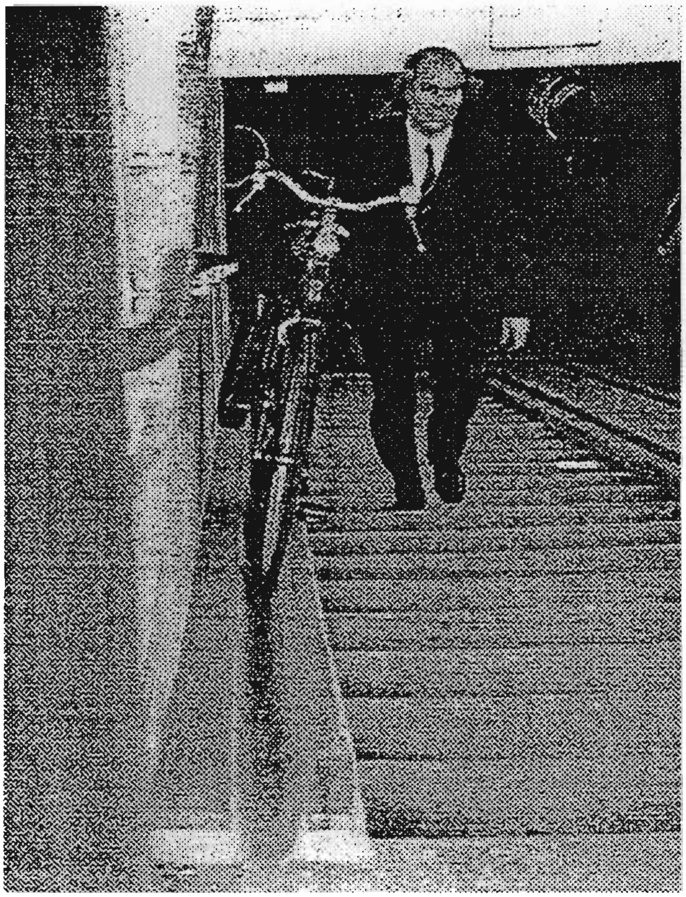


Figure 2.7 A Cycle Ramp to Circumvent Staircases (CROW, 1993)

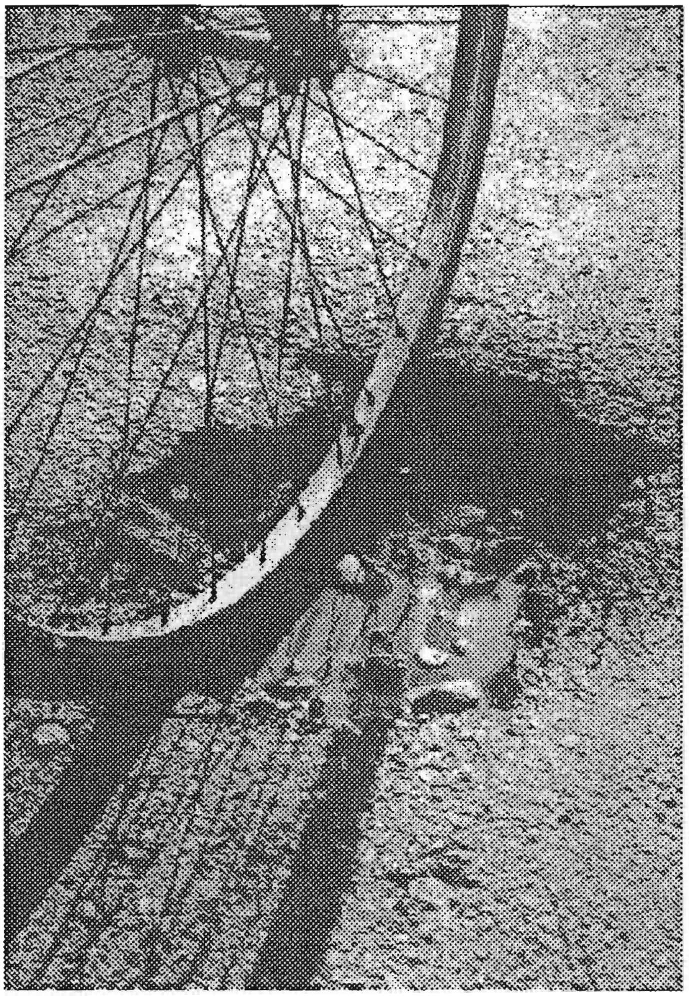


Figure 2.8 Potholes Damage Bike Tires (Hudson, 1982)

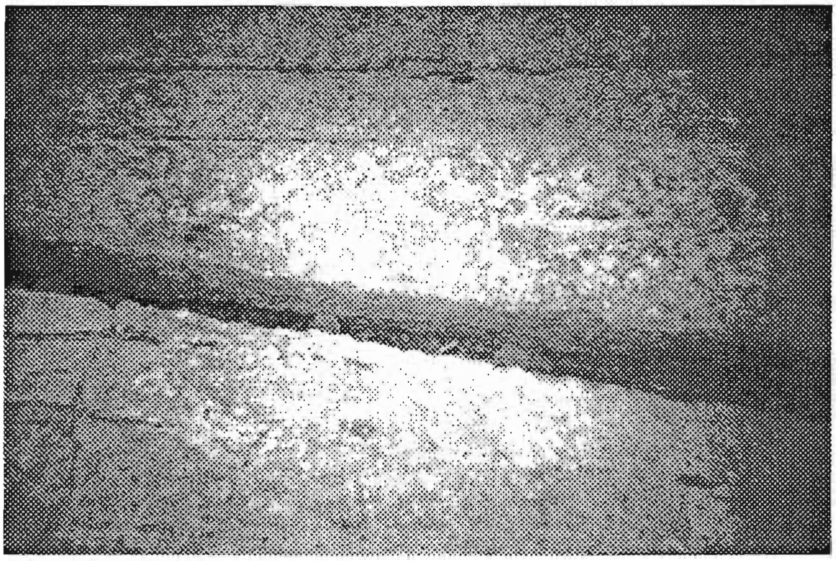


Figure 2.9 Wide Longitudinal Pavement Joints Trap Bike Tires

Figure 2.10 Poor Drainage Reduces Traction and Obscures Other Pavement Problems

Forester (1983) points out, "depressed railroad tracks, rain gutters, and chuckholes act like bumps because the bicycle wheel first falls into the hole and then faces the far wall. A depression 6 inches [152.4 mm] wide is geometrically equal to a 3/4 inch [19 mm] bump." Sorton (1993) suggests bikeway surface tolerances that will insure a comfortable riding surface (see Table 2.4). In addition, Forester (1983) states, "it is...desirable...to fill depressions greater than 6 inches [152.4 mm] across on all roadways used by cyclists." A bike's tires need to remain in contact with the roadway surface at all times for optimum control.

Other pavement conditions contribute to cyclists' control problems. Asphalt ripples (washboard pavement) due to braking action and stone paved roads sometimes jar a rider into losing control. Because a rider could potentially lose control, Forester (1983) states, "...the removal of braking-area ripples along routes with significant cycle traffic is desirable." When asphalt covers the surface aggregates completely, slick, smooth pavement develops that can be dangerous when wet. In one focus group it was mentioned that smooth pavement is desirable as opposed to a rough surface such as a road that has been resurfaced by rolling large-sized aggregate over hot asphalt (chip-coated). One participant stated chip-coated roads are hard to ride on soon after resurfacing is done, noting that they can be soft and excess gravel is still on the roadway.

Table 2.4 Recommended Bikeway Surface Tolerances (Sorton, 1993)

Direction of Travel	Grooves*	Steps**
Parallel to travel	No more than 1/2 inch wide	No more than 3/8 inch high
Perpendicular to travel	----------	No more than 3/4 inch high

1 inch = 25.4 millimeters

* Groove - A narrow slot in the surface that could catch a bicycle wheel, such as a gap between two concrete slabs.

** Step - A ridge in the pavement, such as that which might exist between the pavement and a concrete gutter or manhole cover; or that might exist between two pavement blankets when the top level does not extend to the edge of the roadway.

Temperature sensitive pavements often soften during hot weather, thereby allowing bicycle tires to sink into them. This forces a cyclist to pedal more powerfully or to avoid soft patches altogether. Sorton (1993) points out that concrete is preferable to asphalt for areas with hot or wet climates. Small changes in pavement behavior cause hazardous situations for inexperienced bikers.

Besides pavement conditions, cyclists must be wary of what is resting on top of the pavement surface. Liquids, such as water and oil, reduce the coefficient of friction between the road surface and tire. Bike riders rely heavily on friction to maintain control of their vehicles. Poor drainage on cycle paths and in streets reduces the rider's control (Figure 2.10). Drainage gutters that cut across the street at intersections often carry large flows following major rainstorms and at times seem deceptively shallow. Additionally, poor drainage can hide dangerous surface hazards. In cold climates, ice can form in locations with poor drainage. Ice patches not only pose danger to cyclists and motorists, they also accelerate pavement deterioration. McClintock (1992) recommends improved drainage for cycling facilities to keep the roadway surface free of water. Obviously, oil leaks found on the pavement, primarily near intersections, create dangerous situations. Cars and trucks using unpaved driveways carry sand and gravel onto the pavement. Such loose debris causes serious problems. Forester (1983) explains,

> "Small objects on the roadway surface, such as gravel, broken glass, or sand have two effects on cyclists. The first, ...is that these small items often puncture bicycle tires ..glass fragments 1/4 inch [6.35 mm] or less across are large by cyclists' standards. Particles 1/16 inch [1.59 mm] across are often the found to be the cause of punctures. ...The second...is loss of control. A layer of sand or gravel covering as little as 10% of a paved road surface acts like a layer of ball bearings between tire and road. ...A thicker layer of gravel has the opposite effect of increasing forward friction while decreasing sideways friction. ...When the layer of sand is an inch or so deep, the bicycle wheel digs in as if the front brake had been applied hard."

Therefore, cyclists commonly swerve to avoid debris, possibly steering themselves into conflict, instead of risking a loss of control. To reduce the amount of debris in the travel lanes, a frequent street sweeping program is suggested, but Forester cautions, "even in clean suburbs ...a 10-day sweeping schedule allows noticeable amounts of glass to collect." So, in conjunction with street sweeping he suggests that bottle deposit laws be created to control bottle disposal. To specifically control the sand and gravel coming from driveways, Sorton (1993) suggests all currently unpaved driveways be paved for the first four and one-half meters (fifteen feet). Water, ice, oil, and other substances that reduce the pavement coefficient of friction constitute major hazards for cyclists.

In short, pavement hazards create a loss of control for bicyclists by reducing the roadway coefficient of friction, damaging the bicycle, or trapping their tires and restricting their lateral movement. Proper maintenance and design corrects and prevents a majority of pavement hazards

ROADWAY MAINTENANCE/UPKEEP

The roadways and bike paths that cyclists frequently use need regular maintenance. Lowe (1989), McClintock (1992), AASHTO (1991), Lucero (1975), Wortman (1975), and Hudson (1982) all agree that sand, gravel, broken glass or other debris in the path of a cyclist can pose a serious hazard causing a reduction in both traction and bicycle control. Frequently, cars sweep this debris into exclusive bike lanes because the heavy automobile tires push the debris out of the main lanes (Adams, 1994). Regular street sweeping helps to correct this hazard, as suggested in the preceding section. However, most cities do not have a regular street sweeping program.

Proper maintenance improves the level of safety for cyclists and other road users. As discussed by Hudson (1982) and McClintock (1992) vandalized signs and lights on bike paths and routes, for example, could pose a serious hazard. Damaged lighting decreases personal safety on isolated facilities and vandalized signs reduce the likelihood of cyclists performing expected maneuvers or taking necessary safety precautions. Unpruned trees and overgrown vegetation on bike paths reduce the usable path width and restrict sight distance on the path. Furthermore, unpruned trees that overhang the road surface form an obstacle for cyclists. Sorton (1993) suggests trees, bushes, and other vegetation be kept cut back at least 1 meter from bike facilities and signs be kept clearly in view.

Stray animals, particularly unleashed dogs, represent moving obstacles that could cause loss of control and serious injury or force a rider into conflict with other traffic. Thom and Clayton (1993) identify collisions with moving dogs as the fourth most frequent and fourth most severe classification of bicycle crash. Although bicycle-dog accidents account for only eight percent of the total accidents, they account for ten percent of the serious accidents. Poorly managed work zones could also create cycling hazards by not adequately warning or directing cyclists away from dangerous areas. Work zones should allow a safe path for bikes (Figure 2.11) or an alternate bike route should be designated for the length of the work.

Proper maintenance policies should identify and address cycling hazards to improve the level of service and level of safety for cyclists. To keep roads and paths bike "friendly," local and state governments must commit the funds for frequent and effective maintenance and consider passing bottle deposit laws.

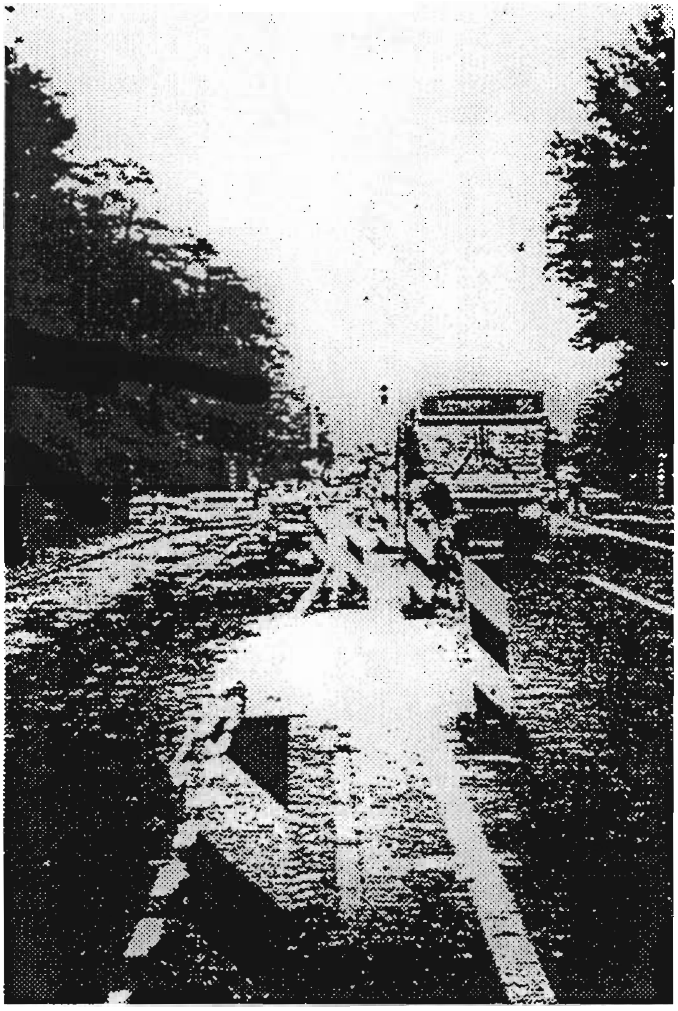


Figure 2.11 Failure to Properly Manage a Work Zone Forces Cyclists to Deviate into the Paths of Motor Vehicles (CROW, 1993)

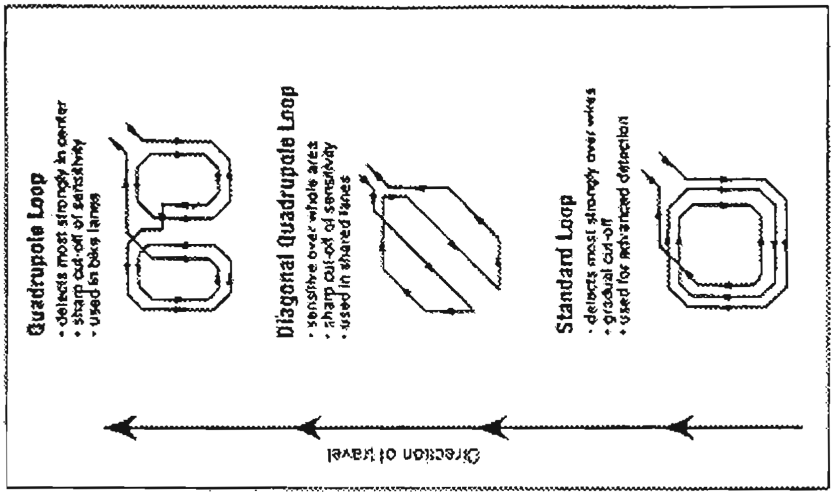
TRAFFIC CONTROL AND CONDITIONS

Traffic controls and traffic conditions can both encourage or discourage cycling depending on the situation. However, some difficult trade-offs and compromises must be made to balance conflicting requirements and interests of bicycles and other modes (primarily automobiles and mass transit vehicles).

Traffic signals tend to ignore bicycles. Often, the presence detectors used in conjunction with fully- and semi-actuated signals are not sensitive enough to detect bicycles, which is a source of frustration to cyclists. When a traffic signal systematically ignores a biker, the latter is likely to violate the signal more frequently. Most experts, including Ferrara (1980), Lowe (1989), McClintock (1992), AASHTO (1991), and Hudson (1982), agree that cyclists need traffic signals that detect their presence. Furthermore, AASHTO, O'Connor (1975), and Hudson emphasize that even if a bike can be detected, the signal phasing and timing may be inappropriate or inadequate for bicycles (for example, the green and yellow duration may not be long enough to allow bicyclists to clear the intersection. In addition, optically programmed signals may not be visible to riders, depending on the signal head location relative to the cyclist's position (Ferrara, 1980). McClintock further suggests the use of bicycle responsive, marked traffic detector loops on streets to facilitate bicycle use. According to Hudson, loop detectors must not only be sensitive to bicycles, but be located in areas where cyclists travel. Both Caltrans and North Carolina recommend the use of three types of loop detectors: the quadropole loop (type Q), the diagonal quadropole loop (type D), and the standard loop (type A). Figure 2.12 shows the loop configurations and suggests the best locations for detecting bicycles. Figure 2.13 illustrates recommended loop markings that should be placed over the most sensitive portion of the detectors to inform cyclists of proper placement. By ignoring cyclists' needs or obstructing their path, traffic control devices may create hazards for cyclists.

Other traffic control devices may also present problems for cyclists. Ferrara (1980) and AASHTO (1991) agree that raised delineators, markers, and berms can cause cyclists to easily lose their balance (Figure 2.14 and Table 2.4). On the subject of berms, Forester (1983) states,

> "where they are installed, they must not occupy all the available width, but must provide channels at least 1 foot [0.3048 meters] wide suitably placed for cyclist travel. All speed berms must be suitably marked to alert all drivers and the channel for cyclists must be marked by discontinuing the normal berm marking and by providing bicycle-channel markings."



Source: NORTH CAROLINA PLANNING AND DESIGN GUIDELINES

Figure 2.12 Recommended Loop Types for Bicycle Detection (U. S. DOT, 1994)

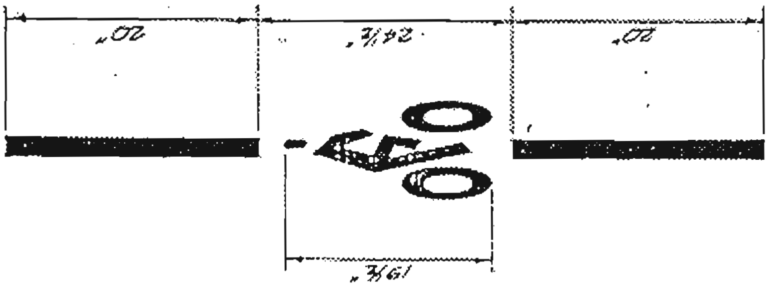


Figure 2.13 Recommended Loop Markings (Sorton, 1993)

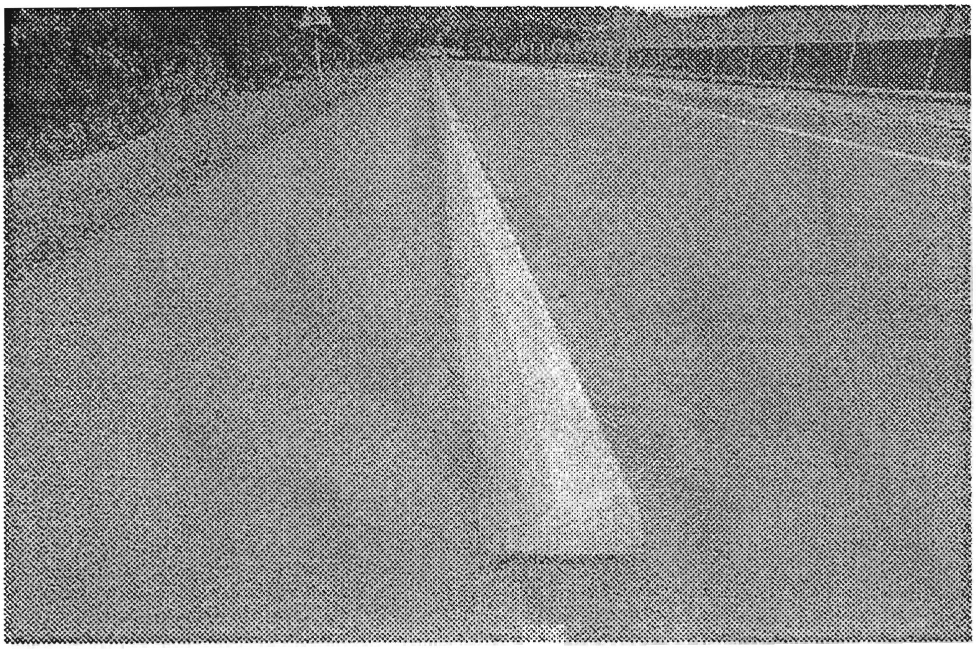


Figure 2.14 An Example of a Hazardous Raised Edge or Berm (CROW, 1993)

Figure 2.15 High Volume and High Truck Volumes Create Unsafe Feelings for Cyclists (Hudson, 1982).

Similarly, speed bumps can throw a cyclist off balance. Raised lane markers, particularly the large six inch version, tend to dismount cyclists when struck. Shoulders provide a safe location for bicycles to ride if they are free of rumble strips. According to AASHTO, rumble strips located on road shoulders because of high truck volumes tend to jeopardize cyclists. Rumble strips and raised lane markers need to be used sparingly in areas frequented by bikers. However, where needed for vehicular safety, rumble strips approximately 381 mm in width in the shoulder area are best located on the edge adjacent to the travel lane, to provide a buffer between autos and bicycles, so long as the rumble-free portion of the shoulder is still sufficiently wide (at least 1.37 meters) to allow cyclists to travel comfortably without forcing them to ride on the strips (Sorton, 1993 and Cheng et al., 1994).

Other traffic control devices need minor improvements. Cyclists collide with street signs located too close to the roadway or bike path. Following the MUTCD guidelines for proper locations would alleviate matters. More signs need to be devoted to bicycle routes and to cyclists. As noted by Ferrara (1980) bike lanes need standardized delineation to improve understanding. Cyclists traveling at different speeds within bike lanes lack separation, which leads to bicycle-bicycle conflicts. However, certain paints used for pavement marking reduce friction on the road surface, and could pose a serious hazard for cyclists.

Traffic conditions influence the number of bike riders and their safety. Poor traffic conditions prevent cyclists from using potential bike routes. High speed traffic reduces the reaction time of motorists overtaking cyclists (Adams, 1994). High volume traffic and high truck volumes (Figure 2.15) create an "unfriendly" environment for cyclists because they must share inadequate roadway area with motorists. Curbside auto parking increases the potential number of motor vehicle-bicycle conflicts (AASHTO, 1991, Wortman, 1975). Not only do cars cross the typical paths of bicycles on their way to park, but the drivers then open their doors into the paths of trailing cyclists. "Unfriendly" conditions discourage bicycling while a "traffic-calmed" neighborhood achieves the opposite.

Cyclists could benefit from more guidance and warning signage devoted to their needs (AASHTO, 1991 and Hudson, 1982). McClintock (1992) suggests a number of treatments for protecting cyclists where cycle paths cross roads. He suggests using speed plateaus to slow down motor vehicles. Additionally, he advocates installing traffic lights for cyclists at intersections of cycle paths and roadways, and microwave detectors at both regular intersections and cycle path-roadway intersections to detect cyclists and trigger a signal phase change. McClintock and Lowe (1989) agree that "traffic-calming" creates a safer environment for cycling. McClintock provides five ideas for traffic calming a neighborhood:

1. Modify the layout of individual streets or neighborhoods to slow traffic speeds
2. Create more lively and attractive spaces
3. Claim space from motor traffic for trees and greenery
4. Provide better rights of way for cyclists and pedestrians
5. Use chicanes, speed plateaus, ramps and carriageway narrowing to make these changes

Additionally, Hudson suggests the use of mini-roundabouts (small traffic circles) to slow motor vehicles (Figure 2.19). At times cyclists may need to be separated from each other; both Lowe and Ying (1987) encourage providing sublanes for cyclists traveling at different speeds. At intersections, they advocate three separate lanes, a left-turn, a right-turn, and a straight through, with pavement markings. Of course, if improperly designed, several of the above items (e.g. traffic circles that are too large, speed bumps) may themselves create hazards to cyclists.

Traffic engineers need to consider bicyclist requirements and concerns in designing the traffic control systems in areas that experience significant bicycle traffic.

BICYCLE CHARACTERISTICS

Some of the operational characteristics of bicycles can make them difficult to use effectively. Bicycles have poor shock absorbing capabilities since a bicycle's high stiffness wheels act as both the shock and spring. A typical bicycle deflects about six millimeters after doubling the normal load, compared with approximately three hundred millimeters for a car (Forester, 1983). The combination of high suspension stiffness, short wheel base, and high center of gravity makes bikes difficult to control after the rider hits a bump or a depression on the road surface. Although mountain bikes have better stability and shock absorbing characteristics, road bikes should be used as the standard design vehicle.

According to Ying (1987), the bicycle is an unstable vehicle, especially at low speeds. As discussed in a previous section, cyclists experience difficulty riding on upgrades and controlling speeds on downgrades. Riders that zigzag when riding uphill come into conflict with other vehicles. When cyclists fail to control their speeds on downgrades, they may exceed the design speed of the roadway. Compared to motorists, cyclists may require additional sight distance, especially at crossing cycle paths and along horizontal and vertical curves, to avoid potential conflicts. Careful designs could mitigate the inherent dangers associated with the bicycle's operational characteristics.

Hudson (1982) discusses bicycle gap requirements while Taylor (1993) points out the limited acceleration characteristics of the bicycle; his research determines that the fifteenth percentile acceleration for bicycles is only 0.3048 m/s^2. Therefore, cyclists need large gaps to be able to safely cross the path of a priority stream of vehicles such as at a two-way stop. In addition, cyclists require sufficient time to complete left turns at both protected and permissive signals. These operational characteristics influence cyclists' riding behavior. When used, exclusive left-turn phases need to allow cyclists to clear the intersection. Low acceleration affects the safety of the cyclists because they remain in areas of conflict longer.

To overcome the limiting operational characteristics of the bicycle, designers could also use special design approaches. For example, Lowe (1989) and McClintock (1992) propose the use of cycle "reservoirs" or advanced stop lines at intersections to allow bicyclists to move first at a green signal (Figure 2.16). These markings allow cyclists space to stop ahead of other traffic and to move first. Hudson (1982) provides additional ideas to help create safer intersections for cyclists, outlined in Figures 2.17 - 2.20. All of the designs shown in Figures 2.16 - 2.20 do not correspond to accepted practice in Texas and would be in violation of TxDOT standards of practice. These would require considerable education of both cyclists and motorists for proper safe and effective usage. A bicycle's operational characteristics create hazardous situations for cyclists; however, these situations can be improved through careful design considerations.

POLICY AND ENFORCEMENT

Governmental entities affect the safety of cyclists through policy and enforcement. Bike "friendly" policies encourage more cycling and improve the safety level for all cyclists. Motorists' and other roadway users' attitudes tend to reflect governmental policies towards cyclists. Enforcement or lack of enforcement of traffic laws for cyclists establishes the government's attitude. Lack of enforcement encourages cyclists to violate traffic laws, thereby creating hazardous encounters (Hope, 1992; Hudson, 1982).

Allowing pedestrians and joggers to use exclusive bike lanes reinforces the notion that the bicycle represents another form of pedestrian travel, causing an increase in bike-pedestrian conflicts. Bike conflicts with pedestrians can be as dangerous as conflicts with automobiles according to Ferrara (1980), AASHTO (1991), and Wortman (1975). Separating modes helps reduce the dangers faced by each mode. Lowe (1989) encourages using separate tracks for motor vehicles, pedestrians, and cyclists in the right-of-way. McClintock (1992) and Hudson (1982) combine to provide three ideas for segregating cyclists from pedestrians:

1. Spatial separation - raising the level of the foot path
2. Color or line segregation - different colors for the respective pathways
3. Barriers - raised dividers separate the paths

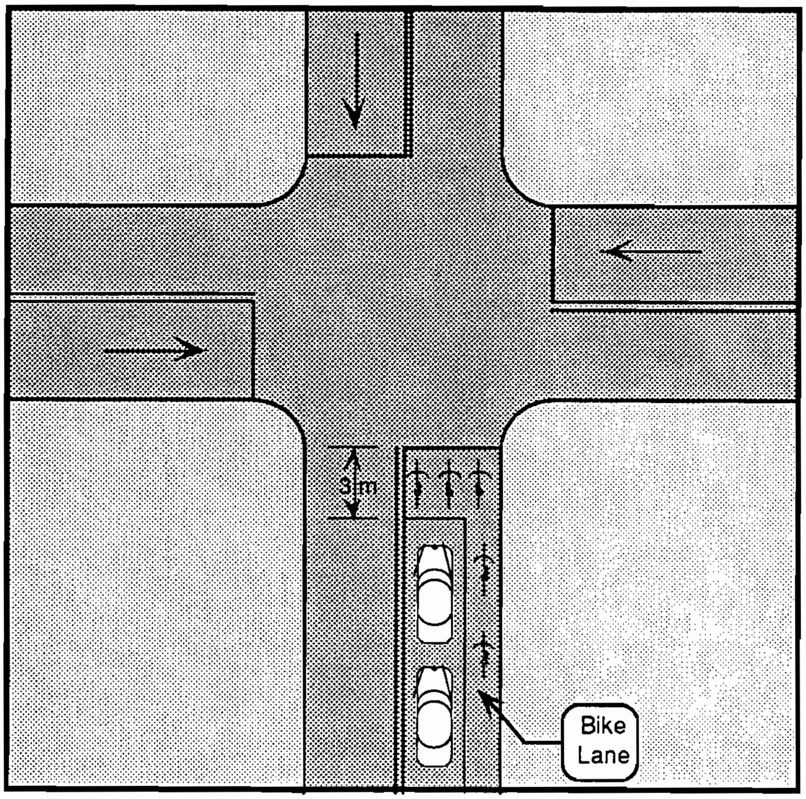


Figure 2.16

A Cycle "Reservoir" Allows Cyclists to Stop in Front of the Vehicle Queue and Pull Away First (Hudson, 1982)

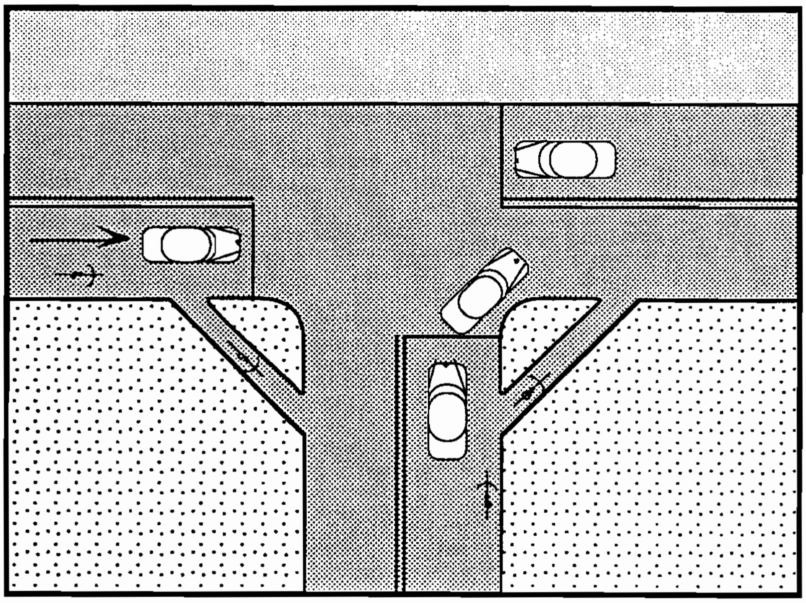


Figure 2.17

Provision for Cyclists Turning Right (Hudson, 1982)

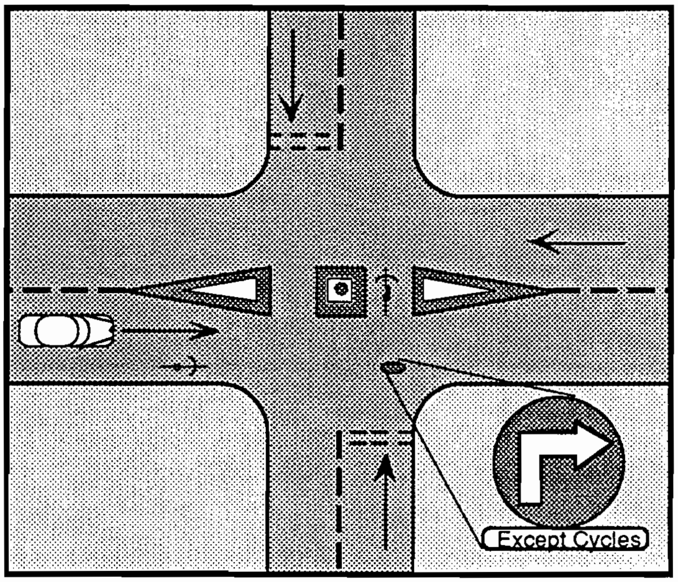


Figure 2.18

An Island Refuge to Protect Cyclists Crossing a Road (Hudson, 1982)

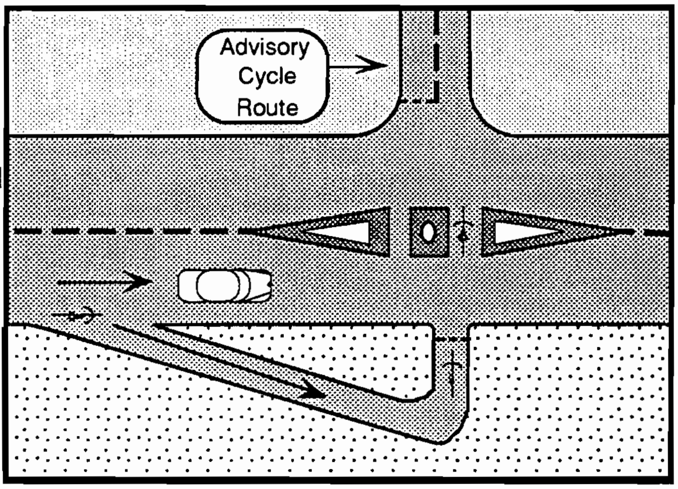
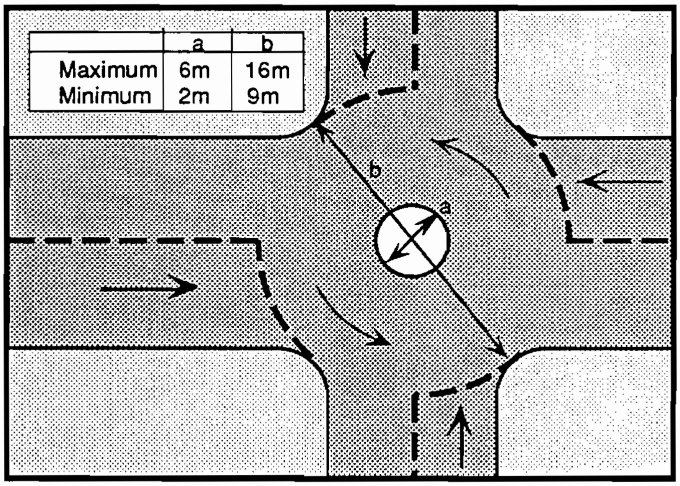


Figure 2.19

A Protective Lane and a Central Island to Help Cyclists Crossing Both Lanes of Traffic (Hudson, 1982)



	a	b
Maximum	6m	16m
Minimum	2m	9m

Figure 2.20

Possible Measurements for a Small Roundabout to Slow Automobiles (Hudson, 1982)

Having advocated separate facilities for bicycles and pedestrians, McClintock suggests the need to maintain both paths equally and to use clear signing and marking. McClintock further advocates three approaches to separating bike lanes and paths from streets:

1. Use a refuge or a white line
2. Use curbstone and asphalt pavement 100 mm higher than the street level, but 30 mm below the sidewalk
3. Same elevation as the street but with a different pavement type

In addition, McClintock describes an exclusive bus, bicycle, pedestrian street. The part of the pedestrian street allocated to bicycle and bus use has a different color, pattern, and level than the rest of the street. When the street becomes bicycle-only, it changes to a new set of color, pattern, and level.

Governmental policies on education could also influence bike safety. By requiring education and training for motorists and cyclists on how to coexist, the roadway users become more familiar with each other's expected behaviors. To encourage improved cycling skills, Ying (1987) advocates licensing bicyclists based on an examination of safety regulations.

Governmental policies would mitigate other bicycle hazards. If possible, planners need to avoid designing bike paths and bike routes through crime-ridden locations since concerns for personal safety discourages the use of such facilities. McClintock (1992) recommends four ways to improve personal security and reduce fears:

1. Wider subways or underpasses
2. Less dense vegetation
3. Improved lighting
4. Careful selection of locations for bike routes

Lack of safe bicycle parking deters bicycle use. According to Lowe and McClintock, governments need to require or to encourage the building of well-lit, clearly signed, plentiful, convenient, guarded bicycle parking. Furthermore, McClintock suggests providing bicycle parking inside mass transit stations and allowing the carriage of bikes on trains, trams, buses, and taxis. Hudson agrees that allowing bikes to be carried on these other modes of transportation encourages bicycle use in a multi-modal system.

ENVIRONMENTAL CONDITIONS

Climatic and other environmental conditions quite often impact upon a person's decision to perform a certain activity. For example, a cyclist concerned with safety will often not ride after dark. Another example is a cyclist who decides not to ride during the winter months because of the cold temperatures and a variety of inclement weather conditions, such as snow and sleet. Although such conditions cannot be controlled, design and maintenance teams knowledgeable about a region's characteristic weather and sensitive to the needs of cyclists can develop alternatives that provide some level of protection or decrease the effects of each hazard.

In the first case, the safety issue at hand may be visibility, in which case placing lights along the route would alleviate this problem. The second case mentions inclement weather which may incorporate rain, snow, sleet, freezing rain, dust storms, hurricanes, and tornadoes. Few people should be caught out in such severe weather conditions as dust storms, hurricanes, and tornadoes, but people will often ride when necessary through the other conditions and therefore these will be addressed. The primary concerns of cyclists in inclement weather include visibility and traction. In other words, can they see and be seen? And can their bike tires stay in good contact with the road? Design teams can help cyclists by sufficiently lighting streets (especially streets with designated bike routes) and using durable pavements that provide good traction. Furthermore, maintenance teams can add lighting to the current street system in selected locations, and increase pavement traction by plowing snow and/or sanding or salting the roadways.

CLOSURE

Through a thorough review of the literature and available accident data summary reports, as well as input from bicyclists (in the form of discussions, focus groups, and survey responses) hazards to bicycling have been identified and described, and grouped into ten hazard categories. Where available, countermeasures discussed in the literature have also been noted.

This list of hazards is consolidated in Appendix A. The majority of these hazards formed the list included in the Hazards to Cycling questionnaire distributed to a sample of cyclists to develop a ranking of the hazards based on perceived danger severity levels, as described in the fourth chapter. But first, the links between cyclists' behaviors and their physical environment is discussed in the next chapter.

CHAPTER III:
INTERACTION OF CYCLIST BEHAVIOR WITH INFRASTRUCTURE

LINKING BEHAVIOR TO THE PHYSICAL INFRASTRUCTURE

In the interest of increasing the safety of roadway users, especially bicyclists, it is essential to understand the links between a user's actions and their surrounding environment so that the responsible agencies can alter the physical environment to lessen the occurrence of dangerous situations. For example, cyclists may continually swerve suddenly at a particular road location and possibly end up in accidents. If the location is investigated carefully, then a physical hazard (such as a parellel-bar drainage grate or a pothole) may be found as the cause of those cyclists' swerves. By replacing the grate or filling the pothole, the hazard may be eliminated and cyclists would no longer swerve at that location. Therefore, by finding the reasons behind the behavior of cyclists, the safety of the road system could be improved by eliminating or reducing the hazardous nature of the physically-based reasons.

The hazards identified in the preceding chapter come in two forms; those that are part of the fabric of the physical environment, and those that pertain to actors within the environment. In this chapter, an attempt is made to link the former with the latter.

DATA COLLECTION

Data related to cyclist hazards were collected through three principal methods: accident databases available from various sources, responses to survey questionnaires administered as part of this study, and video-taping bicyclists riding through several physical environments with obvious hazards. Two types of surveys were conducted: a special-purpose survey focussing on hazards to cycling, and a general survey of bicycle riders. The former was intended primarily for the purpose of the initial hazard severity ranking. The second type of survey seeks to relate bicycle hazard experience and perceptions to the characteristics of the riders, and as such includes a wide range of information on bicyclist characteristics and experience. The video-taping of cyclists allowed for direct observation of the behaviors associated with different hazards. The accident study databases are described below, as are both types of surveys and the video-taping procedures. The analysis in this chapter is primarily based on the results of the second survey and the collected video footage. The next chapter contains a detailed analysis of the seriousness of hazards.

Accident Studies and Databases

Thom and Clayton (1993) state, "effective countermeasures require sound knowledge of bicycle accidents."

Most available accident data are for bicycle-motor vehicle accidents (Williams, 1988). However, most bicycle accidents that do not involve motor vehicles are not reported. For example, Clarke and Tracy in the 1995 FHWA report *Bicycle Safety-Related Research Synthesis* noted that "there are 600,000 crashes involving injury to bicyclists treated in hospital emergency rooms each year. Of these, an average of 850 to 900 are fatal and 70,000 (about 12 percent) are reported to the police as traffic crashes. The economic cost of these crashes is estimated at $3 billion annually." Clarke and Tracy (1995) further point out, "little can be inferred about injuries that are not treated in emergency rooms. [For example,] during a 2-year period in New York, SHASIRS (Scholastic Head and Spine Injury Report System) monitored 83,000 children in grades K-12 and found only 55 percent of any type of head and spine injury were seen in a hospital emergency room." So several injuries that occur because of bicycle accidents may never be seen in hospital emergency rooms, let alone be reported to the police or transportation departments.

The present study obtained motor vehicle-bicycle accident reports and/or databases from: the Texas Department of Public Safety, the city of Winnipeg, Manitoba, Canada, the city of Tempe, Arizona, and the Oregon Department of Transportation. In addition, the city of Madison, Wisconsin provided a bicycle crash report.

The data was not uniform, each state or city collected different sets of factors for varying time periods. The Texas data covers five successive years from 1988 to 1992. Likewise, the Tempe data covers five successive years, from 1987 to 1991. The Oregon accident summaries are for 1990 and 1992. The crash report from Madison provided data for 1992. However, the Winnipeg data included a summary of accidents over a fourteen year period, from 1976 to 1989. From each of these databases the percentages of accidents reported for each year (or time period, in the case of Winnipeg), grouped by causal factors (such as improper passing or turn, driving under the influence, and failure to have control) were culled for analysis (see Appendix F and Table 4.3). The causal factors were further divided by whether the action was performed by the bicyclist or the motorist (e.g. failure to yield right of way to vehicle by motorist), except in the case of the Texas data. Using these data, likely causes of conflict are identified. In addition, areas that pose great risks to bicyclists, such as intersections, are identified.

Hazards to Cycling Questionnaire

This first survey questionnaire was highly focussed on hazard severity, but also includes two sets of behavior-based hazards for respondents to rate. It provided the respondent with a long list of potential hazards, grouped by category, and asked him/her to rate the severity of each hazard on a scale from 1 to 10, with 1 the least dangerous and 10 the most dangerous. This questionnaire did not include any questions regarding the socio-demographic status of the individual respondents, nor their bicycling backgrounds. The main purposes of this questionnaire were to provide initial insights of cyclists' perceptions to serve as a basis for refining the study approach, designing more complete surveys, and other primary data collection activities. The survey questionnaire is shown in Appendix D.

Initially, comments were sought on the questionnaire at a North Central Texas Council of Government (NCTCOG) Bicycle and Pedestrian Task Force meeting. Ten replies were obtained from the NCTCOG committee. Additionally, a focus group meeting was conducted with a small group of cyclists in Arlington, TX and the participants filled out three more questionnaires. Furthermore, approximately fifty questionnaires were distributed to random cyclists. Of those, thirty-five were taped to parked bicycles on the campuses of the University of Texas at Arlington and the University of Texas at Dallas. The remainder were distributed at local bike shops, and to individual cyclists. Fifteen responses were received, corresponding to a response rate of thirty percent. In all, the study received a total of twenty-eight responses to this questionnaire; these are summarized in Appendix E. This sample will be treated as an informal sample because of the collection methods and small size, so care must be taken in analyzing and interpretting this data, which is intended to complement the other data sources in the identification of serious hazards to bicyclists.

Bicycle Riders Survey

The *Bicycle Riders Survey* is a six-page survey (see Appendix B) designed to collect demographic information, general bicycling history, bicycle accident history, and frequency and severity perceptions of hazards from each respondent. The survey was tested for length and clarity by one focus group of five participants before dissemination. It was distributed to three Texas populations and one international population. Two of the four populations were given surveys during the Spring of 1994. Student bicyclists on the University of Texas at Austin campus were the first target population. The second population included participants in Austin's 1994 Bike-to-Work Day. The third Texas population, members of the Texas Bicycle Coalition, was sent surveys during the Summer of 1994. It is important to note that the third sample is by far the most formal, statistically valid, and reliable representative of its target population. Hence, the formal analysis of this survey centers around the data of the TBC respondents. The fourth population included voluntary respondents of an electronic version of the survey who accessed it via the internet and e-mailed a response. This program began in the Spring of 1994 and is an ongoing collection process. The first three samples were entered into a single database while the fourth is being compiled separately. Consequently, the three samples could be analyzed as a whole or individually. For this project, the entire set of responses was initially analyzed informally, then for formal analysis each sample was treated separately, with the TBC member survey as the primary focus. Below is further detail on each of the distribution methods used.

Approximately 1500 surveys were taped to bicycles on the University of Texas at Austin campus to study student bicyclist behavior, with the majority of selected bicycles located on bike racks for dormitories. The surveys were placed on Thursday afternoons between the hours of 2 p.m. and 5 p.m. when classes were in session. The response rate was only 7 percent, resulting in 105 completed surveys. The low return rate is partly caused by the high number of surveys placed near dormitories, where parked bicycles may not actually be used for several weeks, even months. A higher response rate, with more respondents being regular (or daily) cyclists, might be found by concentrating the survey placement at academic facilities.

The second set of surveys was distributed at three check-in stations on the University of Texas at Austin campus during Austin's Bike-to-Work Day. Sixty-three responses were received which included both students and other residents of Austin.

The third target population consisted of Texas Bicycle Coalition members residing all over the State of Texas. A mail survey was administered over the Summer of 1994 and responses came back over the following months with May 1995 the approximate cut-off date for responses accepted for final analysis. Of the 1,102 surveys sent out to 1,097 Texas addresses (some addresses included multiple TBC members), 646 surveys were returned in time for the final analysis, 1 survey was returned because of a wrong address, 2 surveys were sent to people that had business and home addresses listed with TBC (hence they filled out only one copy), 3 to 5 respondents may or may not have been TBC members but received copies of the survey from members, and finally, 1 survey received in July 1995 could not be added. So the net response rate is approximately 59 percent. This is a very high rate for mail surveys not accompanied by response enhancement techniques. This high rate is however consistent with our prior experience with TBC members, who tend to be highly cooperative with studies pertaining to bicycle matters, and are more involved in civic matters than the population at large.

Lastly, the fourth target population consists of electronic respondents through an Internet discussion list. Because of its nature, the resulting sample must be treated with considerable caution. While it contains very useful qualitative information, it is likely to suffer from serious self-selection bias. Nevertheless, it could add an international perspective to the responses.

Video Footage of Cyclists

There is a need to observe actual behavior of cyclists to identify major types of actions and maneuvers in the presence of physical hazards, therefore video footage of cyclists is an important component of bicycle safety research and hazard mitigation development. Video-taping is an opportunity to observe actual "revealed preferences" rather than just "stated preferences" as collected from the survey responses. Hence, it allows for comparison and reconciliation between what cyclists might report and what they actually do. It is also a meaningful basis for formulating engineering solutions to the identified hazards. Therefore, cyclist behavior in the vicinity of physical hazards was observed and video-taped for further analysis in this report.

Cyclists were video-taped and observed during the Summer of 1994. Six types of hazards were used for the project: autos in bike lanes; asphalt ripples and potholes; steel plates across a section of roadway; asphalt patches and associated gravel following the removal of steel plates; construction sites; and intersections. These hazards were found and selected for analysis at a total of nine locations. Bicyclists were filmed by two-person teams in Austin, Texas, generally during weekday mornings. It is important to note that the cyclists were not volunteers, they were just persons happening to bike by our hazard location. In addition, they were not informed that they were being taped for research; if a cyclist or other road user did stop to inquire about filming, the research team explained that they were studying the traffic (no specifics were given). General characteristics of the bicyclists and their behavior was recorded, including their gender, the bike type ridden, whether or not they wore helmets, and whether they rode directly over the hazard or around it in some manner. Further details were compiled while viewing the tapes after field collection was completed. Presented herein is a detailed analysis of three hazard locations to indicate how cyclists respond when confronted by certain types of hazards and enumerate implications their actions may have on their safety and the safety of other road users.

DATA ANALYSES

Results of the Accident Studies

The accident information has been analyzed in two steps: first, the percentage of observed cyclist behaviors is compared to the percentage of accidents affected by hazardous behaviors; then, the data from each accident study is combined for easier comparison. The study looks for similarities between findings from the first step and the combined accident data. The accident data are listed in Appendix F.

Certain behaviors associated with cycling carry a high degree of risk, for example, the accident data collected suggests that cyclists cause a high percentage of accidents per year by riding against traffic and riding in pedestrian areas (see Table 4.3 reprinted below). In addition, the data shows cyclists cause the majority of accidents in which disregard of traffic signals is cited. To further gauge which behaviors are the most dangerous, Thom and Clayton (1992) compared cyclist behaviors and accident rates in Winnipeg. Their study adds the hazard factor for each behavior by dividing the percent of accidents attributed to a certain behavior by the percent of instances of the behavior. Although some behaviors occur rarely, they account for a high percentage of the bicycle crashes, hence a high hazard factor value. These hazardous cyclist behaviors include:

1. Failing to yield the right of way to other vehicles
2. Disregarding traffic control devices
3. Weaving (to avoid roadway hazards or due to lack of stability)
4. Riding the wrong way

From the accident data collected for this project and this list developed by Thom and Clayton three cyclist behaviors might be related to the physical environment: riding against traffic, disregarding traffic control devices, and weaving to avoid roadway hazards. The first case can lead to serious accidents involving bicyclists and motor vehicles because drivers are not expecting cyclists to be travelling the wrong way, so they do not look for cyclists and do not anticipate encountering them. To reduce the amount of wrong way riding, maintenance crews can post signs along roadways (especially on designated bike routes) and paint stencils in bike lanes indicating the proper direction of travel. The second case is often due to a cyclist who wishes to keep his or her momentum and not have to stop for a traffic light or a Stop sign to pass through an intersection. Unfortunately this can lead to serious collisions with other traffic, "Thom (1992) observed less than 3 percent of bicyclists disobeying Stop signs at selected sites in Winnipeg, Canada, yet this action contributed to 11 percent of car-bicycle collisions, suggesting 'that when a bicyclist does disobey a traffic control device, the probability of a collision is high'" (Clarke & Tracy, 1995). To alleviate this problem it is helpful for planners to locate bicycle routes on roads with a minimum of Stop signs. If a bicycle boulevard is being designed, then signals along the route could be timed to allow for a reasonable bicycle progression speed in addition to providing for motorized vehicles' progression speed. A maintenance solution for this behavior could be the clearing of any vegetation or signs that obstruct the view of the traffic control device and checking the proper placement of all traffic control devices. The last case, weaving, is often caused by a cyclist who at the last minute spots a dangerous surface hazard and takes corrective action by suddenly swerving. This can lead to collisions with a nearby curb or motorized vehicles, depending on the direction of the swerve. Weaving by cyclists can be reduced by maintenance crews repairing the roadway surface and removing roadside obstructions that were spotted by scheduled maintenance or reported by users.

Table 4.3 Bicycle Accidents with Known Causes

	Texas DPS Accs/year* (% accs/yr)	Tempe, Az. Accs/year** (% accs/yr)	Madison, Wis. Accs/year*** (% accs/yr)	Winnipeg, Man., Canada Accs/year*** (% accs/yr)	Oregon DOT Accs/year**** (% accs/yr)	Cross & Fisher % Accidents ******
Speed too fast (1)	51.6 (4.4%)	n/a	3.0 (1.6%)	n/a	n/a	n.a
Speed too slow (1)	150.2 (12.8%)	n/a	n/a	n/a	n/a	n/a
Fail to yield ROW to other vehicles: Total	375.0 (32.0%)	67.6 (26.3%)	87.0 (47.3%)	56.7 (34.6%)	276.5 (23.9%)	8.9%
Motorists	n/a	43.8 (17.0%)	61.0 (33.2%)	31.9 (19.5%)	208.5 (18%)	6.3%
Cyclists	n/a	23.8 (9.3%)	26.0 (14.1%)	24.8 (15.1%)	68.0 (5.9%)	2.6%
Disregard traffic control device: Total	60.0 (5.1%)	25.8 (10.1%)	7.0 (3.8%)	20.4 (12.5%)	177 (15.2%)	n/a
Motorists	n/a	6.6 (2.6%)	n/a	2.2 (1.4%)	30.5 (2.6%	n/a
Cyclists	n/a	19.2 (7.5%)	7.0 (3.8%)	18.2 (11.1%)	146.5 (12.6%)	11.4%
Improper passing or turning: Total	68.8 (5.9%)	33.6 (13.1%)	n/a	23.8 (14.5%)	140.5 (12.1%)	22.5%
Motorists	n/a	28.0 (10.9%)	n/a	15.5 (9.4%)	107 (9.2%)	14.3%
Cyclists	n/a	5.6 (2.2%)	n/a	8.4 (5.1%)	33.5 (2.9%)	8.2%
No light/reflector on bike at night	n/a	5.4 (2.1%)	n/a	16.4 (10.0%)	n/a	n/a
Riding against traffic	n/a	112.2 (43.7%)	n/a	12.4 (7.6%)	167.5 (14.4%)	13.7%
Following too closely	13.0 (1.1%)	9.4 (3.7%)	n/a	n/a	25.5 (2.2%)	1.1%
Driving under influence	79.0 (6.7%)	n/a	n/a	n/a	n/a	n/a
Failure to have control	n/a	n/a	n/a	6.4 (3.9%)	15 (1.3%)	n/a

Table 4.3 (Continued)

	Texas DPS Accs/year* (% accs/yr)	Tempe, Az. Accs/year** (% accs/yr)	Madison, Wis. Accs/year*** (% accs/yr)	Winnipeg, Man., Canada Accs/year**** (% accs/yr)	Oregon DOT Accs/year***** (% accs/yr)	Cross & Fisher % Accs ******
Inattentive riding	n/a	n/a	32.0 (17.4%)	n/a	n/a	n.a
Bicyclist travelling in pedestrian areas	n/a	n/a	55.0 (29.9%)	23.4 (14.3%)	n/a	6.60%
Cyclists too close to parked car	n/a	n/a	n/a	7.6 (4.7%)	14 (1.2%)	n/a
Cyclists swerves unexpectedly	n/a	n/a	n/a	7.3 (4.5%)	61 (5.3%)	1.30%
Other violations	374.6 (32.0%)	254 (1.0%)	n/a	0.4 (0.2%)	n/a	n/a
Total accidents with known causes	1172.2 (100%)	256.6 (100%)	184.0 (100%)	163.8 (100%)		

* 1988- 92 Data

** 1987- 91 Data

*** 1992 Data

**** 1976- 89 Data

***** 1990, 1992 Data

****** 1977 Study

(1) In the Texas data, motorists most likely account for "speed too fast" and the cyclists account for "speed too slow" but the data does not specify whether one or both classes of vehicle exhibited the identified cause.

Hazards to Cycling Questionnaire Results

Responses to the hazard questionnaire were analyzed by examining means and confidence intervals of the ratings for each listed hazard. Then the severity of each hazard was evaluated based on its mean rating to determine the critical hazards. Several cyclist behaviors ranked high as hazards, including: failure to yield right-of-way - cyclist, riding against traffic, reluctance to decelerate or stop at crossings, and riding under the influence (of alcohol or drugs). Both the *Hazards to Cycling* questionnaire and accident studies reveal similar hazardous behaviors (see Chapter 4) that are of concern to cyclists and are potential causes of accidents. In fact, all the hazards that are identified from the accident studies as major causes of crashes rank in the top twenty hazards of the questionnaire (please see discussion in Chapter 4 and Table 4.7). Hence, finding methods of design and maintenance to curb inappropriate behaviors could reduce some of the most dangerous hazards.

Bicycle Riders Survey Results

To introduce the *Bicycle Riders Survey* analysis, general and bicycle rider characteristics for the respondents are included for informational purposes. Following these are dicussions developed around the topics of helmet use, road type preferences, reported accident types, and commonly listed hazards for the reported accidents.

General Characteristics. The results presented for the *Bicycle Riders Survey* are from the pooled responses of three populations: the University of Texas at Austin campus bicycling population (UT-Aus), the 1994 Austin Bike-to-Work Day participants that stopped at check-in stations around the UT-Austin Campus (Aus-BWD), and members of the Texas Bicycle Coalition (TBC). A total of 814 responses were received, 105 from UT-Aus, 63 from Aus-BWD, and 646 from TBC. Table 3.1 lists some general statistics while Tables 3.2, 3.3, and 3.4 present socio-demographic and mobility characteristics of all the respondents, UT-Aus and Aus-BWD pooled, and TBC respectively.

Table 3.1 General Statistics

Sample	**Total**	**UT-Aus**	**Aus-BWD**	**TBC**
Respondents	814	105	63	646
Percent of Respondents	100	12.90	7.74	79.36
Percent of Male Respondents	80.65	64.08	77.42	83.65
Predominant Age Group (years)	35 - 49	18 - 24	25 - 34	35 - 49
Ridden a Touring Bike	88% (712)	60% (63)	73% (46)	93% (603)
Ridden a Mountain Bike	64% (515)	80% (84)	73% (46)	60% (385)
Ridden Another Bike Type	12% (92)	12% (13)	6% (4)	12% (75)

Table 3.2 Characteristics of All Respondents (n = 814)

Characteristics	**Categories**	**Mean**	**Relative Frequency**
Gender	Female		19.35
	Male		80.65
Age	18 - 24		11.11
	25 - 34		18.52
	35 - 49		47.41
	50 - 65		19.01
	over 65		3.95
Total number of people in household		2.61	
Gross annual household income	under $15,000		8.29
	$15,000-$30,000		9.97
	$30,000-$45,000		12.44
	$45,000-$60,000		16.32
	$60,000-$75,000		13.08
	over $75,000		39.90
Access to transit	Yes		58.78
	No		41.22
Use mass transit for:	Shopping/Errands		10.72
	Social Act./Rec.		12.09
	Work		15.79
	School		15.98
Number of automobiles for household		2.13	
Ridden a touring bicycle			87.47
Years of riding a touring bicycle		12.13	
Ridden a mountain bicycle			63.27
Years of riding a mountain bicycle		3.44	
Ridden another bicycle type			11.30
Bicycle riding training received (please note: respondents may have received several forms of training)	Learned as a child		95.29
	Learned as an adult		28.88
	Trained by other cyclists		41.38
	Saw a film/video		14.21
	Read an article/pamphlet		39.14
	Read a book/monograph		29.50
	Formal training		8.00
Number of months/year not bicycling because of bad weather		1.34	
Percent of bicycling done at night		15.89	
Average weekly bicycle-miles for	Shopping/Errands	2.67	
	Social Act./Rec.	11.54	
	Exercise/Training	46.58	
	Work	9.59	
	School	2.07	
	Other	0.40	
	Total	72.74	
Average weekly auto-miles for	Shopping/Errands	33.11	
	Social Act./Rec.	42.43	
	Work	87.63	
	School	3.28	
	Total	154.44	
Number of citations received in the last 2 years	while bicycling	0.04	
	while driving	0.30	
Number of accidents in last 2 years (regardless of fault)	while bicycling	0.75	
	while driving	0.14	

Table 3.3 Characteristics of UT-Aus and Aus-BWD Respondents (n = 168)

Characteristics	Categories	Mean	Relative Frequency
Gender	Female		30.91
	Male		69.09
Age	18 - 24		53.61
	25 - 34		31.93
	35 - 49		13.25
	50 - 65		1.20
	over 65		0.00
Total number of people in household		2.82	
Gross annual household income	under $15,000		36.08
	$15,000-$30,000		22.78
	$30,000-$45,000		12.66
	$45,000-$60,000		10.76
	$60,000-$75,000		8.23
	over $75,000		9.49
Access to transit	Yes		88.02
	No		11.98
Use mass transit for:	Shopping/Errands		21.43
	Social Act./Rec.		16.07
	Work		22.02
	School		41.07
Number of automobiles for household		1.95	
Ridden a touring bicycle			65.48
Years of riding a touring bicycle		7.24	
Ridden a mountain bicycle			77.98
Years of riding a mountain bicycle		3.69	
Ridden another bicycle type			10.12
Bicycle riding training received (please note: respondents may have received several forms of training)	Learned as a child		98.80
	Learned as an adult		12.05
	Trained by other cyclists		19.28
	Saw a film/video		3.61
	Read an article/pamphlet		12.65
	Read a book/monograph		7.83
	Formal training		1.20
Number of months/year not bicycling because of bad weather		1.12	
Percent of bicycling done at night		19.57	
Average weekly bicycle-miles for	Shopping/Errands	3.72	
	Social Act./Rec.	5.94	
	Exercise/Training	12.65	
	Work	7.70	
	School	8.40	
	Other	0.24	
	Total	38.65	
Average weekly auto-miles for	Shopping/Errands	2.47	
	Social Act./Rec.	13.20	
	Work	13.55	
	School	11.80	
	Total	41.02	
Number of citations received in the last 2 years	while bicycling	0.14	
	while driving	0.47	
Number of accidents in last 2 years (regardless of fault)	while bicycling	1.06	
	while driving	0.24	

Table 3.4 Characteristics of TBC Respondents (n = 646)

Characteristics	Categories	Mean	Relative Frequency
Gender	Female		16.35
	Male		83.65
Age	18 - 24		0.16
	25 - 34		15.06
	35 - 49		56.21
	50 - 65		23.60
	over 65		4.97
Total number of people in household		2.55	
Gross annual household income	under $15,000		1.14
	$15,000-$30,000		6.68
	$30,000-$45,000		12.38
	$45,000-$60,000		17.75
	$60,000-$75,000		14.33
	over $75,000		47.72
Access to transit	Yes		51.10
	No		48.90
Use mass transit for:	Shopping/Errands		5.51
	Social Act./Rec.		10.14
	Work		12.75
	School		3.77
Number of automobiles for household		2.18	
Ridden a touring bicycle			93.34
Years of riding a touring bicycle		13.41	
Ridden a mountain bicycle			59.60
Years of riding a mountain bicycle		3.38	
Ridden another bicycle type			11.61
Bicycle riding training received (please note: respondents may have received several forms of training)	Learned as a child		94.47
	Learned as an adult		32.24
	Trained by other cyclists		47.19
	Saw a film/video		16.99
	Read an article/pamphlet		45.78
	Read a book/monograph		34.57
	Formal training		10.16
Number of months/year not bicycling because of bad weather		1.40	
Percent of bicycling done at night		14.93	
Average weekly bicycle-miles for	Shopping/Errands	2.39	
	Social Act./Rec.	13.00	
	Exercise/Training	55.43	
	Work	10.08	
	School	0.42	
	Other	0.44	
	Total	81.67	
Average weekly auto-miles for	Shopping/Errands	38.69	
	Social Act./Rec.	50.09	
	Work	107.	
	School	3.50	
	Total	184.	
Number of citations received in the last 2 years	while bicycling	0.01	
	while driving	0.25	
Number of accidents in last 2 years (regardless of fault)	while bicycling	0.64	
	while driving	0.12	

The combined sample primarily consists of males (80.7 percent), with the UT-Aus sample having the lowest proportion of males (64.1 percent) and the TBC sample having the highest proportion at 83.7 percent. Most participants (47.4 percent) were between the ages of 35 and 49, however this is due to the large number of TBC respondents in this category (363, or 56.2 percent of the TBC sample). In the UT-Aus sample the predominant age group is 18 to 24 years old and for the Aus-BWD sample the predominant age group is 25 to 34 years old, which is not surprising, since an overwhelming majority of these two samples' respondents (72.6 percent) are students. Similarly, the annual household incomes of respondents varied dramatically between the samples. Almost half of TBC respondents (47.7 percent) earn an annual household income of over $75,000 and 80 percent earn at least $45,000 per year. Examining UT-Aus and Aus-BWD respondents together, incomes tend towards the lower end of the spectrum with 36.1 percent reporting an income of less than $15,000 per year and more than 50 percent of the sample reporting incomes less than $30,000 per year.

An average of 2.61 people live in the households of all respondents and have access to an average of 2.13 automobiles. With easy access to cars, it is no surprise that respondents drive an average of 154 miles per week (see Table 3.2). The relative frequency of the miles driven weekly by respondents is given in Table 3.5. The majority of UT-Aus bicyclists drive less than 50 miles per week (82 percent). Drivers in the Aus-BWD sample primarily drive between 1 and 100 miles per week (62 percent). TBC respondents drive a wide range of distances per week unlike the previous two samples that have narrow spreads. Most respondents travel between 50 and 300 miles in a typical week (71 percent). In addition, almost 60 percent of the sample stated that they have access to transit within their community. However, only 51.1 percent of TBC respondents have access while 88.0 percent of the UT-Aus and Aus-BWD respondents have access -- which

Table 3.5 Number of Miles Driven Weekly by Respondents

Weekly Miles	less than 1	1 to 49	50 to 99	100 to 149	150 to 199	200 to 299	300 to 399	400 to 499	500 or more
% of Respondents	6.20	16.60	20.69	15.74	9.05	16.60	8.80	2.85	3.47
% of UT-Aus	33.33	48.57	11.43	5.71	0.00	0.95	0.00	0.00	0.00
% of Aus-BWD	14.29	36.51	25.40	9.52	6.35	6.35	1.59	0.00	0.00
% of TBC	0.94	9.39	21.75	18.00	10.80	20.19	10.95	3.60	4.38

seems reasonable since the last two samples were both taken in Austin where transit service reaches most neighborhoods where students tend to live.

Bicycling Characteristics. The samples again differ when considering what kind of bicycle the respondents ride and how long they have ridden a particular bike type (see Tables 3.1 and 3.6 and Figure 3.1). For example, 60 percent of the UT-Aus sample has ridden touring bikes (a touring bicycle is defined as a bicycle with thin tires for this study), as compared to 73 percent of the Aus-BWD sample, and a huge 93.3 percent of the TBC sample -- resulting in 87.5 percent of all respondents having ridden a touring bike. The opposite trend exists for the riding of a mountain bike (a mountain bike is defined as a bicycle with wide tires for this study): 80 percent of UT-Aus respondents have ridden a mountain bike, in contrast to 73 percent of Aus-BWD respondents, and only 59.6 percent of TBC respondents -- resulting in 63.3 percent of all respondents having ridden a mountain bike.

The respondents learned to ride bicycles through a variety of means, with the overwhelming majority (95.3 percent) learning to ride when they were children (please refer to Table 3.2). Unfortunately, only 8 percent of the sample received formal training (e.g. a course in Effective Cycling). The respondents also learned to ride by watching a film or video (14.2 percent), by reading an article or pamphlet (39.1 percent), by reading a book or monograph (29.5 percent), and by other cyclists training them (41.4 percent). Finally, 28.9 percent of the respondents stated that they taught (or retaught) themselves as adults.

Supporting the fact that touring bicycles have been in existence longer than mountain bicycles is the average number of years the respondents have ridden each bicycle type, 12.13 years for touring bicycles while only 3.44 years for mountain bicycles. Looking at the distances cyclists travel (as listed in Table 3.7), the majority of respondents ride between 1 and 100 miles per week (nearly 70 percent). However, the spread differs greatly depending on the sample. For instance, 81.0 percent of UT-Aus respondents ride from 1 to 49 miles a week -- this sample is concentrated in this range, whereas the Aus-BWD sample is clustered over two ranges with 57.1 percent of the respondents riding between 1 and 49 miles per week and 30.2 percent riding between 50 and 100 miles per week. The most variability is found among TBC respondents (similar to the miles driven weekly), the percent of riders in any range does not exceed 33 so this is the most diverse sample. All of these cyclists, on average, ride 10.66 months out of a year with over 45 percent of the TBC sample riding year-round. Furthermore, respondents of all the samples, on average, report that riding during the evening or night hours constitutes 15.9 percent of their total bicycle riding, however this statistic is only 14.9 percent for the TBC sample.

Table 3.6 Percentages of All Respondents Riding a Bicycle Type for a Certain Number of Years

Touring bicycle = a bicycle with thin tires
Mountain bicycle = a bicycle with wide tires
Other bicycle = not a standard two-wheeled design (ex. unicycle, recumbant, tricycle)

Number of Years	Touring	Mountain	Other
0 (never ridden)	12.10	36.34	88.51
1 - 5	20.25	42.65	7.73
6 - 10	24.44	16.81	1.74
11 - 15	13.33	2.84	0.99
16 - 20	11.60	0.62	0.37
21 - 25	8.64	0	0
26 - 30	4.69	0.12	0.25
31 - 35	2.10	0	0
36 - 40	1.73	0.37	0.37
41 - 50	0.86	0.25	0
51 - 60	0	0	0
61 - 70	0.25	0	0

Figure 3.1 Number of Years Respondents have Ridden a Type of Bicycle

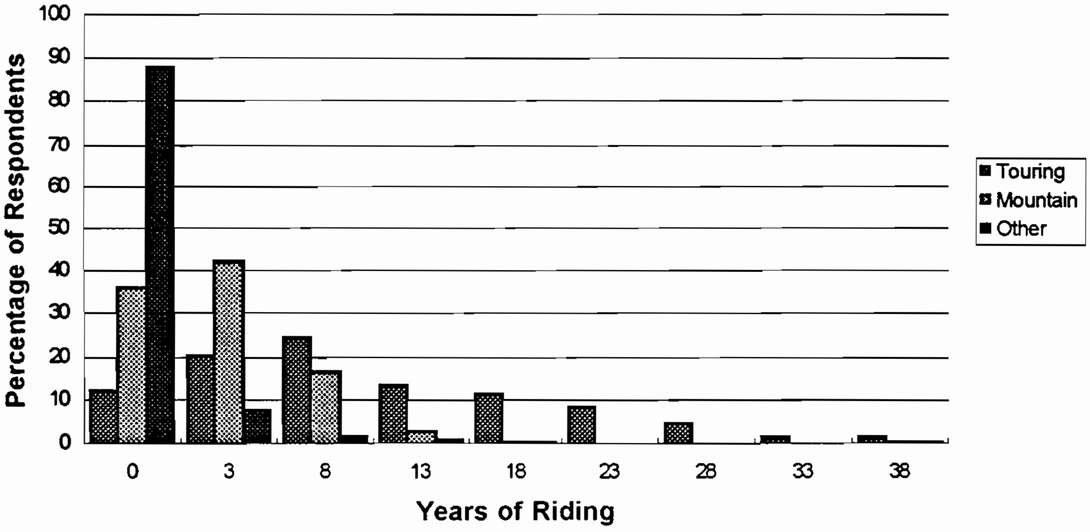


Table 3.7 Number of Miles Ridden Weekly by Respondents

Weekly Miles	less than 1	1 to 49	50 to 99	100 to 149	150 to 199	200 or more
% of Respondents	0.87	39.43	29.42	16.81	9.15	4.33
% of UT-Aus	2.86	80.95	12.38	1.90	0.95	0.95
% of Aus-BWD	1.59	57.14	30.16	4.76	4.76	1.59
% of TBC	0.47	30.89	32.14	20.44	10.92	5.15

Helmet Usage. A key issue regarding bicycle safety is helmet usage, which could make the difference between life or death in the event of an accident. Yet the decision to wear or use safety equipment is a personal one, based on one's own experiences and preferences. Table 3.8 shows the decisions of all respondents concerning the use of safety equipment. Helmet use is high, with approximately 90 percent of the sample often or always wearing helmets. However, note the drastic difference between helmet use and reflective markings, with only 60 to 70 percent of respondents reporting use of reflective markings to increase their visibility on the road. This difference is probably related to the purpose of the safety device and the amount of media attention it is given. Reflective markings are not promoted by the media like helmets as life-savers (they just are not promoted at all). Instead, their sole purpose is to make the cyclist visible so as to lessen the chances of him or her getting hit by another moving vehicle, especially at night. Reflective markings are to prevent accidents, whereas helmets are for lessening the impacts of an accident. Helmets do not prevent accidents, nor do they necessarily make an individual more visible (several sporty varieties come in dark colors such as black or purple). However, they reduce the risk of serious head injuries resulting from many accident types -- not just collisions with other moving vehicles. As such, they are probably viewed as more essential and valued more highly than reflective markings. A similar argument can be made for the use of front and rear lights, which again provide visibility but do not lessen the severity of injuries in the event of an accident.

Table 3.8 Percentage of Respondents Often or Always Using Safety Equipment when Riding a Certain Bike Type
(based on the number of valid observations)

Bike Type / Equipment	Helmet	Gloves	Glasses	Mirrors	Reflective Markings	Front Light	Rear Light
Touring	92	83	90	37	71	56	58
Mountain	85	73	82	26	62	49	47

Table 3.9 Helmet Usage by Bicyclists Riding Touring Bikes
(percentages based on the number of valid observations; often or always worn)

Gender / Sample	UT-Aus	Aus-BWD	TBC	Total Sample
Male	30	85	98	92
Female	20	100	97	90
Total Sample	28	88	98	92

Table 3.10 Helmet Usage by Bicyclists Riding Mountain Bikes
(percentages based on the number of valid observations; often or always worn)

Gender / Sample	UT-Aus	Aus-BWD	TBC	Total Sample
Male	47	67	97	88
Female	40	44	98	77
Total Sample	45	62	97	85

Figure 3.2 Helmet Usage by Bicyclists Riding Touring Bikes

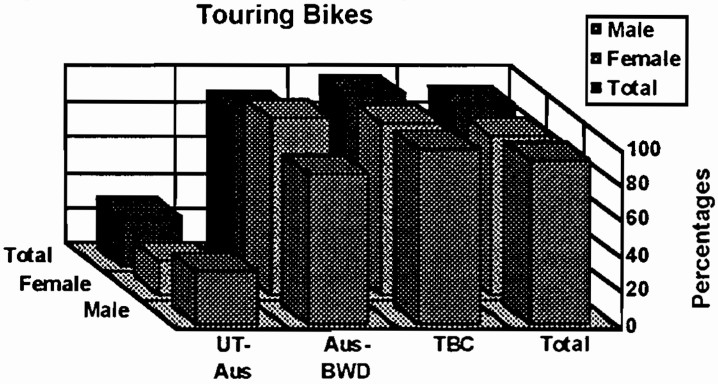
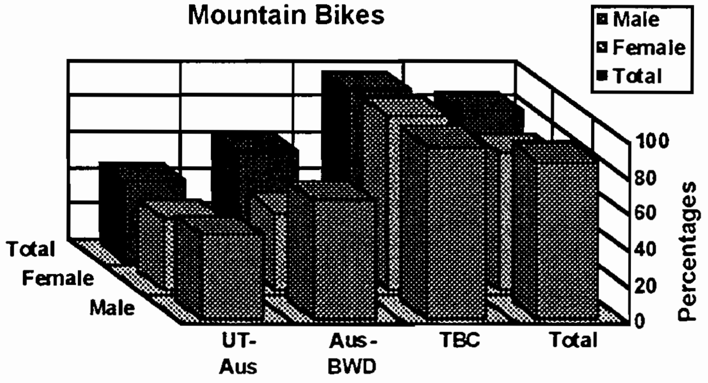


Figure 3.3 Helmet Usage by Bicyclists Riding Mountain Bikes



Examining helmet use trends more closely, it is apparent that the TBC respondents value the injury-reducing potential of wearing a helmet much more than respondents from the other two samples. Whether this valuation is related to TBC respondents being better informed about bicycling safety or being more risk averse than the other samples is not known but is speculated. Also possibly bearing on the valuation is the fact that TBC respondents tend to be somewhat older and to have higher incomes than the other two samples. In Table 3.9 a marked difference in use is evident between the UT-Aus sample with only 28 percent often or always wearing helmets and the TBC sample with 98 percent of respondents using helmets while riding a touring bike. Similarly, in Table 3.10 only 45 percent of UT-Aus mountain bike riders wear helmets often or always while 97 percent of TBC riders consistently wear helmets. The Aus-BWD mountain bike riders also markedly differ from the TBC sample with only 62 percent regularly wearing helmets. The low percentages of helmet use by UT-Aus and Aus-BWD are troublesome because the injury-reducing potential of a helmet is not being capitalized upon.

> Almost one-third (30 percent) of all operator injuries involved the head or face; 27 percent of these head/face injuries involved potentially serious diagnoses, such as fractures, internal injuries, or concussions. Young children suffered a significantly higher proportion of head injuries than older victims; 50 percent of the injuries suffered by children under age 10 involved the head or face, compared with 19 percent for riders age 10 or older. (Rodgers et al., 1995)
>
> Four percent of all injured children in SHASIRS [Scholastic Head and Spine Injury Report System] had a bicycle-related injury and 92 percent of them were not wearing a helmet at the time. (Clarke & Tracy, 1995)

Only 8 percent of the SHASIRS injured child cyclists were wearing helmets. The use of helmets by all cyclists must be encouraged to reduce severe injuries.

Road Type Preferences. The types of roads used by bicyclists and associated traffic volumes affect the risk of accident involvement. In other words, some roads are more dangerous than others. Unfortunately, often the most dangerous roads offer the direct connections.

To indirectly examine the choice of road types one question on the *Bicycle Riders Survey* asked respondents the following:

"Check the street environments in which you do most of your bicycle riding:

	Auto traffic	Bike traffic	Pedestrian traffic
Streets with little or no	______	______	______
Streets with moderate	______	______	______
Streets with heavy	______	______	______

Bike paths with light / moderate / heavy traffic. (Circle all applicable.)"

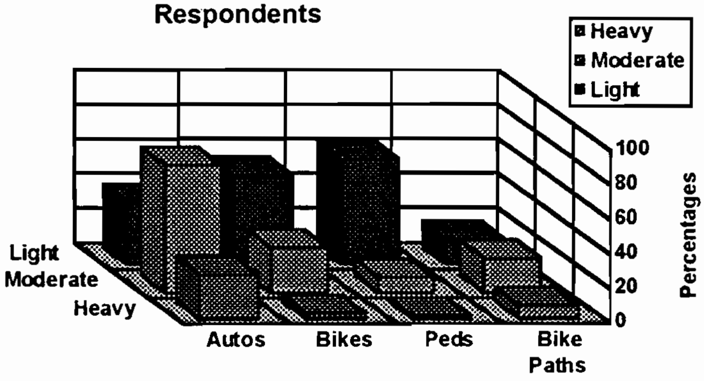
The question was posed to gain insights about the variety of environments a person rides in and the approximate traffic volumes they encounter. The results of the question for the TBC sample are presented in Table 3.11 and Figure 3.4.

Table 3.11 Percentages of TBC Respondents Riding in Various Street Environments

(based on 631 TBC respondents)

Traffic Volume / Traffic Type	Little or no traffic	Moderate traffic	Heavy traffic
Do not ride in any kind of	17.27	20.29	70.79
Automobiles	36.29	73.53	26.98
Bicycles	52.15	25.83	3.96
Pedestrians	61.49	9.18	1.75
Bike Paths	14.42	19.81	7.45

Figure 3.4 Street Environments Ridden in by TBC Respondents



The question was designed with the intent of discovering what combinations of traffic volumes (auto, bike, pedestrian) exist in each of the street environments that a cyclist rides through. For example, a cyclist may ride in two distinct environments, one that has heavy auto traffic, light bike traffic, and no pedestrian traffic and a second one that includes moderate auto traffic, light bike traffic, and heavy pedestrian flows. To answer the survey question the respondent would then check off five categories: auto-heavy, auto-moderate, bike-light, pedestrian-heavy, pedestrian-light. Care must be taken in analyzing the responses. In the example, five separate environments may be intended with singular volume characteristics or multiple environments with combinations of road user-volume types may be intended. Therefore, the results of this section are limited to a discussion of a single road user-volume characteristic for an environment that may or may not be in conjunction with other road user-volumes. Furthermore, since respondents can check-off multiple categories the category percentages do not necessarily add up to 100 percent (the categories are not exclusive). Finally, Table 3.11 contains one variable "Do not ride in any kind of" that is not in the survey question. This variable was primarily used as a data check, but can be interpretted in the following manner: if none of the traffic volume groups were checked, then the information for this question is left blank (marked as missing data); if one traffic volume group is left entirely blank, however other categories are checked-off by a respondent, then the blank volume group is marked to signify that the respondent did answer the question, the respondent just did not select any category within one or two groups.

Suprisingly few cyclists ride most of the time in street environments with any form of heavy traffic (29.2 percent) but 27.0 percent of the cyclists do ride with heavy auto traffic. Of course, not many places exist in Texas with high volumes of bicycles or pedestrians. Alternatively, this sample of cyclists predominantly ride where traffic volumes of autos, bicycles, and pedestrians are light to moderate. Almost three-quarters of TBC respondents (73.5 percent) ride in moderate auto traffic volumes, just over a quarter (25.8 percent) ride in moderate bike traffic volumes, and 9.2 percent ride in environments with moderate levels of pedestrian traffic. The reverse trend is seen for street environments with light traffic volumes. About one-third (36.3 percent) of TBC bicyclists ride in areas with light auto traffic. Over one-half (52.5 percent) of the respondents ride in light bicycle traffic. In addition, 61.5 percent of the sample rides in environments that have light volumes of pedestrians. Finally, 30.9 percent of the TBC sample respondents use bike paths.

Rodgers, et al. (1995), in the 1995 Consumer Products Safety Commission (CPSC) study entitled *Bicycle Use and Hazard Patterns in the United States,* analyzed what streets cyclists in the United States ride upon and found that,

> most bicyclists (64 percent) ride a substantial proportion of the time on neighborhood streets with low traffic volume, but sizeable proportions also spend a lot of their riding time on sidewalks and playgrounds (29 percent), bike paths (17 percent), and unpaved roads (18 percent); smaller proportions ride on major thoroughfares with high traffic volumes (7 percent) and on other unpaved surfaces or trails (11 percent).

Parallels can be drawn between this study and the TBC data presented herein but care must be taken because the TBC respondents are all adult cyclists whereas the CPSC study includes children, in fact "about 22 percent of cyclists are under age 10 and 40 percent are under age 15" (Rodgers, et al., 1995). In general, both groups have small proportions of riders on streets with high auto traffic volumes, substantial proportions of riders who spend time on roads with low (or low to moderate for TBC) traffic volumes, and in both cases about 30 percent of the riders spend most of their time riding on bike paths or trails. From these results it can be inferred that riders do try to select routes which have few, if any, high auto volume segments, even though these may be the most direct paths. To assess the relative hazard of different road types, risk models were developed in the CPSC study. For example,

> in the model for riders 15 years of age and older [this would include our TBC sample age range], risk was ... affected by riding surface. As in the children's model, the adult risk was higher on paved roadways. The risk on neighborhood streets was about 7 times the risk on bike paths and about 9 times the risk on unpaved surfaces. Moreover, the risk on major thoroughfares, the highest risk riding surface, was about 2.5 times the risk on neighborhood streets. As in the children's model, risk was higher for riders who lived in areas with greater population density. However, there was no significant difference in risk between daylight and non-daylight hours. Nor did rider gender independently affect the injury risk. (Rodgers, et al., 1995)

As expected, the more auto traffic on a road the riskier it is for a cyclist. The relative safety of different facilities could be communicated to cyclists so they can select their paths accordingly. Bike route designations may be one way to achieve this. However, the risk involved for routes should be weighed against the time-savings that direct connections yield when designing interneighborhood routes for commuters.

Reported Accident Types. One primary method to find out what is dangerous and causing problems in a transportation system is analyzing accident data. For this study, bicycle-motor vehicle accident information was collected from a variety of government agencies and examined (see the Results of the Accident Studies section and Chapter 4), but the data is not consistent in how it was collected from the field and defined, nor does it supply the details of bicycle accidents not involving motor vehicles. To try and fill this void, a series of twelve questions were included in the *Bicycle Riders Survey* that asked respondents for detailed accounts of bicycle accidents they had in the past. The questions were set up in a table format (see Appendix B) to allow respondents to easily list information for multiple accidents. The following pieces of information were requested for each accident listed:

1. Type of accident - from solo accidents to collisions with animals to collisions with cars
2. Date of accident - month and year
3. Level of injury to the rider - from no injuries to a critical injury
4. Level of damage to the bike - from no damage to unrepairable

5. Bicycle type ridden at time of accident - touring, mountain, or another bike type
6. Bicycle speed at time of accident - slow, intermediate, or fast
7. Whether or not a police report was filed
8. Whether or not an insurance claim was filed
9. Whether or not human error (rider's or someone else's) contributed to the accident
10. Whether or not the street design or condition contributed to the accident
11. Whether or not the bike rider could have avoided the accident
12. Hazards or causes of the accident - listed by the respondent

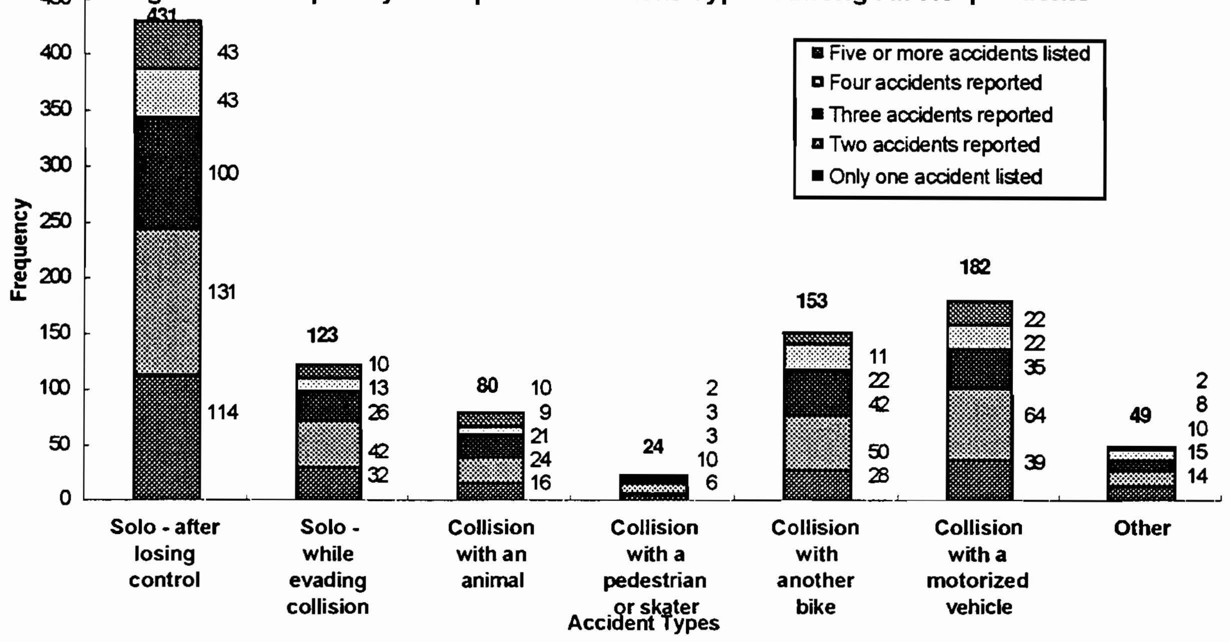
The responses to this table varied across the respondents and the samples; 183 respondents did not fill out the table at all, 84 commented that they had never had a bicycle accident, and the remaining 547 respondents either partially or completely filled out the table -- with the question asking them to list hazards or causes unfortunately left blank often. Table 3.12 shows the breakdown of accidents by sample. It is clear that the TBC respondents, on average, listed the most accidents (1.67 accidents per respondent). In fact, there were a few TBC people who listed six accidents and one who listed nine accidents. For analysis, a maximum of five accidents per respondent was allowed. In this section and the following one two pieces of collected information will be discussed: the reported accident types and their associated causes as detailed by respondents. The remaining information culled from the accident history tables is presented in Appendix C.

Table 3.12 Overall Accident Data

Sample	Total Accidents	Recorded by	Zero Accidents	Total Responses	Avg. Accidents
UT-Aus & Aus-BWD	170	97	10	107	1.59
TBC	873	450	74	524	1.67
All Respondents	1043	547	84	631	1.65

When asked to classify their accidents into one of seven categories they answered with the frequencies shown in Figure 3.5. The overwhelming majority of accidents listed (431, or 41.3 percent) were categorized as a "Solo accident after losing control," as compared to only 182 (or 17.5 percent) collisions with motorized vehicles listed. Collisions with pedestrians or skaters were listed the least -- only 24 accidents (or 2.3 percent) for all respondents. However, for the UT-Aus and Aus-BWD samples this proportion was much higher, 7.7 percent (or 13 accidents) of the listed accidents were collisions with pedestrians or skaters (see Figure 3.6). This proportional change can be explained by noting where the samples were drawn from: the UT-Aus and Aus-BWD samples were taken in Austin, Texas on the University of Texas campus where there are large numbers of pedestrians, but the TBC sample (see Figure 3.7) includes people from all over the state -- in big cities, suburban areas, and rural areas -- so that the proportion of pedestrian conflicts is lower than for the other two samples. Also of interest is the marked difference between collisions with another bike for the TBC sample versus the other two samples. The UT-Aus and Aus-BWD sample respondents listed 16 accidents of this type (or 9.4 percent) while the TBC respondents listed 137 accidents (or 15.7 percent), which may be attributed, in part, to the pack riding (riding in tight groups to reduce air resistance thereby increasing speed) often cited by those in TBC.

Figure 3.5 Frequency of Reported Accident Types Among All Respondents



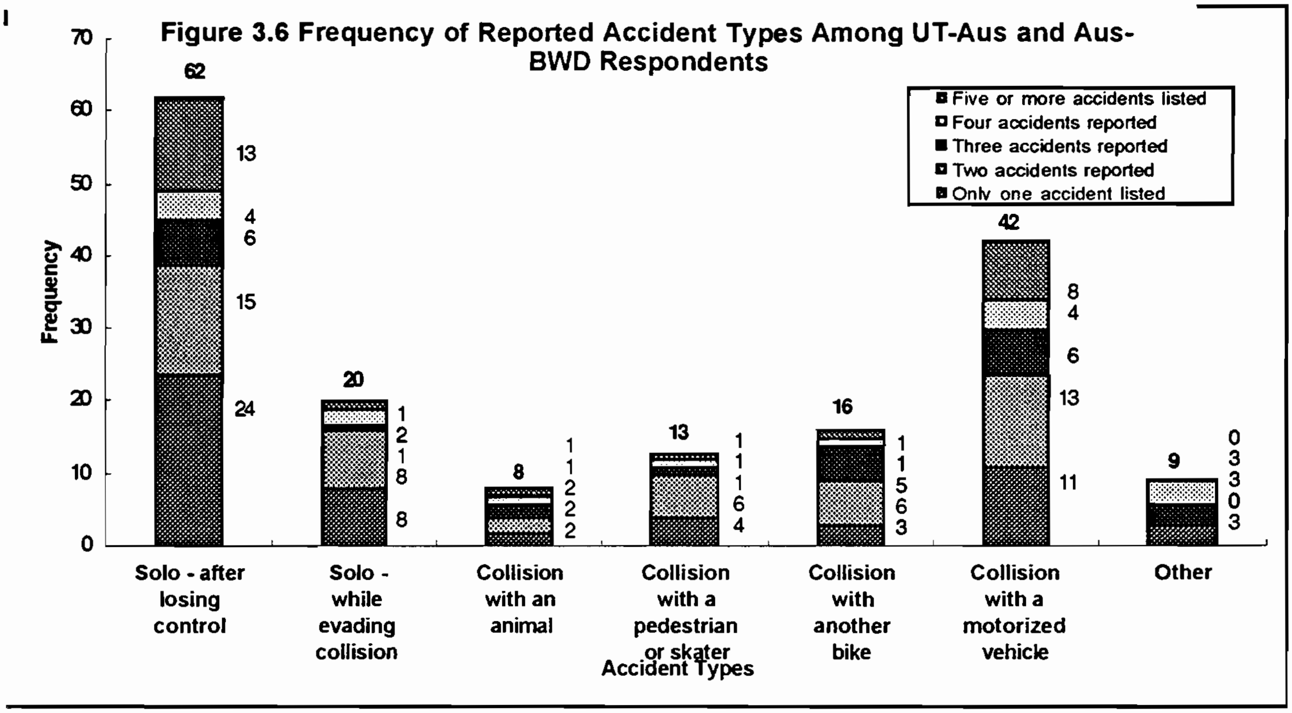


Figure 3.6 Frequency of Reported Accident Types Among UT-Aus and Aus-BWD Respondents

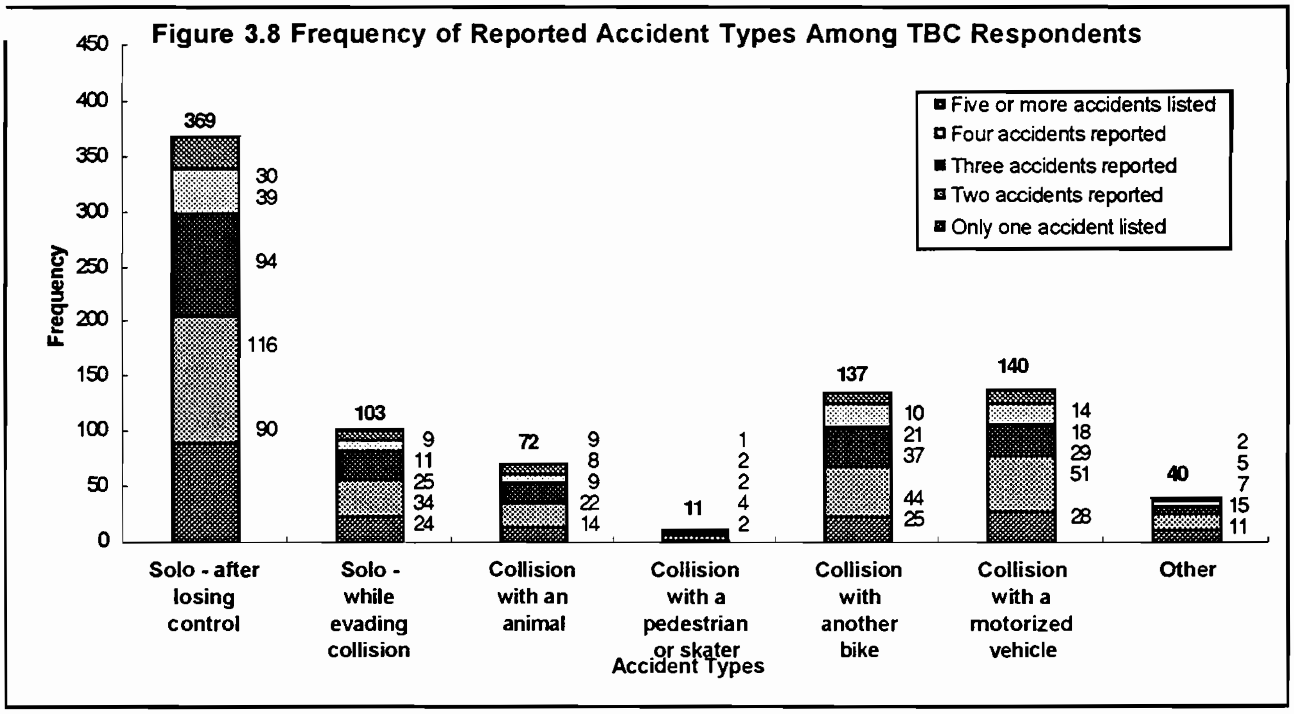


Figure 3.8 Frequency of Reported Accident Types Among TBC Respondents

Commonly Listed Hazards. The last four questions respondents were asked to complete concerning their accidents centered around what had caused the accidents (see Appendix B), however the final question could yield the most information since it was open-ended -- encouraging respondents to describe their accidents in further detail and relate what they thought had contributed to or caused the accident. Their responses ranged from detailed descriptions with diagrams to simple lists of hazards. The respondents recorded many hazards, some that were not yet on the master list compiled for this study. These and other new hazards found in the literature were added to the list, for a grand total of 130 identified hazards for bicyclists (see Appendix A).

The hazards from the accident histories have been ranked according to the frequency in which they were mentioned by respondents, with the highest frequency assigned the rank of 1. Table 3.13 shows the ten most frequently listed hazards and their corresponding ranks. These top hazards range from 107 times to only 26 times in frequency of being mentioned with a noticeable drop (from 58 to 30) occurring after the sixth most mentioned hazard. The respondents often faulted themselves, *lapse of rider's attention* ranked first with 107 mentions by TBC respondents. Also with high counts are three hazards associated with street maintenance or design: *unswept debris on pavement* (mentioned 94 times, ranked second), *smooth/slick pavement* (mentioned 67 times, ranked fifth), and *too small a turning radius on a horizontal curve* (mentioned 26 times, ranked tenth).

Table 3.13 Commonly Listed Hazards by TBC Respondents

Code	Hazard	Count	Rank
711	Lapse of rider's attention	107	1
504	Unswept debris on pavement	94	2
807	Motorist error	74	3
908	Stray animals/ dogs not on leashes	71	4
313	Smooth / slick pavement	67	5
718	Following a cyclist too closely	58	6
717	Reckless riding of other cyclist(s)	30	7
804	Motorist not knowing/ observing cyclist's right to use road	30	7
712	Riding too fast	29	8
721	Loss of control due to bike failure or defect	28	9
114	Too small a turning radius on a horizontal curve	26	10

To examine the importance of these hazards in more depth Table 3.14 was created; it compares these ten hazards with the accident types. Please note that the following accident types have been combined for analysis: *solo-after losing control* and *solo-while evading collision* into the *solo* category and *collision with an animal* and *collision with a pedestrian* into the *animal/ped* category.

Table 3.14 Frequencies of Commonly Listed Hazards as They Match-up with the Accident Types

Code	Hazard	Solo	Animal / Ped	Another Bike	Motor Vehicle	Other
711	Lapse of rider's attention	55	4	27	18	3
504	Unswept debris on pavement	79	2	6	0	7
807	Motorist error	13	1	1	58	1
908	Stray animals/ dogs not on leashes	13	53	2	1	2
313	Smooth / slick pavement	60	0	0	2	5
718	Following a cyclist too closely	8	0	49	1	0
717	Reckless riding of other cyclist(s)	8	0	22	0	0
804	Motorist not knowing/ observing cyclist's right to use road	18	0	1	10	1
712	Riding too fast	20	3	2	3	0
721	Loss of control due to bike failure or defect	20	0	1	0	7
114	Too small a turning radius on a horizontal curve	22	0	2	2	0

Table 3.14 reveals several important results. Over three-quarters (78.4 percent) of the time that *Motorist error* was cited as a hazard it was linked to a collision with a motorist. About three-quarters (74.6 percent) of the time that *Stray animals/ dogs not on leashes* was cited, it was associated with bike-animal collisions. Additionally, approximately 84.5 percent of the times that *Following a cyclist too closely* was listed as a hazard, it was associated with a bike-bike collision. This correlation between hazard perception and accident experience is not surprising.

Somewhat less obvious are the results of the next four hazards, which show definite links between physical hazards and cyclist behavior. First, approximately half (51.4 percent) of the time that *Lapse of rider's attention* was listed it was linked to a Solo accident. If the rider is not paying attention he or she may end up in a solo accident by running into an object or over a surface hazard as 107 of the TBC cyclists did. Yet cyclists, like drivers, cannot pay full attention to the road every moment, they must also pay attention to traffic and signage and may want to enjoy the scenery part of the time. Therefore it is imperative that the roadway be clear of obstructions and the road surface be free of dangerous flaws (such as ruts over a certain width) so cyclists can safely direct their attention elsewhere when necessary. Second, about 84.0 percent of the times that *Unswept debris on pavement* was listed, it was associated with Solo accidents -- cyclists should not ride over many types of debris since it can puncture their bicycle's tires or unbalance them, yet a last-minute swerve to avoid the debris can also unbalance them and cause an accident.

The high number of associations points to a need for mitigation, such as through the implementation of a street sweeping program. Third, almost 90 percent of the time (89.6 percent) that *Smooth/ slick pavement* was cited as a hazard it was associated with a Solo accident. A slick surface reduces traction causing serious problems for unaware cyclists that are travelling too fast, corner too tightly, or brake too hard for a slippery surface and the wheels of their bicycles do not hug the road but instead slip out from under them or skid. Depending on the cause of the slipperiness different countermeasures can be taken, for example if asphalt bleeding is occurring then a slurry seal can be applied to the problem area to increase traction. Finally fourth, over three-quarters of the time (84.6 percent) that *Too small a turning radius on a horizontal curve* was cited as a hazard it was associated with a Solo accident. This is a frequent problem associated with horizontal curves at the bottom of hills -- cyclists pick up speed travelling down a hill and then do not or cannot sufficiently slow down to safely make the curve. This is also a problem associated with curves on separated facilities (e.g. bike paths, hike-and-bike trails), as the curves may have been designed with the pedestrian in mind, thereby not providing for an adequate bicycling design speed. In both cases the long-term mitigation would be to try and increase the radius of the curve or eliminate the curve altogether. In the interim, the addition of signs warning cyclists of the curve, and advising them to reduce their speed can aid in the reduction of accidents.

Results of the Video Footage

The video-taping of cyclists during the Summer of 1994 captured their behaviors with repect to six distinct physical hazard situations: autos in bike lanes; asphalt ripples and potholes; steel plates across a section of roadway; asphalt patches and associated gravel following the removal of steel plates; construction sites; and intersections. For ease of data collection all observations were done in Austin, Texas. In addition, it is important to mention that the bicyclists observed were predominantly student bicycle commuters, unless otherwise noted. For each hazard discussed background information is first presented, then site descriptions are given, followed by a discussion of the behaviors found and their implications. Detailed analyses of the data collected at three locations was possible because of the large number of bicyclists recorded; this work is discussed first. The data collected at other locations is presented second, but is examined only in a qualitative fashion because the number of observed bicyclists was relatively small.

Asphalt Ripples and Potholes. Pavement hazards can be dangerous for bicyclists who cannot see them or have no safe path around them. In fact, "a depression 6 inches [152.4 mm] wide is geometrically equal to a 3/4 inch [19.1 mm] bump," (Forester, 1993) so asphalt ripples and potholes can suddenly jar a cyclist and cause him or her to lose control of the bicycle. This could lead to an out-of-control cyclist heading into traffic--which would cause further and more serious accidents. On the other hand, the cyclist may spot the potential hazard in time to decide how to proceed, whether to go over the hazard or attempt to circumvent it. The action of the cyclist will then affect the surrounding traffic. It is therefore essential to document what actions cyclists presently take to handle potential hazards and how these decisions affect other road users.

To examine the effects of asphalt ripples and potholes on cyclists, the southbound direction of travel (toward the University of Texas campus) on Speedway near its intersection with West 38-1/2 Street was chosen for taping. The intersection is a three-legged T intersection (see Figure 3.8) however, West 38-1/2 Street is a narrow alley with very low volumes of traffic. Speedway is a major two-way student commuter route (via bus, bike, and car) with striped bike lanes on both sides of the street. A bus stop is located just upstream of the hazards so bicyclists sometimes must also be watchful of waiting pedestrians, in addition to buses needing to enter the bike lane to pick-up and drop-off passengers. The hazards cover the entire bike lane and part of the adjacent auto lane as can be seen in Figures 3.9 and 3.10, which are taken from the perspective of the cyclist. In Figure 3.10 one can see asphalt ripples near the curb and a large pothole surrounded by broken pavement that is partly in the bike lane and partly in the auto lane. Figure 3.11 shows a close-up of the pothole.

The lane location and size of these two hazards are the keys to their dangerous nature. If both hazards were small and fully in the bike lane or fully in the auto lane, then bicyclists could simply choose to avoid the hazard and ride in the other lane or stay in the lane and ride over the hazard. However, at this location on Speedway the hazards take up much of the roadway and force a rider to carefully choose a path. Therefore, this filming site was chosen for the unique location of hazards, in addition to the high volume of bike traffic.

Filming was performed on two occasions, the afternoon of Tuesday, July 5th, 1994 from 2 to 4 p.m. and the morning of Monday, August 15th, 1994 from 8 to 10 a.m. A total of 41 data points were collected. Table 3.15 lists some general information and path choice data collected about the cyclists. For path A the cyclist rides in the bike lane but travels over the asphalt ripples; for path B the cyclist travels over the pothole near the edge of the bike lane; and for path C the cyclist can avoid both physical hazards but must contend with auto traffic. In Table 3.15 the path each category of cyclists decided to take is outlined. For example, of the 33 males taped, 54.5% of them chose path A--they decided to ride in the bike lane over the asphalt ripples. It is interesting to note that few of the riders chose to ride in the auto lane and avoid both pavement hazards. This is more evident when the place of origination is considered as in Table 3.16. The lane switching behavior of cyclists in this situation is quite distinct. Persons riding in the bike lane did not switch

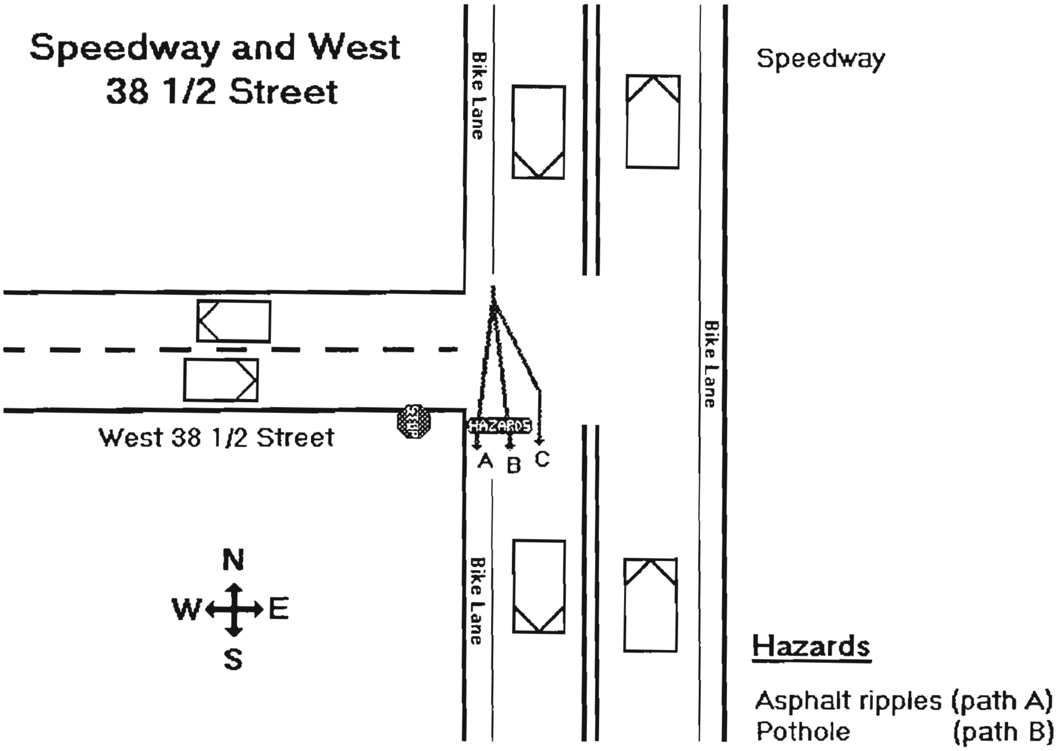


Figure 3.8 Diagram of Speedway and West 38-1/2 Street Intersection

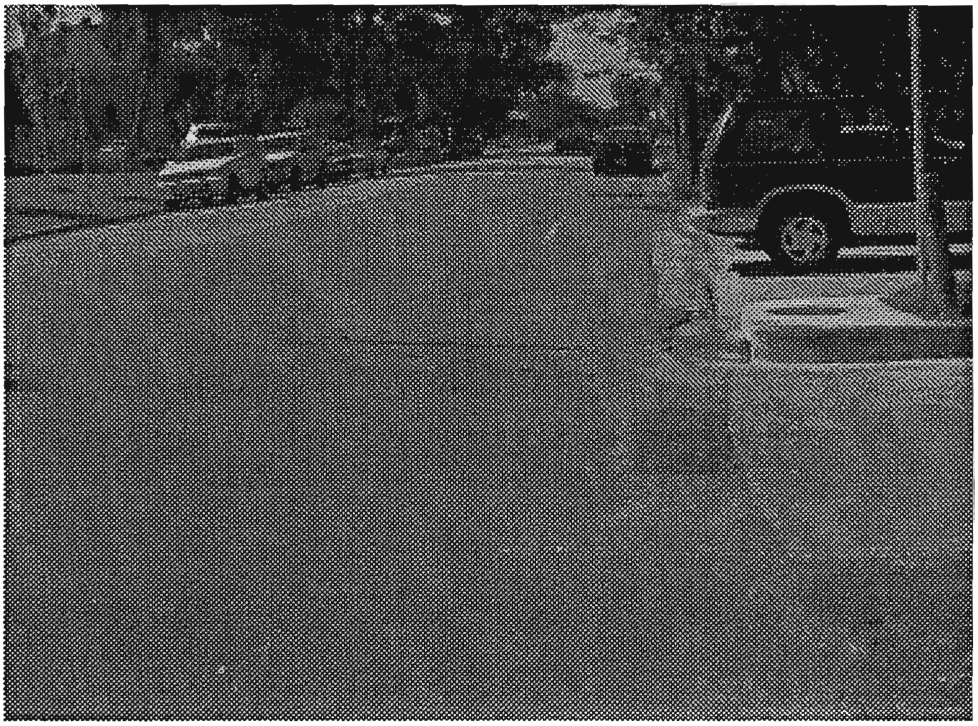


Figure 3.9 A Cyclist's View of Hazards at Speedway and West 38-1/2 Street

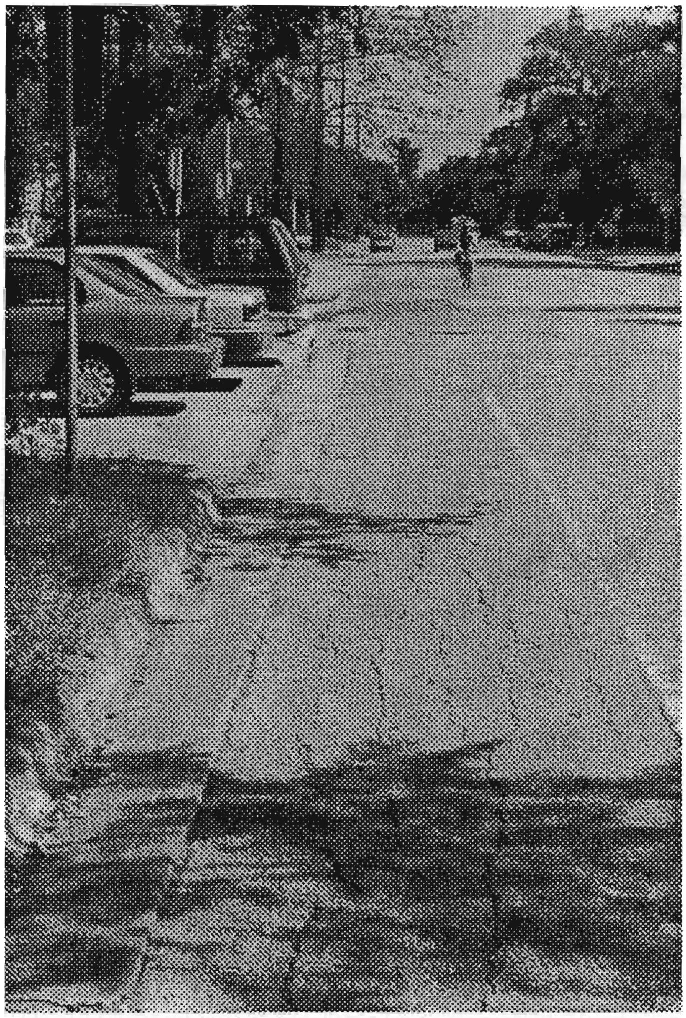


Figure 3.10 Close-up of Asphalt Ripples and Pothole at Speedway and West 38-1/2 Street

Figure 3.11 Close-up of Pothole at Speedway and West 38-1/2 Street

Table 3.15 General Characteristics and Path Choices of Speedway and 38-1/2 Street Cyclists

	Chose path A	Chose path B	Chose path C
Of the 41 total data points	56.1 %	34.1 %	9.8 %
Of the 33 Males	54.5 %	36.4 %	9.1 %
Of the 8 Females	62.5 %	25.0 %	12.5 %
Of the 31 with No Helmet	58.1 %	32.2 %	9.7 %
Of the 10 with a Helmet	50.0 %	40.0 %	10.0 %
Of the 23 with Wide tires	60.9 %	34.8 %	4.3 %
Of the 18 with Thin tires	50.0 %	33.3 %	16.7 %

Table 3.16 Path Choice According to Original (Upstream) Position for Speedway and 38-1/2 Street Cyclists

	Chose path A	Chose path B	Chose path C
Of the 27 who originated in the Bike lane	81.5 %	18.5 %	0 %
Of the 5 who originated in the Auto lane	0 %	60.0 %	40.0 %
Of the 9 who originated on the Bike lane line	11.1 %	66.7 %	22.2 %

to ride in the auto lane (path C), rather they dealt with one of the physical hazards. Likewise, riders starting in the auto lane did not switch to ride in the bike lane over the asphalt ripples (path A). So there seems to be a limit to how far a cyclist will move over to avoid potential dangers--prior lane choice is a major determinant of end path choice.

The implications of the behaviors found due to this hazard are that changing of paths by the cyclists disrupts other traffic, however the change is minor -- no cyclist makes a large change, but the method used to make this change could be crucial (gradual path change versus a last-minute swerve). One possible countermeasure is repairing the damaged pavement to reduce the weaving of cyclists at this point, which would also increase the available opportunities for cyclists.

Asphalt Ripples and Dropoffs Near an Intersection with a Blocked Stop Sign. The hazardous situation described by the title of this section is a combination of four hazards: asphalt ripples and dropoffs, vegetation too close to the roadway, vegetation blocking a Stop sign, and bike lanes that extend too far into the intersection. Each hazard is now briefly described.

If ridden over, asphalt ripples and dropoffs jar a cyclist thereby causing loss of control, as discussed in the previous section.

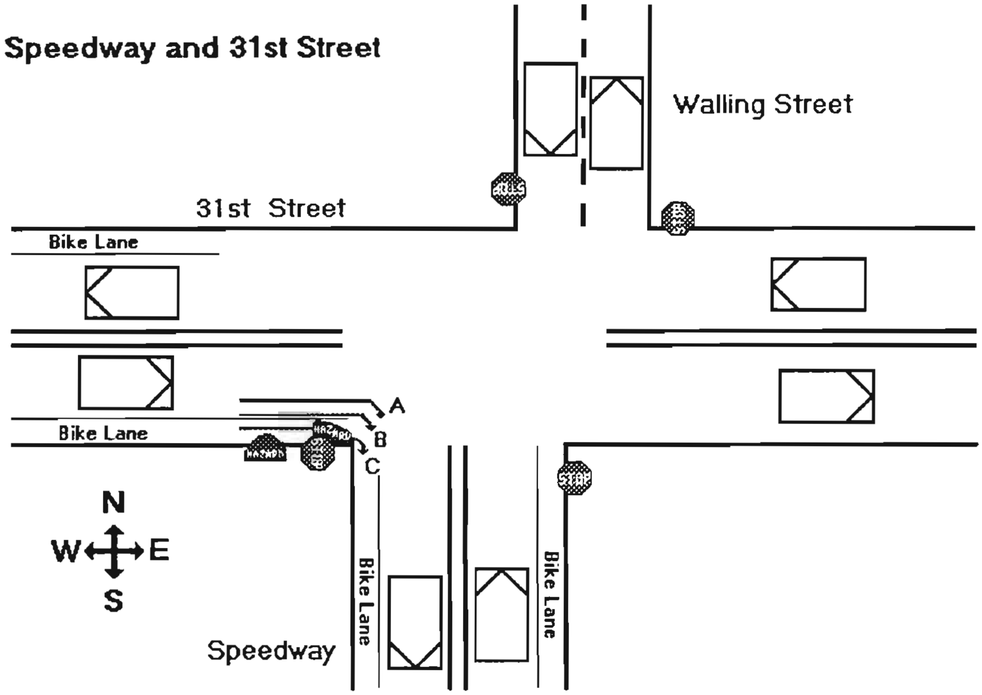
Vegetation that is too close to the roadway or blocking part of the roadway can cause several problems. It lessens the sight distance of vehicle operators. It narrows the available road width, often making bike lanes unusable. It blocks traffic control signs which can lead to serious accidents at an intersection. In addition, vegetation blocking the road creates an obstacle for cyclists.

Bike lanes that extend all the way up to the intersection are dangerous because cyclists are then encouraged to stay in them, thereby causing turning movement conflicts. For example, a cyclist needing to make a left turn would have to not only cross the opposing-direction traffic but also cross the auto traffic in the same direction--so the movement is much more dangerous than if the cyclist was next to the centerline, and it requires more time to complete.

The intersection of Speedway, 31st Street, and Walling Street was chosen for taping. It is a four-legged atypical intersection, as can be seen in Figure 3.12 with the majority of traffic travelling on the west leg of 31st Street and on Speedway. This location was chosen because a combination of hazards existed on what is a major commuter bike route with bike lanes. The site has multiple hazards, both physical and traffic-control related. The physical hazards include asphalt ripples and dropoffs parallel to the direction of travel and vegetation that is encroaching upon the roadway, so a cyclist would see what is pictured in Figures 3.13, 3.14, and 3.15. But what a cyclist would fail to see until quite close is the Stop sign at the corner, as is evident when looking from the viewpoint of the camera, shown in Figure 3.16. To further complicate matters, the roadway leading up to this location is a downhill segment, so riders would naturally speed up as they approach the intersection and would have to apply increased braking power to stop.

This location was filmed on Thursday, August 18, 1994 from 8:30 to 11 a.m. A total of 62 useful data points were collected. Table 3.17 shows general characteristics of the cyclists and their path choices; 50 of them were male and only 12 were female. Approximately an even number of them rode bicycles with wide tires (34) and thin tires (28). But only 19 of the total wore helmets for protection. Similar to the previous case, three main paths were travelled. Path A cyclists rode in the auto lane. Path B cyclists rode on the bike lane line -- avoiding the asphalt ripples and dropoffs, but nearing auto traffic. And path C cyclists rode fully in the bike lane and had to ride over the asphalt ripples and dropoffs. Table 3.18 lists the path taken by cyclists starting in different positions.

In an effort to draw links between behaviors and hazards the stopping behavior and lane choices of each cyclist are examined. One telling statistic was whether or not a cyclist rode through, slowed down, or stopped at the Stop sign (see Table 3.17). All three path A cyclists rode through the stop sign whereas all riders who stopped rode in path B. Path C cyclists predominantly slowed down. Just over half of the cyclists rode through the Stop sign while just under half slowed down -- but only 2 out of the 63 observed cyclists came to a full stop. The



Hazards

Primary Hazards : Asphalt ripples and dropoffs in pavement (path C)

Secondary Hazards : Vegetation blocking view of stop sign
Bike lanes extend too far into intersection

Figure 3.12 Diagram of Speedway and 31st Street Intersection

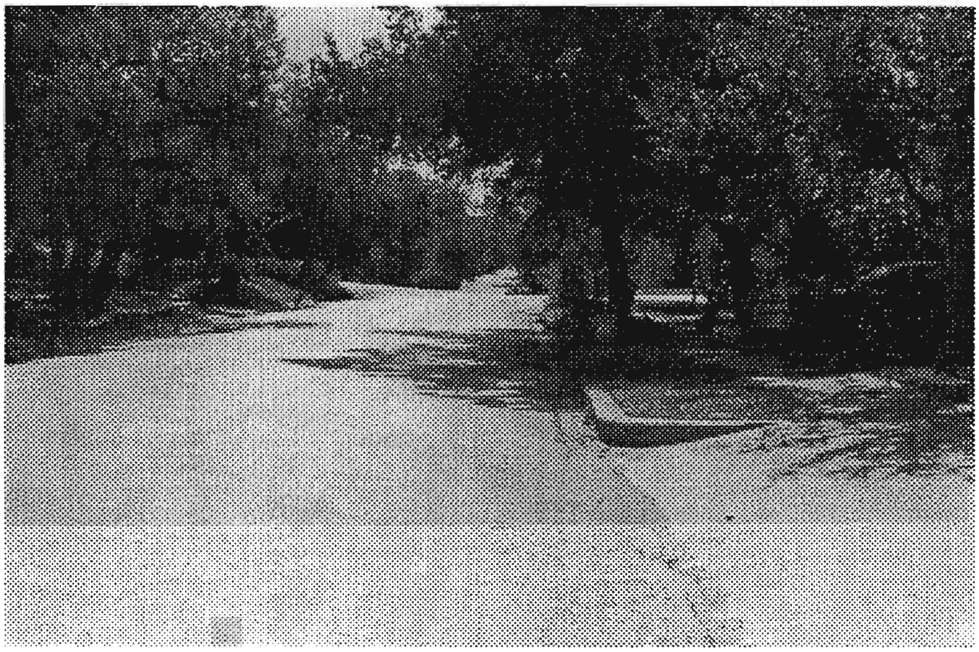


Figure 3.13 A Cyclist's View of the Hazards at Speedway and 31st Street

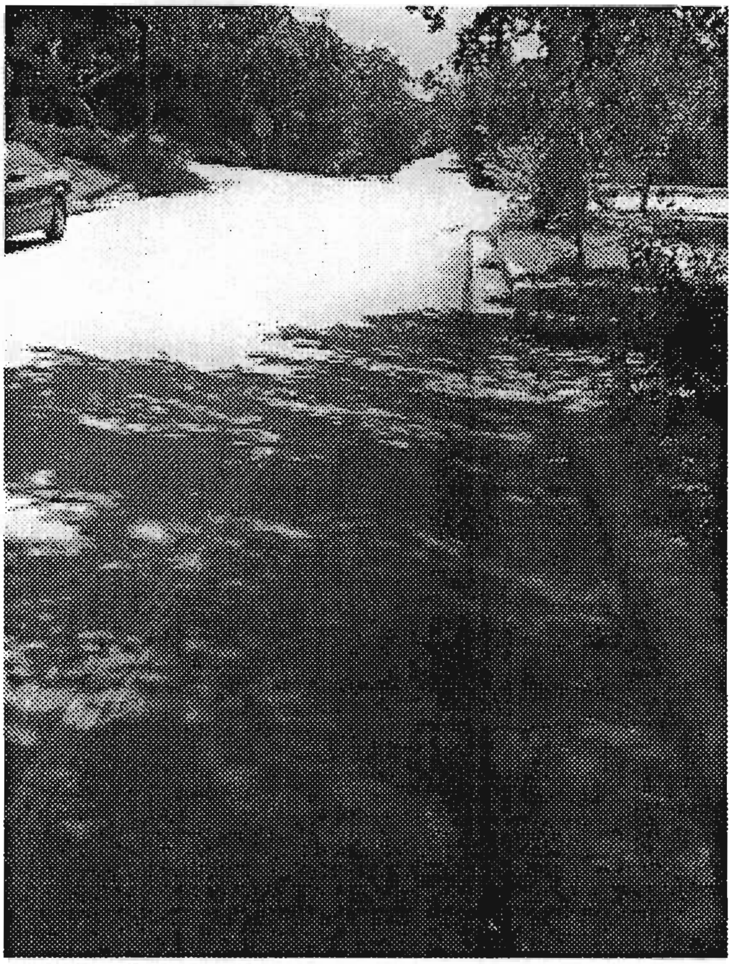


Figure 3.14 Another View from a Cyclist's Perspective at Speedway and 31st Street

Figure 3.15 Close-up of Asphalt Ripples and Drop-offs at Speedway and 31st Street

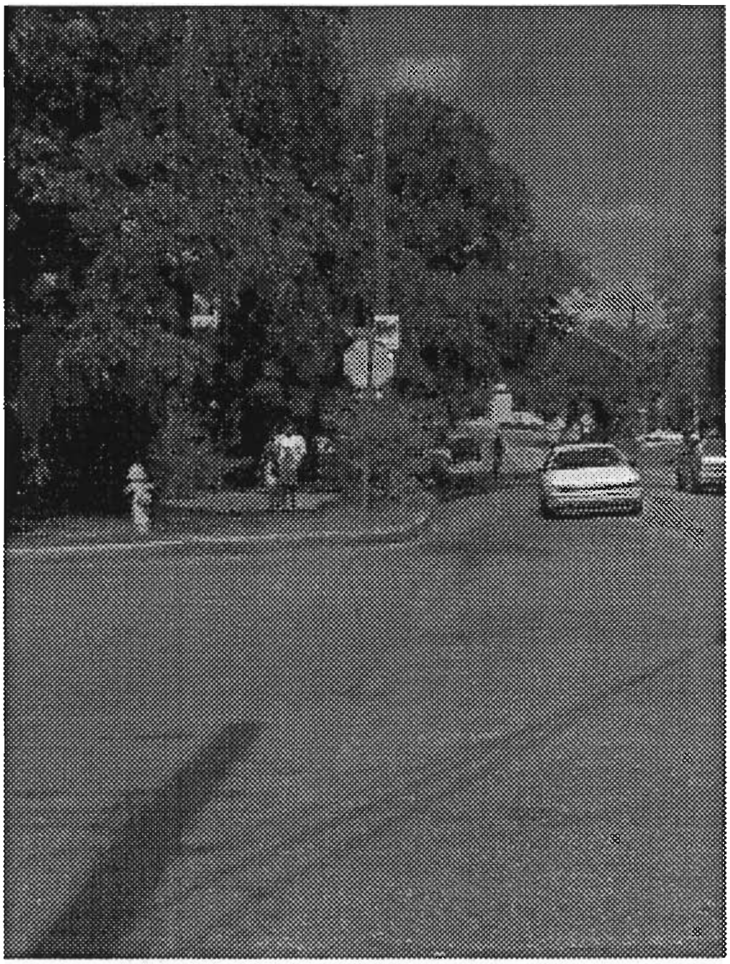


Figure 3.16 View from Video Camera at Speedway and 31st Street

Table 3.17 General Characteristics and Path Choices of Speedway and 31st Street Cyclists

	Chose path A	Chose path B	Chose path C
Of the 62 total data points	4.8 %	77.4 %	17.8 %
Of the 50 Males	4.0 %	80.0 %	16.0 %
Of the 12 Females	8.3 %	66.7 %	25.0 %
Of the 43 with No Helmet	7.0 %	72.1 %	20.9 %
Of the 19 with a Helmet	0 %	89.5 %	10.5 %
Of the 32 who Rode through the stop sign	9.4 %	87.5 %	3.1 %
Of the 28 who Slowed down at the stop sign	0 %	64.3 %	35.7 %
Of the 2 who Stopped at the stop sign	0 %	100.0 %	0 %
Of the 34 with Wide tires	2.9 %	73.6 %	23.5 %
Of the 28 with Thin tires	7.1 %	82.2 %	10.7 %

Table 3.18 Path Choice According to Original (Upstream) Position for Speedway and 31st Street Cyclists

	Chose path A	Chose path B	Chose path C
Of the 31 who originated in the Bike lane	0 %	67.8 %	32.2 %
Of the 14 who originated on the Bike lane line	14.3 %	78.6 %	7.1 %
Of the 17 who originated in the Auto lane	5.9 %	94.1 %	0 %

behavior can be attributed, in part, to an inability to see the Stop sign and, in part, to the cyclists being familiar with the route. In either case, this is dangerous behavior that could lead to serious accidents. Although it is illegal not to stop, bicyclists commonly disobey Stop signs to keep momentum (Forester, 1983). In this case, riders may be riding without stopping in response to the bike lane lines having been painted up to the intersection. Notice the bike lane striping in Figure 3.12; cyclists can make the right-turn movement that was filmed travelling fully in the bike lanes so they never cross paths with other traffic. Because no conflicting movements arise for path C cyclists, they probably see little need to stop.

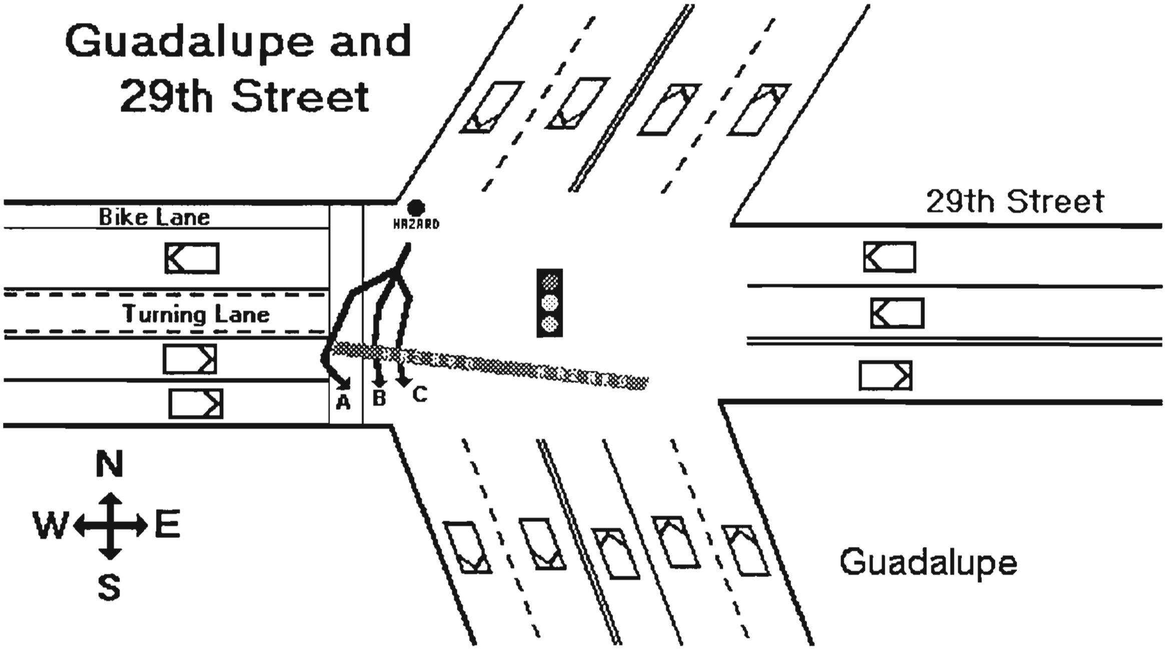
Further examination of the riders' lane choices suggest an important point. Only 28 percent of the riders that were originally in the bike lane stayed in the bike lane up to the intersection and no other riders entered the bike lane. Cyclists clearly seemed to avoid the asphalt ripples and dropoffs. The rest of the riders chose to ride on the bike lane line or in the auto lane. However, no bicyclist was seen switching from the bike lane to the auto lane or vice versa, suggesting that only small lane adjustments were acceptable to these bicyclists.

Countermeasures for the problems of this site include the removal of bike lane striping that is near an intersection, and Sorton (1993) suggests vegetation be kept cut back at least 0.9 meters from bike facilities and signs be kept clearly in view. Broader countermeasures to curtail non-compliance with the Stop sign include education on proper riding techniques and enforcement.

Asphalt Patches in place of Steel Plates. Roads that are patched up where steel plates once laid can be hazardous to cyclists because of the uneven road surface and excess gravel. Both pavement-related hazards can cause a bicycle's wheels to lose contact with the road, thereby creating a loss of control for the cyclist involved. In fact, an uneven road surface can make a cyclist airborne, to avoid this it is important for a smooth road surface to be maintained. Excess gravel reduces a bicycle's coefficient of friction which can lead to serious problems including tire punctures and a loss of control (for a more thorough discussion please refer to the Pavement Conditions section of Chapter 2). Therefore, by examining how cyclists behave when confronted with patched road surfaces their movements can be anticipated and countermeasures to insure safety can be developed.

The intersection of Guadalupe and 29th Street was chosen because footage of cyclists confronted with all the hazards associated with steel plates had been collected earlier in the Summer, plus the patch covered all of the southbound lanes on Guadalupe so cyclists could not easily avoid it. The intersection is a four-legged atypical one as is evident in Figure 3.17, with high volumes of fast auto traffic on Guadalupe and the west leg of 29th Street. This location had three hazards including two primary ones (unsmooth road surface, excess gravel) and one secondary hazard (a non-flush manhole cover). Figure 3.18 shows the cyclist's view of the intersection. Figure 3.19 depicts a close-up view of the manhole cover while Figure 3.20 is a close-up of the asphalt patch. And Figure 3.21 is a view from the camera position. Bike traffic was seen travelling in all directions but we only filmed the predominant direction of that traffic, southbound on Guadalupe.

The site was filmed on Tuesday, July 19, 1994 between the hours of 8 a.m. and noon. A total of 42 data points were recorded. General characteristics of the cyclists and their path choices are listed in Table 3.19. Only 9 of the bicyclists were female, even fewer cyclists wore helmets -- a total of 8, and 9 cyclists rode thin-tired bicycles. Again, there were three distinct paths that the bicyclists took (see Figure 3.17). Path A required the rider to leave the traffic lane and enter the crosswalk on 29th Street to avoid riding over the patch. Path B required the rider to stay in the traffic lane and pass over the asphalt patch, plus ride through gravel. Path C required the rider again to stay in the traffic lane and pass over the patch but without encountering gravel, however the rider had to contend with auto traffic. The paths that various riders travelled are listed in Table 3.19. The path that was chosen the least (9.5 percent of the time) was path C, in fact no females



Hazards

Primary Hazards : Asphalt patches, after removal of steel plates (paths B and C)
Gravel on road surface (path B)
Secondary Hazards : Small dropoff surrounding manhole cover

Figure 3.17 Diagram of Guadalupe and 29th Street Intersection

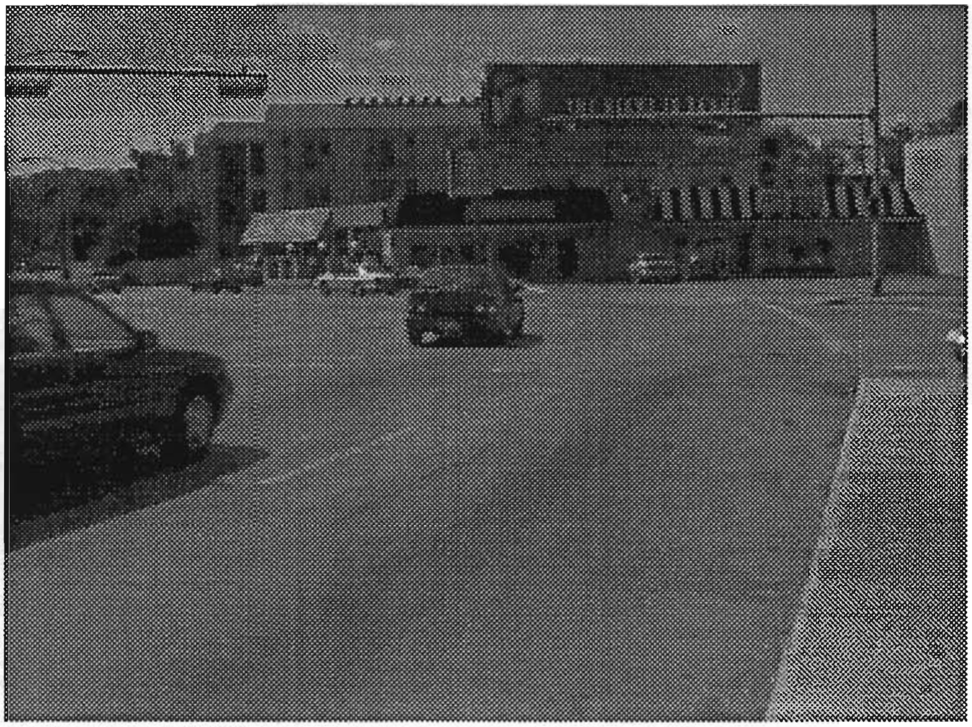


Figure 3.18 Cyclist's View of Guadalupe and 29^{th} Street Intersection

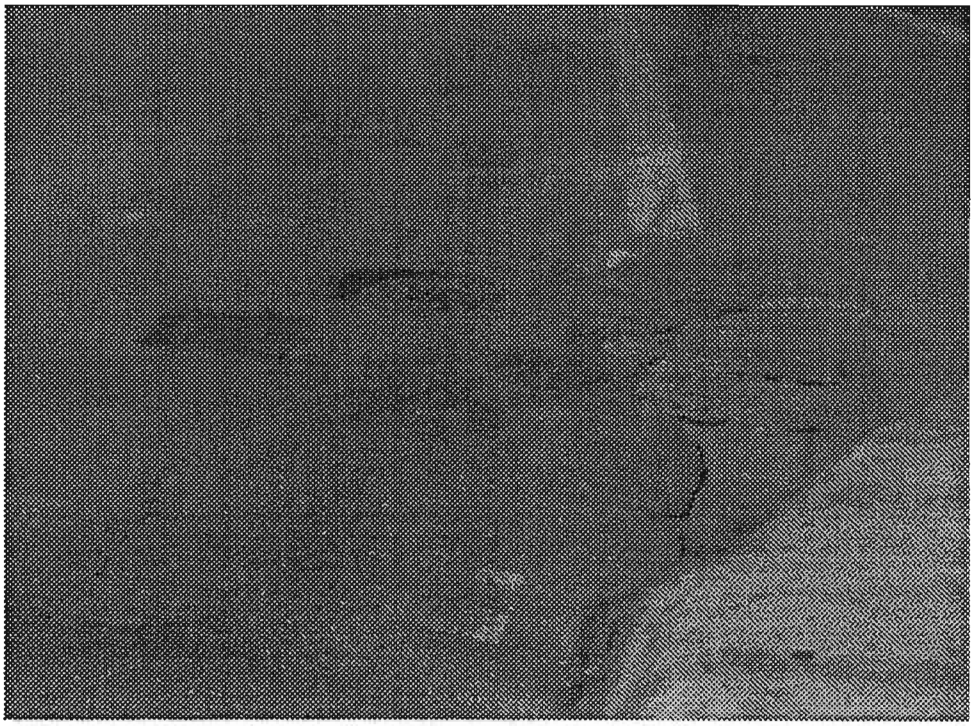


Figure 3.19 Close-up of Secondary Hazard (a non-flush manhole cover) at Guadalupe and 29th Street Intersection

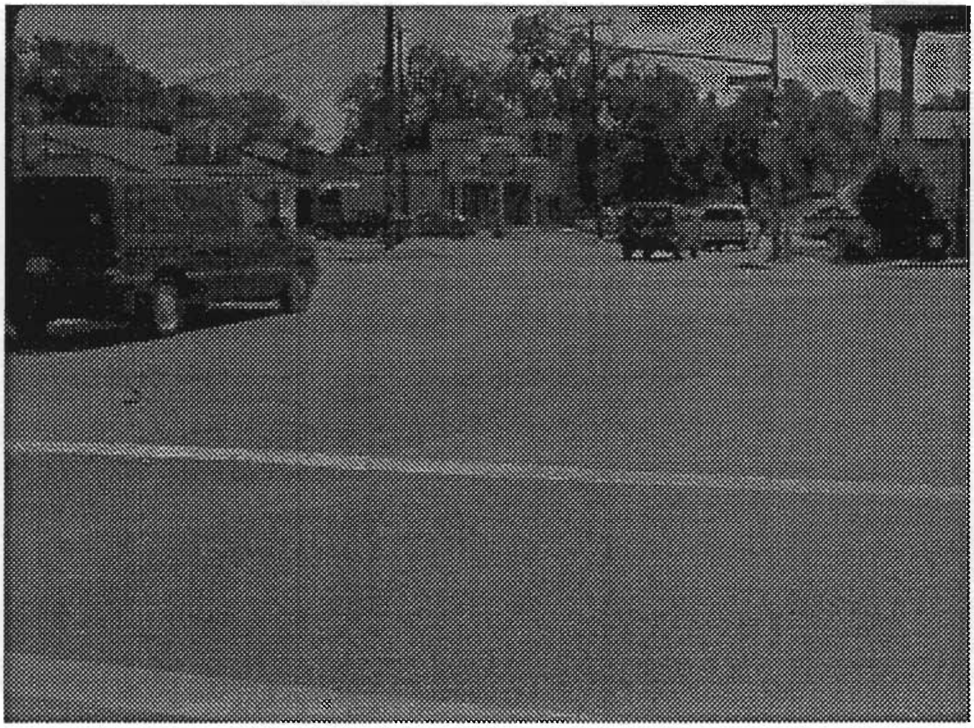


Figure 3.20 Close-up of the Asphalt Patch at Guadalupe and 29th Street Intersection

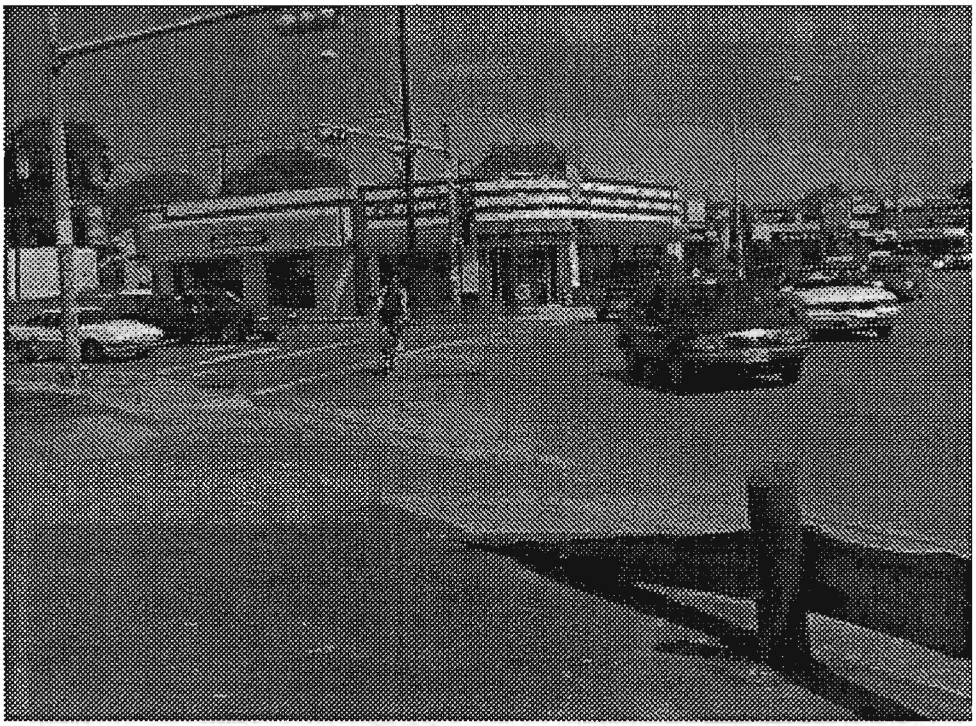


Figure 3.21 View from Video Camera at Guadalupe and 29th Street Intersection

Table 3.19 **General Characteristics and Path Choices of Guadalupe and 29th Street Cyclists**

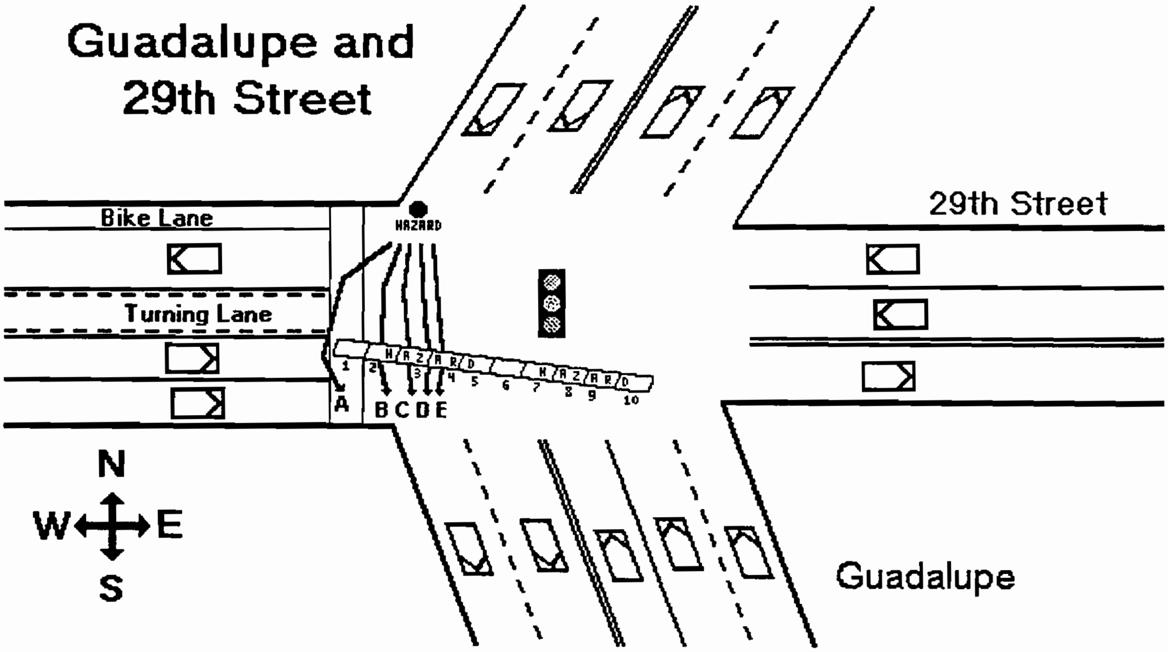
	Chose path A	Chose path B	Chose path C
Of the 42 total data points	40.5 %	50.0 %	9.5 %
Of the 33 Males	42.4 %	45.5 %	12.1 %
Of the 9 Females	33.3 %	66.7 %	0 %
Of the 34 with No Helmet	41.2 %	50.0 %	8.8 %
Of the 8 with a Helmet	37.5 %	50.0 %	12.5 %
Of the 33 with Wide tires	39.4 %	51.5 %	9.1 %
Of the 9 with Thin tires	44.4 %	44.4 %	11.2 %

took this path. The rest of the riders nearly evenly distributed themselves between paths A and B (of all the riders: 40.5 percent chose path A and 50.0 percent chose path B).

The data suggests that the cyclists preferred staying on the edge of the auto lane or travelling partially in the crosswalk to avoid an even greater perceived hazard than the gravel from the asphalt patch, the high speed auto traffic of Guadalupe Street. The inconsistent behavior of the cyclists, from a driver's standpoint could lead to confusion, especially at the far side of the intersection where all cyclists again must merge with the auto traffic. In addition, pedestrians using the crosswalk must be wary of cyclists darting in to avoid the cars and gravel. Therefore, it would be in the best interest of all road users to lessen the number of paths that the cyclists travel through this intersection. Possible countermeasures include strict resurfacing standards when a right-hand traffic lane is being patched along a major bike route and frequent street sweeping of newly patched areas.

Steel Plates Across a Section of Roadway. Steel plates on a roadway are hazardous to cyclists for several reasons. They move or shift when motorized vehicles ride over them. They are usually smooth-sufaced and therefore slippery (especially when wet). They are held in place by asphalt which creates a lot of loose gravel that is dangerous for cyclists to ride through. In addition, they rarely have beveled edges but instead have squared edges that are approximately 125 mm in height -- a lip that could cause problems for cyclists (especially if their bicycles are not perpendicular to the edges). Finally, steel plates are quite common in cities because of road repairs or work by various agencies (water, steam, electric, telephone) on the infrastructure below the road surface so it is hard to avoid them. Therefore, steel plates warrant attention.

The intersection of Guadalupe and 29th Streets was chosen for filming cyclists confronted with steel plates. As previously mentioned (see the previous section), it is a four-legged atypical intersection (see Figure 3.22) with high volumes of fast traffic. There are ten steel plates laying end-to-end across Guadalupe. The plates are all smooth except for the second plate from the left



Hazards

Primary Hazards : Steel plates across roadway (paths B, C, D, and E)
Gravel on road surface (all paths)
Secondary Hazard : Small dropoff surrounding manhole cover

Figure 3.22 Diagram of Guadalupe St. and 29th St. Intersection with Steel Plates (showing paths of southbound bicyclists only) NOT TO SCALE (in the diagram) which is textured. The fourth plate from the left shifts under the weight of a car. In addition, there was a lot of gravel near and on plates 1, 2, 3, and 4 from sealing the plates in place. Figures 3.18, 3.20, and 3.21 show the cyclist's and camera's perspectives (unfortunately, these were taken after the plates were removed).

This location was used because the steel plates lay across the majority of Guadalupe -- forcing riders to cross the plates at some location or else veer into the 29th Street traffic path to go around the plates. Furthermore, the fast traffic on Guadalupe is a big danger. Hence the hazard was rather unavoidable and dangerous. In addition, this street is heavily used by cyclists.

On Tuesday, July 12th, 1994 between 8 a.m. and noon we filmed this site. We collected data on 40 bicycle riders. Five primary paths were followed by the riders regardless of whether they were initially travelling along the road or the sidewalk (see Figure 3.22). Path A cyclists avoided the plates and veered toward the 29th Street traffic to travel around the plates. Path B cyclists travelled over plate number 2 which is textured. Path C cyclists rode over plate number 3. Path D cyclists rode over the seam aligning plates 3 and 4 (note that plate 4 shifts and moves when struck by a car). Path E cyclists rode over plate 4. For all paths gravel was present, however, it was predominantly near the intersection of plates 2 and 3. Table 3.20 includes a breakdown of the riders by gender, helmet usage, and bike type across the five path choices. Similar in composition to the other sample taken at this intersection (for an asphalt patch), there were only 11 females as compared to 29 males and again, there were even fewer cyclists who wore helmets (just 10 riders). Only one cyclist chose path A and only one cyclist chose path E. The majority of cyclists chose path C -- 62.5% of all riders filmed rode over plate 3.

Table 3.20 General Characteristics and Path Choices of Guadalupe St. and 29th St. Cyclists Travelling over Steel Plates

	Chose path A	Chose path B	Chose path C	Chose path D	Chose path E
Of the 40 total data points	2.5 %	12.5 %	62.5 %	20.0 %	2.5 %
Of the 29 Males	3.5 %	13.8 %	58.6 %	20.7 %	3.4 %
Of the 11 Females	0 %	9.1 %	72.7 %	18.2 %	0 %
Of the 30 with No Helmet	3.3 %	16.7 %	60.0 %	16.7 %	3.3 %
Of the 10 with a Helmet	0 %	0 %	70.0 %	30.0 %	0 %
Of the 31 with Wide tires	3.2 %	9.7 %	64.5 %	19.4 %	3.2 %
Of the 9 with Thin tires	0 %	22.2 %	55.5 %	22.2 %	0 %

The implication of riders choosing among five different paths is confusion on the part of motorized vehicle operators because they cannot anticipate the movement of these riders.

However, without a uniform road surface bicyclists must be picky about where they ride so as not to unbalance themselves and get into an accident. The data collected tells us that although cyclists could completely avoid the steel plates they choose not to, instead they predominantly ride over the third plate which has loose gravel on it but is at the edge of the roadway as far away from both the 29th St. and Guadalupe traffic as possible without leaving the road.

Possible maintenance countermeasures include providing texture on all steel plates to reduce slippage and skidding, carefully bevelling the steel plates to the road surface for safety, and sweeping streets more frequently while steel plates are in place to remove excess gravel.

Autos in Bike Lanes. Automobiles that are using bike lanes for parking or driving create major obstacles and hazards to cyclists. For example, cars parked in a bike lane force inexperienced cyclists to merge with auto traffic thereby creating uncomfortable and dangerous situations. In addition, the parallel-parked autos restrict the usable lane width and present a potential hazard for cyclists when a driver opens his or her car door, suddenly further blocking bike traffic. Hence, it is unsafe to have bike lanes that are occupied by automobiles -- especially since this defeats the purpose of designating lanes for bike use. Furthermore, when sections of a bike lane are continually blocked by parked cars riders cannot rely on using it -- making it, in effect, a part-time bike lane. Unfortunately, parking in bike lanes is not prohibited in many cities throughout the U.S.; it is important to examine and understand the ramifications of this problem.

The location filmed was a section of Speedway Street between 39th and 40th Streets. Bicyclists travelling southbound (toward the U.T. campus) were the focus of the investigation. This stretch of roadway is bordered on both sides by a church complex. There is one traffic lane in each direction in addition to one bike lane each way (see the diagram in Figure 3.23). Figure 3.24 shows the view from a cyclist's perspective while Figure 3.25 shows the view from the video camera.

This site was chosen because it is part of a major bike route with striped bike lanes that is predominantly ridden by students, so high levels of bike traffic occur naturally. In addition, this section was chosen because cars consistently park on this street segment which is across from a large church (congregation approximately 2,000) that runs a school and several other programs generating considerable traffic throughout the week. It is important to note that bicycle riders who travel this section frequently are often exposed to parked cars and can be assumed to anticipate parked vehicles blocking the bike lanes.

This section of Speedway St. was filmed on Thursday, June 30th, 1994 from 8:30 a.m. to 11 a.m. Eight different maneuvers, listed below, were found to occur. Figure 3.26 shows the various possible maneuvers in small sketches and they are explicitly listed below. Note that what is listed as maneuver 2 (maneuver 3) actually consists of two different variants, both with the cyclist starting (ending) in the auto lane.

1. Cyclist rides in auto lane continually.
2. Cyclist rides in the auto lane and then either gradually or sharply moves into the bike lane after passing the parked cars.
3. Cyclist either gradually or sharply moves from bike lane to auto lane and then stays in the auto lane after passing the parked cars.
4. Cyclist gradually moves from bike lane to auto lane and gradually back to bike lane after passing the parked cars.
5. Cyclist gradually moves from bike lane to auto lane and sharply back to bike lane after passing the parked cars.
6. Cyclist sharply moves from bike lane to auto lane and gradually back to bike lane after passing the parked cars.
7. Cyclist sharply moves from bike lane to auto lane and sharply back to bike lane after passing the parked cars.
8. Cyclist, not anticipating movement, gets caught behind the parked cars waiting to travel around them as he or she got boxed in by motorized vehicles passing by.

Notice that the cyclist may have started or ended the maneuver in either the bike lane or the auto lane. Plus, if the cyclist at some point was in the bike lane then transfer to or from the auto lane could have been a gradual or sharp movement. However, as stated in scenario 8, we did film one person that had to completely stop in the bike lane just behind the parked cars because he did not plan ahead. In general, sharp movements are dangerous. But, scenarios 3b, 6, 7, and 8 seem the most dangerous because the cyclist's sharp movements are prior to the parked cars in order to merge with auto traffic. This can lead to serious collisions caused by the cyclist being unbalanced or a motor vehicle operator not being able to compensate quickly. Some drivers were seen to brake when bike riders sharply moved into the auto lane and most drove near the double yellow striping or slightly beyond it. The sharp movements in scenarios 2a, 5, and 7 after the parked cars are also unsafe, however, the movements disengage the cyclist from the auto traffic thereby lessening the danger. In conclusion, gradual lane changing movements were observed to work well, as was travelling always in the auto lane, but sharp movements were seen to cause problems for both cyclists and drivers. Further filming of this hazard is necessary because although we found several potential sites it was difficult to find a good vantage point for accurate filming (the best point would be directly overhead). Hence, we relied heavily on the observations we jotted down.

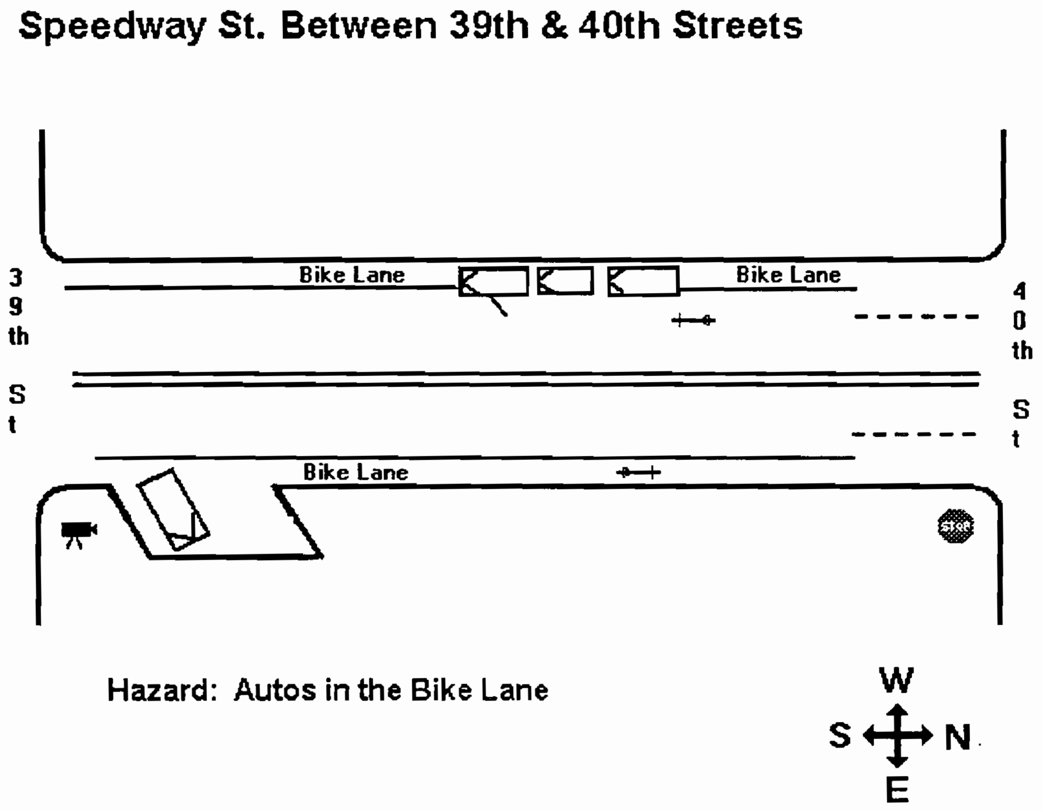


Figure 3.23 Diagram of Speedway Street Between 39th and 40th Streets
NOT TO SCALE

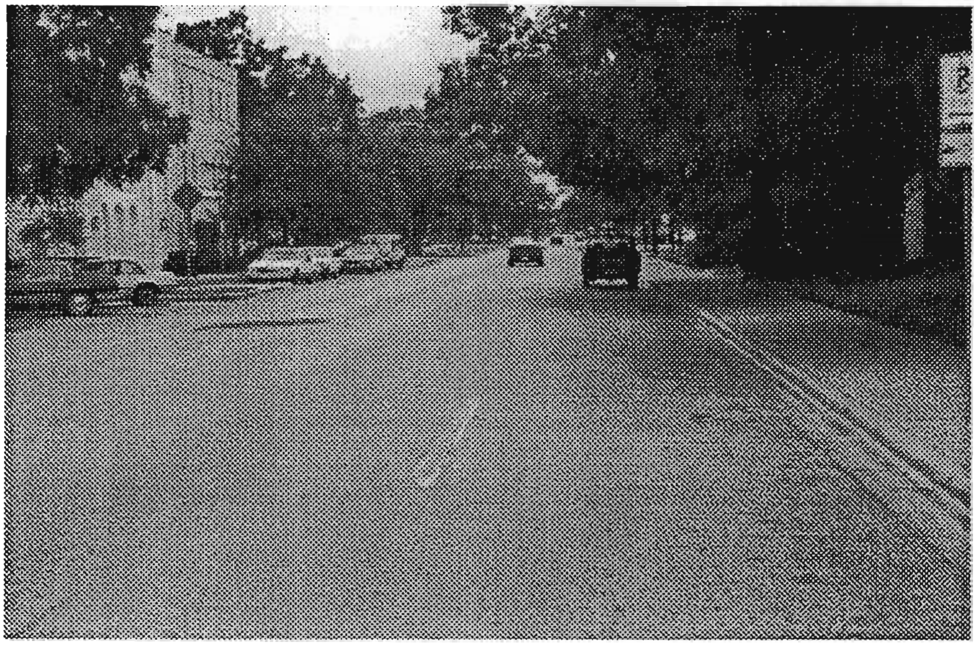


Figure 3.24 A Cyclist's Perspective of the Parked Cars in the Bike Lane (the bike lane striping begins right about where the truck is parked in this photo)

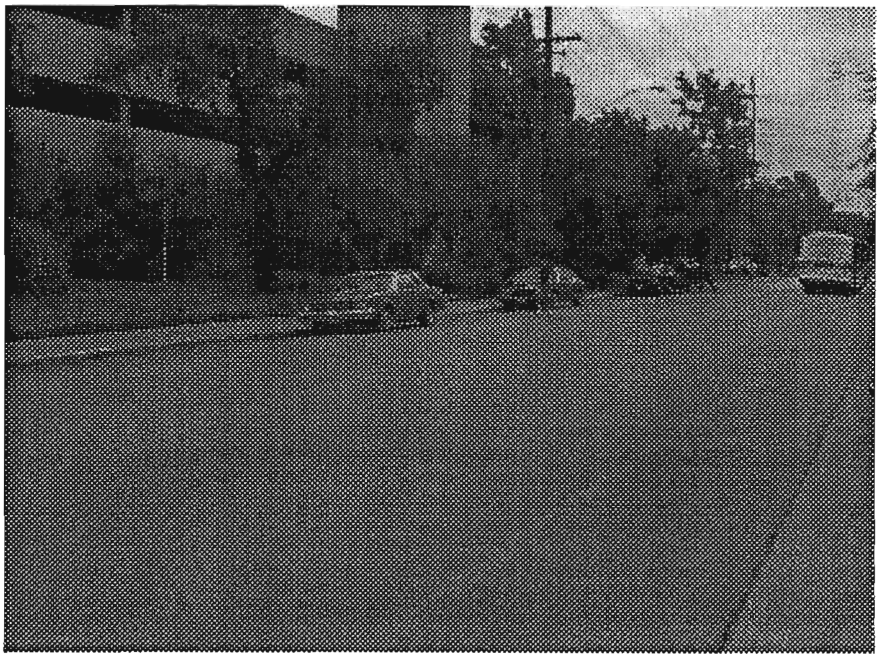
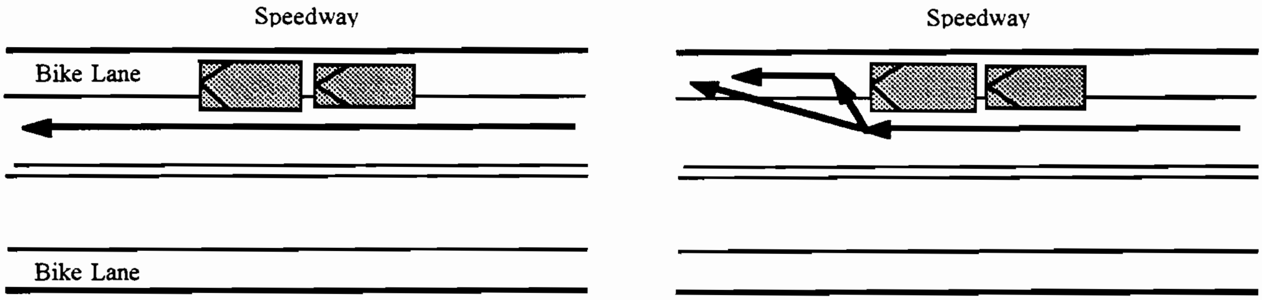
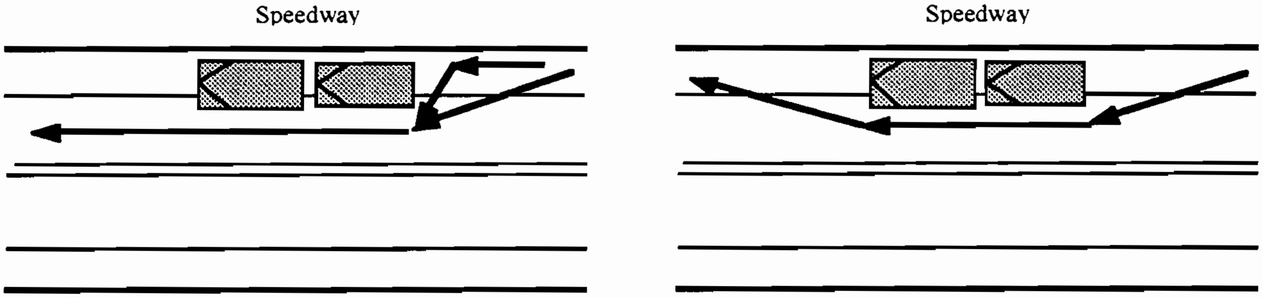


Figure 3.25 Views from the Camera of the Parked Car Site



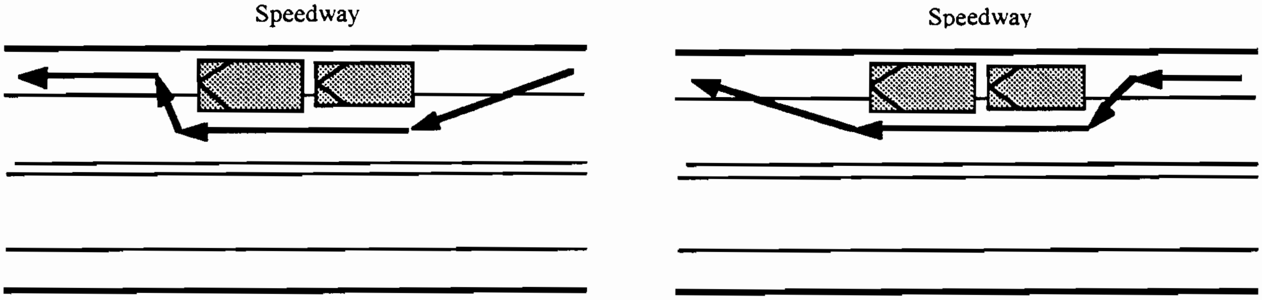
1. Cyclist rides solely in auto lane.

2. Cyclist rides in auto lane then makes a sharp or gradual turn into bike lane.



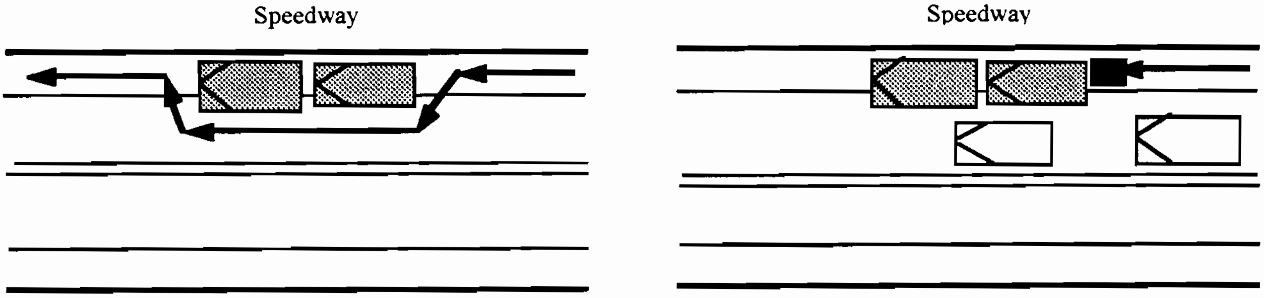
3. Cyclist rides in bike lane then makes a gradual or sharp turn into auto lane.

4. Cyclist makes two gradual turns.



5. Cyclist makes gradual then sharp turn.

6. Cyclist makes sharp then gradual turn.



7. Cyclist does two sharp turns.

8. Cyclist is forced to stop.

Figure 3.26 Sketches of the Eight Possible Maneuvers to Pass the Parked Cars

Possible countermeasures to eliminate the hazard of cars in bike lanes include: removing parking in bike lanes -- permanently disallowing car parking, restricting parking in bike lanes to certain posted hours and/or days, or removing the bike lane striping and use a wide curb lane instead.

Construction Site. With lane closures associated with road repair often comes confusion; people are unsure of the proper path to take to weave through a construction site. Therefore, to help people travel through a work zone a plan may suggest directional devices (such as flagpersons, signage, and pylons) be posted for guidance. Unfortunately, there will always be some vehicle operators that do not comply with the directional devices either because of not seeing or understanding a device or knowingly disregarding its instructions. Examining construction sites in operation can yield insights into whether or not a particular directional device is effective and why people often ignore them.

South Lamar Boulevard and Barton Springs Road were each undergoing major reconstructions during the Summer of 1994. The intersection of these two roads was chosen for observation and analysis (see Figure 3.27). This was the site of a major road and intersection widening project with both roads being widened and modified from 4 lanes to seven lanes for each leg. South Lamar Blvd. has a grade of approximately +4 percent starting at the intersection and going south; the other three legs of the intersection are primarily level. Several road sections, in varying states of construction, were blocked off to motor vehicle traffic, but accessible by bike. The intersection was very congested and there were no extra provisions for bikes. The videotape footage taken was primarily of non-student bicyclists to observe how they navigated through the intersection as compared to their motorized counterparts.

We filmed the intersection on Thursday, July 7th, 1994 from 8 a.m. to noon. We captured 18 cyclists on tape; although not a statistically representative sample, these cyclists do give us an indication of existing behaviors. Figure 3.28 illustrates incorrect movements performed by motorists and Figure 3.29 diagrams all of the bicycle movements we taped. To follow a single movement, find a vehicle at the beginning of a path, then follow the path (note that a path is followed by only the vehicle type at the start of said path). Below is a brief discussion of both figures.

As seen in Figure 3.28, the intersection was confusing for motorists trying to travel through it. One motorist travelling eastbound on Barton Springs Rd. crossed the centerline (unknowingly) to make a left turn onto Lamar Blvd. Later in the filming session, two motorists

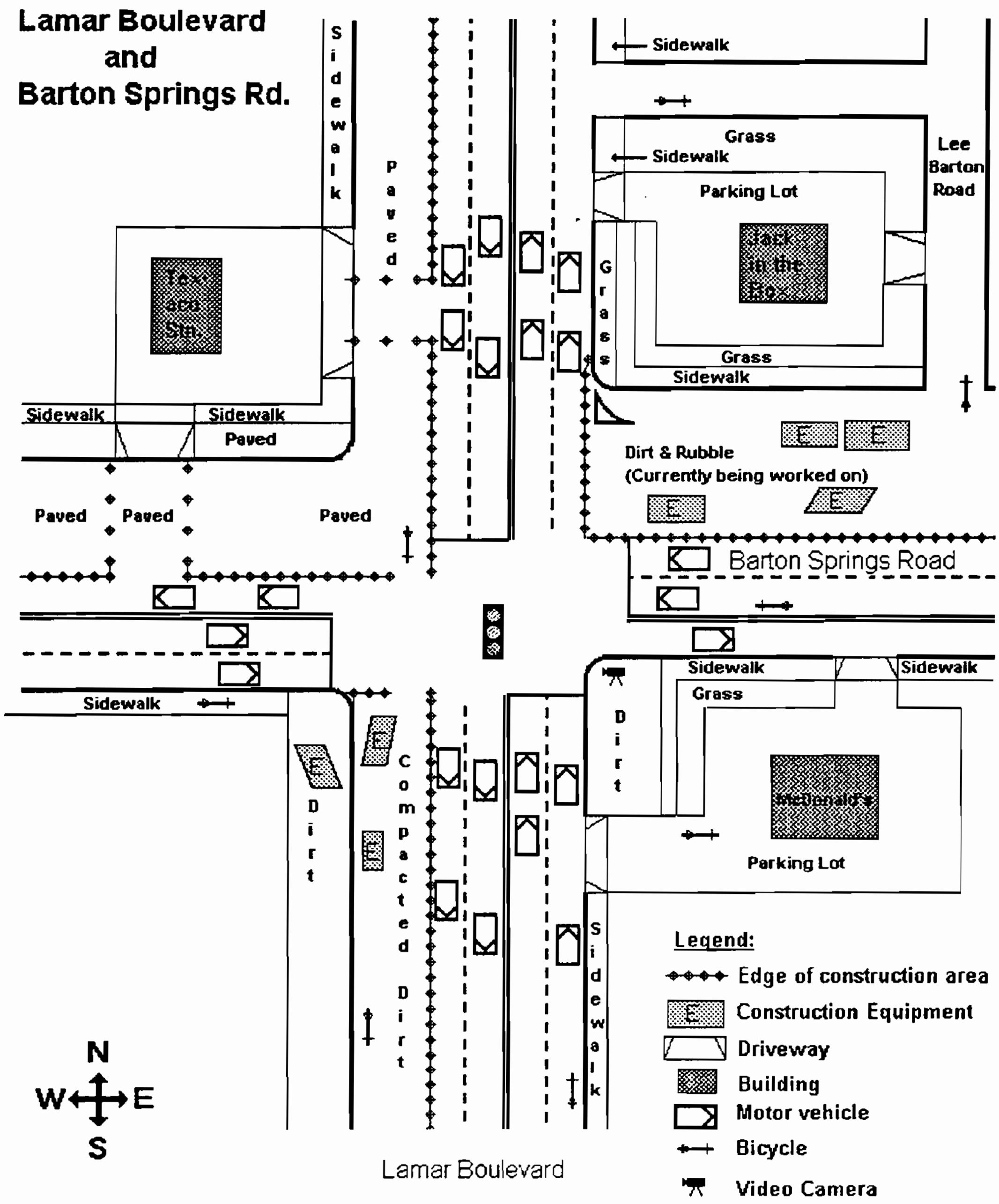


Figure 3.27 Diagram of Intersection of South Lamar Boulevard and Barton Springs Road while Under Construction to Widen Both Roadways NOT TO SCALE

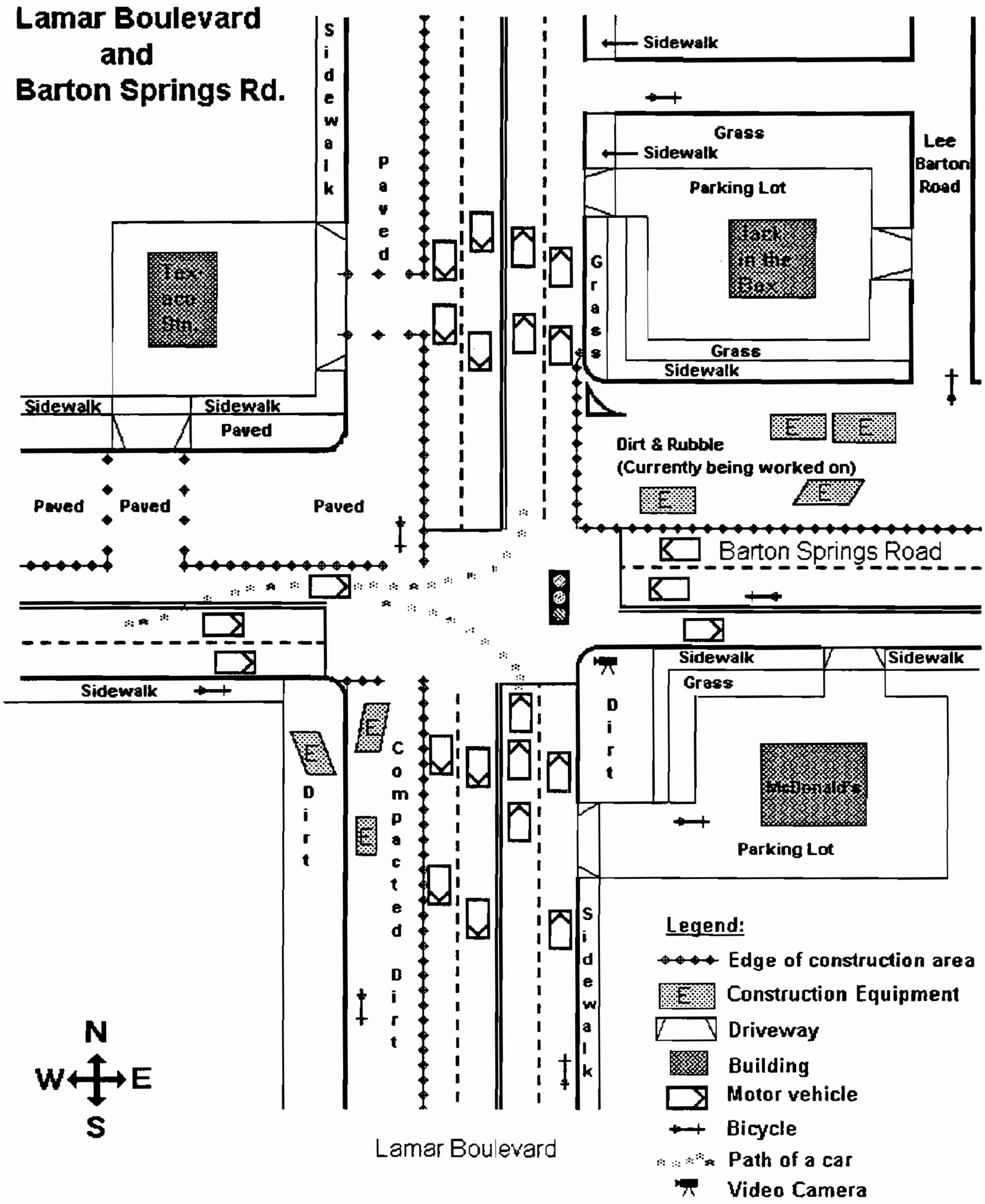


Figure 3.28 Observed Motorists' Errors

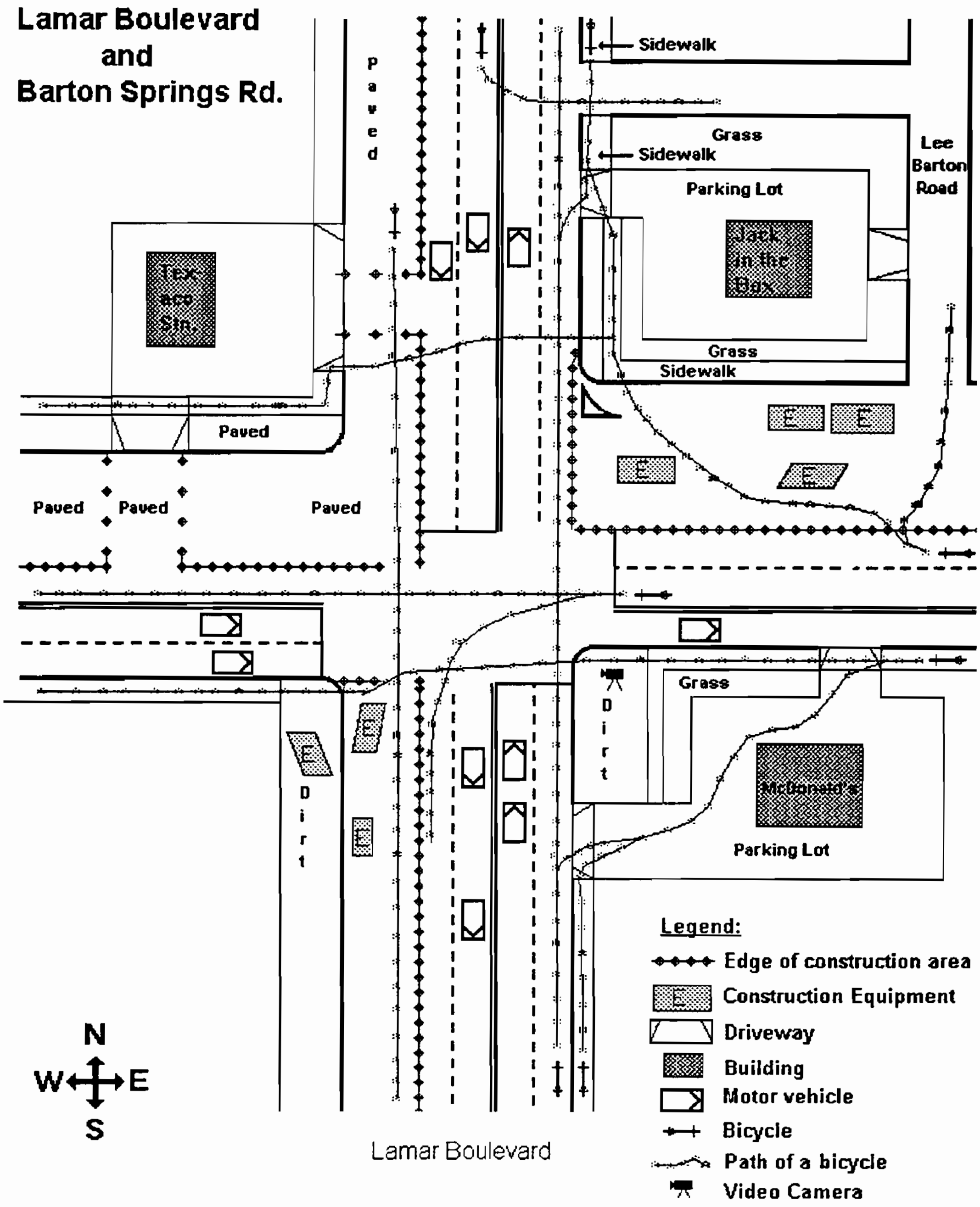


Figure 3.29 Bike Movements In and Around the Intersection

were seen illegally turning left from the leftmost northbound lane of Lamar Blvd. to go westbound on Barton Springs Rd. even though there was a no-left-turn sign directly above the Lamar Blvd. lane.

Examining Figure 3.29 carefully one can see that few cyclists rode entirely on the road. Most avoided Lamar Blvd. and Barton Springs Rd. by riding on sidewalks, through parking lots, on smaller side roads, and through the construction areas. Several cyclists riding on the road were observed to turn off of Lamar Blvd. or Barton Springs Rd. onto side streets prior to reaching the intersection; they smartly avoided the intersection by taking slightly longer routes around it. Furthermore, cyclists purposely rode through construction areas that were fully paved, only compacted dirt, or simply loose dirt and rubble. For the most part, they seemed to enjoy the vehicular separation created by the construction. The closed-off lanes allowed them to travel on two major trunk routes without full interaction with drivers. We could tell that some riders had grown accustomed to the construction set-up because of their carefully chosen paths. Unfortunately, we observed one or two sidewalk cyclists who ran into problems and showed definite signs of confusion, especially one woman that wanted to cross Lamar Blvd. from the Northeast corner to the Northwest one -- she eventually dismounted and crossed the street, weaving between standing vehicles.

The behaviors by the cyclists observed imply that in construction areas, especially heavily congested ones, separate provisions should be made for cyclists to not only ensure their safety but to stop them from riding in the construction areas. Four possible countermeasures could lessen the confusion. First, the area should be carefully signed, especially concerning how riders and drivers are to proceed through it. Second, place announcements of construction and diagrams of the worksite if possible in local papers and local news spots. Third, offer bike lanes through the site. And fourth, sign alternate routes.

SUMMARY OF RESULTS

Bicycle accidents result from complex interactions among various factors, including human behavior, bicycle and other vehicle performance characteristics, as well as the many elements of the physical environment and infrastructure. Accident records, bicyclist surveys, and field observation all strongly point to the importance of behavioral considerations in the occurrence and severity of accidents and incidents involving bicycles. In fact, bicyclist behavior consistently ranks as a major contributing factor to actual accidents. However, it is also readily apparent that the roadway environment presents a variety of safety hazards to bicyclists, exacerbating the risk encountered by conservative bicyclists who respect the rules of the road, and certainly contributing to the seriousness of the consequences of any let-up of bicyclist attention. Furthermore, the very fact that bicycles share the roadway with automobiles dramatically constrains the riders' ability to maneuver around potential hazardous spots on the road (as amply evidenced in the video observations taken for this study).

It also appears that the most important potential roadway-related hazards, those that interact most strongly with bicyclist behavior, are relatively easy to address through simple, relatively low-cost maintenance actions. The surveys conducted herein clearly point to any kind of unexpected obstacle or discontinuity in pavement condition, especially in constrained mixed-traffic environments, like unswept debris on pavements, and smooth/slick pavements, as major potential hazards with relatively simple maintenance solutions. Given the frequency with which these hazards are cited by bicyclists of all stripes, riding abilities and backgrounds, this seems to be an obvious area for targetting resources for cost-effective mitigation of bicycle-related hazards. A more complete discussion of such hazards and associated mitigation actions is provided in the next chapter.

CHAPTER IV: HAZARD PRIORITIZATION

The review of previous studies presented in Chapter II, as well as discussions conducted with bicyclists in focus group sessions, led to the identification of various situations considered hazardous to bicycle safety. To further refine this list, and ascertain the relative seriousness of these hazards as a basis for resource allocation decisions, additional data was collected in the form of direct primary survey responses as well as from available accident databases. In this chapter, we summarize the results of an analysis focusing on ranking the identified hazards on the basis of their perceived seriousness.

The sources of data used in this chapter, namely the surveys and the accident databases, were described in Chapter III. Specifically, two types of surveys were conducted: a special-purpose survey focusing on hazards to cycling, and a general survey of bicycle riders. The former was intended primarily for the purpose of the hazard severity ranking, whereas the latter sought to relate bicycle hazard experience and perception to the characteristics of the riders. As such it includes a wide range of information on bicyclist characteristics and experience, as discussed in Chapter III. The analysis in this chapter is primarily based on the first survey type, with additional information reported from the accident databases as well as the second survey type.

HAZARDS TO CYCLING QUESTIONNAIRE RESULTS

Responses to the hazard questionnaire were analyzed by examining means and confidence intervals. Each of eighty-six hazards were evaluated based on their mean ratings to determine the critical hazards. The questionnaire survey provides insight into cyclists' needs and their relative perception of hazardous situations.

Table 4.1 provides a summary of hazard survey responses. The total number of responses for each hazard varies because some respondents failed to rate every listed hazard. The survey directions instructed them to leave the items blank when they felt they had not encountered a specific hazard or did not understand the item. The mean values indicate the rating attributed to each hazard while the standard deviations describe the degree of variation in the responses. The top ten concerns for cyclists on the roadway network identified through these responses are outlined in Table 4.2.

Confidence intervals specify a range where the actual mean is likely to fall. A ninety percent confidence interval means the researcher is ninety percent confident that the actual mean falls between the two interval limits. For small sample sizes (less than thirty), the confidence interval is

Table 4.1 Summary of Hazard Survey Results

H#	Hazards	Number of Responses	Average Rating	Standard Deviation
78	Driving under the influence	25	9.12	1.80
75	Failure to yield right of way - motorist	27	8.69	1.92
77	Not knowing or observing the cyclist's right to use the road	27	8.65	1.80
43	High truck volumes	24	8.63	2.08
42	High speed or high-volume traffic	27	8.52	1.83
47	Wheel trapping catch basin gates and gutters	23	8.43	1.69
64	Failure to yield right of way - cyclist	27	8.41	2.11
72	Riding against traffic	26	8.27	2.23
50	Sand, gravel, and other debris on the pavement	26	8.19	2.20
74	Right-turning motor vehicles crossing bike lanes	26	8.15	1.97
66	Reluctance to decelerate or stop at crossings	27	8.07	1.90
81	Traffic engineer untrained or unfamiliar with concerns of cyclists	25	8.04	1.75
20	Roadway bottle necks	24	8.00	2.25
51	Debris swept into the bike lanes from motor vehicle lanes	24	7.71	2.17
28	Bike paths that are discontinued by a curb	23	7.63	2.14
76	Encroachment of cars into street space allocated for bicycles	24	7.38	2.34
79	Lack of enforcement of the rules of the road for cyclists	26	7.38	2.43
68	Lack of safety equipment	26	7.38	2.57
73	Riding under the influence	25	7.38	3.08
26	Bike path, route on same roadway as a bus route	20	7.21	2.12
27	Bike paths with poorly designed ramps	24	7.21	2.12
22	Crossing major barriers	25	7.20	2.21
80	Cyclist education and training	25	7.20	2.91
70	Turning left from the right lane	26	7.19	2.86
1	Potholes, ruts, wide pavement cracks	27	7.07	2.58
17	Narrow right lanes	23	7.00	2.27
71	Not maintaining a straight predictable path	27	6.93	2.45
19	Narrow, unmarked shoulders	23	6.74	2.64
15	Cold weather and resulting ice patches	25	6.64	2.71
16	Non-uniform design standards for cycle paths and lanes	25	6.64	2.71
10	Slick/smooth pavement	23	6.59	2.25
32	Improved signal timing	26	6.58	2.45
30	Bicycle insensitive signal detectors	25	6.56	2.83
53	Poorly managed work zones	24	6.50	2.61
23	At-grade railroad crossings	21	6.48	2.46
85	Bike paths and bike routes through crime-ridden locations	23	6.48	2.81
56	Stray animals, unleashed dogs	25	6.44	2.52
41	Curbside auto parking	26	6.44	2.55
86	Air quality.	25	6.44	3.01
18	Narrow cycle paths	25	6.40	2.59
48	Insufficient lighting	25	6.40	2.71
25	Turning radius on horizontal curves at the bottom of a steep grade	21	6.38	2.38
61	Large gap requirements when crossing streets	23	6.35	2.08
5	Wide longitudinal pavement joints	23	6.28	2.60

Table 4.1 Summary of Hazard Survey Results (cont'd)

H#	Hazards	Number of Responses	Average Rating	Standard Deviation
44	Metal grace bridge decks	23	6.26	2.85
24	Frequent driveways	22	6.23	2.09
83	Pedestrians, joggers, etc. on exclusive bicycle lanes	24	6.00	2.14
63	Turning left on protected left-turn passes that are too short	41	6.00	2.76
4	Pavement overlay drop-offs parallel to travel	27	5.98	2.68
55	Unpruned trees	24	5.79	2.,38
36	Raised lane markers	25	5.76	2.92
65	Exceeding design speed on downhill grades	26	5.73	2.85
60	Lack of adequate sight distance	24	5.71	2.11
69	Turning right from left of exclusive bus lanes	25	5.68	2.91
21	Lack of lateral space for load-carrying cyclists	22	5.66	2.43
82	Lack of safe bicycle parking	26	5.62	2.92
54	Overgrown vegetation on bike paths	24	5.58	2.22
45	Bridge expansion joints	22	5.55	2.44
46	Improper bridge railing height	23	5.48	2.48
33	Street signs too close to the roadway or bike path	23	5.48	2.84
29	Large roundabouts	18	5.44	2.81
14	Poor drainage	27	5.43	2.53
62	Lack of acceleration when turning left	23	5.43	2.81
35	Rumble strips	22	5.41	2.35
40	Lack of signage devoted to bicycle route and cyclists	23	5.22	2.60
3	Uneven manhole covers	27	5.17	2.56
84	Unable to transport bikes on trains, trams, buses, and ferries	25	5.16	3.11
31	Inability of cyclists to see optically programmed signals	23	5.04	2.71
49	Stairways	22	5.00	3.10
34	Speed bumps	26	4.96	2.74
67	Carriage of large, heavy, or bulky packages	26	4.81	2.62
52	Vandalized signs and lights on bike paths	23	4.70	2.46
9	Stone paved roads	24	4.69	2.24
6	Open drainage ditches across the street	22	4.66	2.15
13	Oil leaks	24	4.56	2.24
12	Unpaved driveways	27	4.49	2.37
38	Lack of speed separation for cyclists	23	4.43	2.24
11	Temperature sensitive asphalt pavements in hot climates	23	4.35	2.22
8	Differential pavement settlement	26	4.31	1.93
2	Unsmooth patches	27	4.30	2.00
37	Friction reducing paints	23	4.30	2.27
58	Difficulty controlling speeds on downgrades	23	4.09	2.06
39	Non-standard delineation for bike lanes	22	4.00	2.30
59	Difficulty riding uphill grades	24	3.67	2.03
57	Unstable at low speeds	23	3.65	2.31
7	Asphalt ripples due to braking action	27	3.36	1.74

Table 4.2 Top Ten Concerns for Cyclists on the Roadway Networks

1.	Motorists driving under the influence of drugs or alcohol	(9.12)
2.	Failure to yield right of way by the motorist	(8.69)
3.	Motorists fail to observe the cyclists' right to use the road	(8.65)
4.	High truck volumes	(8.63)
5.	High speed/high volume traffic	(8.52)
6.	Wheel trapping catch basins, grates, and gutters	(8.43)
7.	Failure to yield the right of way by the cyclist	(8.41)
8.	Riding against traffic	(8.27)
9.	Sand, gravel, and other debris on the pavement	(8.19)
10.	Right-turning motor vehicles crossing bike lanes	(8.15)

calculated as:

$$[\bar{x}-t(\alpha/2;n-1)(s/\sqrt{n}),\bar{x}+t(\alpha/2;n-1)(s/\sqrt{n})]$$

where: α = the level of significance (i.e. 100 - confidence level)
x = the sample mean
s = the sample standard deviation
n = the sample size
$t(\alpha/2;\ n-1)$ = the t-statistic value corresponding to a significance level α and $(n-1)$ degrees of freedom

The ninety percent confidence intervals are plotted in Figure 4.1. The identification numbers in Figure 4.1 correspond to the hazard number (h#) from Table 4.1. The figure shows that many of the confidence intervals include values greater than 5.5 which represents the midpoint of the 1-10 scale used in the survey. Using this midpoint as a threshold above which cyclists find the particular situation or behavior dangerous, the survey responses have thus identified many areas of concern present on the roadway today which both deter potential cyclists and endanger current cyclists.

ACCIDENT STUDY RESULTS

Although cyclist behaviors contribute to a majority of motor vehicle-bicycle crashes (as discussed in Chapter III), the motorists create dangerous situations too. To examine motor vehicle-bicycle crashes, accident data from: the Texas Department of Public Safety, the city of Tempe, Arizona, the city of Madison, Wisconsin, the city of Winnipeg, Manitoba, Canada, and the Oregon Department of Transportation was collected. The data received ranged from single year reports to five year data sets to one fourteen-year summary (please see the Chapter III section entitled *Accident Studies and Databases* for further details). After combining the data from multiple years to find the average accidents per year, we obtain the percent of accidents with known causes for each significant behavior. Table 4.3 summarizes the accident causes in each of the five locales. The remaining accident data from Texas, Tempe, Madison, Winnipeg, and Oregon support the contention that the previously discussed hazardous cyclist behaviors are major contributors to bicycle-motor vehicle crashes. The predominant motorist mistakes include *failing to yield the right-of-way*, *improper passing or turning*, and *driving under the influence*; these behaviors correspond to those found to be hazardous based on the surveys. Cyclists in Tempe cause more crashes by *riding against traffic* than bikers in Winnipeg while in Madison more cyclists crash when *traveling in pedestrian areas*, such as sidewalks and crosswalks. Also shown in Table 4.3 (in the last column) are the results from Cross and Fisher's (1977) national database, included here for reference.

The data from each accident study reveals similar characteristics. In all but one study, *failure to yield right-of-way* accounts for a majority of the crashes. Motorists cause most of the crashes that cite *failure to yield right-of-way* and *improper passing or turning* as contributing factors. Cyclists, on the other hand, cause most of the accidents that cite *disregarding traffic signals*.

The accident study and questionnaire survey demonstrate the seriousness attributed to inappropriate behaviors. For example, *failing to yield the right-of-way*, *riding against traffic*, and *failing to obey traffic control devices* rank very high in both the cyclist survey and accident studies. In addition, all the hazards that the accident study identifies as major causes of crashes, rank in the top twenty hazards of the questionnaire survey. Although *driving under the influence* ranks highly in the questionnaire survey, it fails to account for many of the accidents because few cyclists ride at night when most drunk drivers take to the roadway. However, approximately a third of all bicycle fatalities involved cyclists that have been drinking (Baker, et al., 1993). The accident data from each location seems consistent with the previous findings from the questionnaire survey because both sets of data rate the hazards with similar degrees of concern.

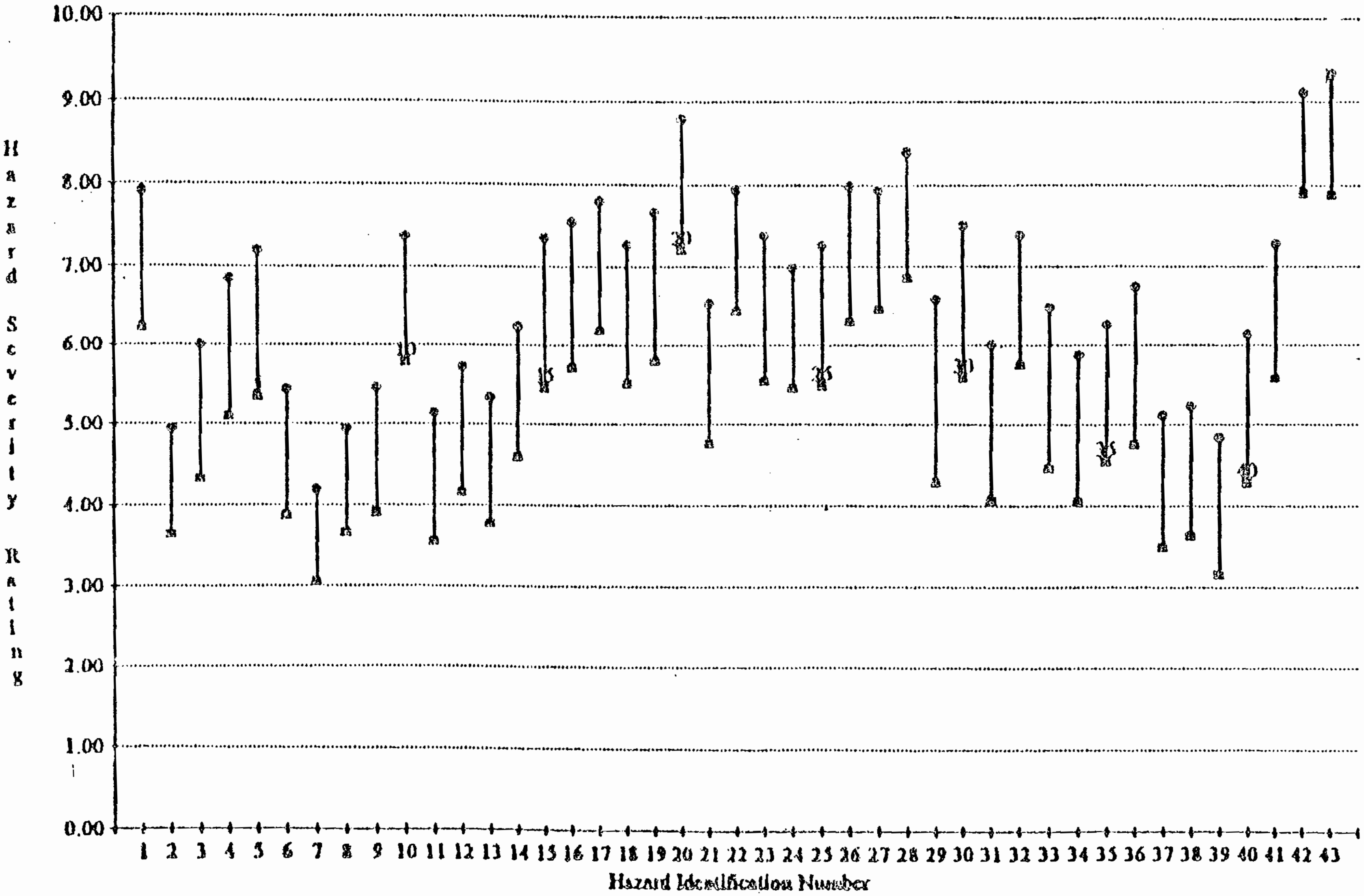


Figure 4.1a **Confidence intervals at ninety percent confidence for the questionnaire survey means**

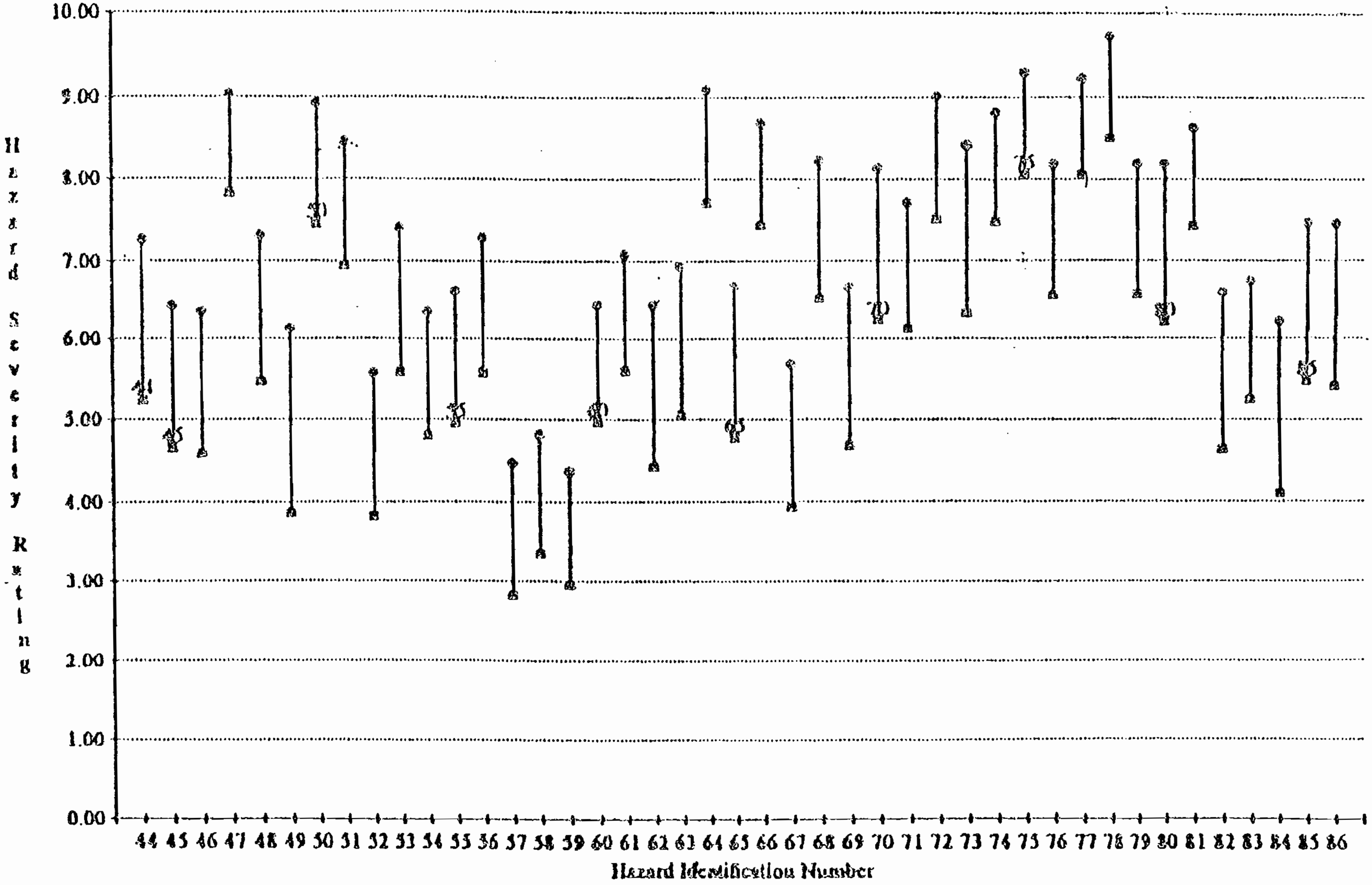


Figure 4.1b Confidence intervals at ninety percent confidence for the questionnaire survey means

Table 4.3 Bicycle Accidents with Known Causes

	Texas DPS Accs/year* (% accs/yr)	Tempe, Az. Accs/year** (% accs/yr)	Madison, Wis. Accs/year*** (% accs/yr)	Winnipeg, Man., Canada Accs/year*** (% accs/yr)	Oregon DOT Accs/year**** (% accs/yr)	Cross & Fisher % Accidents ******
Speed too fast (1)	51.6 (4.4%)	n/a	3.0 (1.6%)	n/a	n/a	n.a
Speed too slow (1)	150.2 (12.8%)	n/a	n/a	n/a	n/a	n/a
Fail to yield ROW to other vehicles: Total	375.0 (32.0%)	67.6 (26.3%)	87.0 (47.3%)	56.7 (34.6%)	276.5 (23.9%)	8.9%
Motorists	n/a	43.8 (17.0%)	61.0 (33.2%)	31.9 (19.5%)	208.5 (18%)	6.3%
Cyclists	n/a	23.8 (9.3%)	26.0 (14.1%)	24.8 (15.1%)	68.0 (5.9%)	2.6%
Disregard traffic control device: Total	60.0 (5.1%)	25.8 (10.1%)	7.0 (3.8%)	20.4 (12.5%)	177 (15.2%)	n/a
Motorists	n/a	6.6 (2.6%)	n/a	2.2 (1.4%)	30.5 (2.6%	n/a
Cyclists	n/a	19.2 (7.5%)	7.0 (3.8%)	18.2 (11.1%)	146.5 (12.6%)	11.4%
Improper passing or turning: Total	68.8 (5.9%)	33.6 (13.1%)	n/a	23.8 (14.5%)	140.5 (12.1%)	22.5%
Motorists	n/a	28.0 (10.9%)	n/a	15.5 (9.4%)	107 (9.2%)	14.3%
Cyclists	n/a	5.6 (2.2%)	n/a	8.4 (5.1%)	33.5 (2.9%)	8.2%
No light/reflector on bike at night	n/a	5.4 (2.1%)	n/a	16.4 (10.0%)	n/a	n/a
Riding against traffic	n/a	112.2 (43.7%)	n/a	12.4 (7.6%)	167.5 (14.4%)	13.7%
Following too closely	13.0 (1.1%)	9.4 (3.7%)	n/a	n/a	25.5 (2.2%)	1.1%
Driving under influence	79.0 (6.7%)	n/a	n/a	n/a	n/a	n/a
Failure to have control	n/a	n/a	n/a	6.4 (3.9%)	15 (1.3%)	n/a

Table 4.3 (Continued)

	Texas DPS Accs/year* (% accs/yr)	Tempe, Az. Accs/year** (% accs/yr)	Madison, Wis. Accs/year*** (% accs/yr)	Winnipeg, Man., Canada Accs/year**** (% accs/yr)	Oregon DOT Accs/year***** (% accs/yr)	Cross & Fisher % Accs ******
Inattentive riding	n/a	n/a	32.0 (17.4%)	n/a	n/a	n.a
Bicyclist travelling in pedestrian areas	n/a	n/a	55.0 (29.9%)	23.4 (14.3%)	n/a	6.60%
Cyclists too close to parked car	n/a	n/a	n/a	7.6 (4.7%)	14 (1.2%)	n/a
Cyclists swerves unexpectedly	n/a	n/a	n/a	7.3 (4.5%)	61 (5.3%)	1.30%
Other violations	374.6 (32.0%)	254 (1.0%)	n/a	0.4 (0.2%)	n/a	n/a
Total accidents with known causes	1172.2 (100%)	256.6 (100%)	184.0 (100%)	163.8 (100%)		

* 1988- 92 Data

** 1987- 91 Data

*** 1992 Data

**** 1976- 89 Data

***** 1990, 1992 Data

****** 1977 Study

(1) In the Texas data, motorists most likely account for "speed too fast" and the cyclists account for "speed too slow" but the data does not specify whether one or both classes of vehicle exhibited the identified cause.

For the purposes of the present study, accident databases are of very limited use. By their nature, being based on self-reported accidents typically involving some form of insurance compensation, these databases concentrate on situations where one of the parties involved was at fault. As such, they are not a very useful source for information on sources of hazards in the roadway elements and physical infrastructure. It is the influence of such hazards on bicyclist (and motorist) behavior that is of primary concern here, and the physical motivation for the primary data collection activities undertaken.

BICYCLE RIDERS SURVEY RESULTS

The ranking of hazard severity included in this report is based primarily on the Hazards to Cycling questionnaire survey results and supporting evidence from the accident databases and reports. The larger and more general survey of bicycle rider characteristics and hazard experience is used to augment and enhance the hazard analysis and prioritization framework. In particular, reported hazard frequency experience obtained from the survey allows us to introduce the risk exposure dimension, in addition to severity, in the framework. In the previous chapter general bicycle rider characteristics were included for informational purposes and to support the analysis of behavior. In this chapter, data from this survey is used to rank a selected set of hazards on the basis of frequency and severity for comparison to the questionnaire survey results.

Respondents were provided with a list of 14 selected hazards spanning various categories, and asked to rate these hazards in terms of frequency, as well as in terms of severity. The rating was in the form of a number from 1 to 3 for severity and 1 to 4 for frequency. Rank orderings on the basis of the mean ratings are given in Table 4.4 and shown in Figure 4.2. More extensive treatment of this data can be found in Appendix C. The respondents found *wheel trapping* (in drainage grates and the like) to be the most serious hazard, closely followed by *autos encroaching on bicycle lanes*, and *potholes/ruts/wide cracks* in the pavement. The latter two hazards (autos encroaching, potholes, etc.) were ranked in first and second places respectively in terms of frequency, therefore these hazards are quite dangerous because they are perceived by the cyclists to occur frequently and cause potentially serious accidents. In Figure 4.2 the perceived nature of each hazard is plotted so its frequency and severity characteristics can easily be compared to other hazards. Hazards in the lower left-hand corner (such as *signs too close to bike lanes*) represent minor hazards that are rarely encountered, as compared to hazards in the upper right-hand corner (such as *potholes/ruts/wide cracks*) which represent major hazards that are very commonly seen. Hence, maintenance and design hazards that are in the vicinity of the upper right-hand corner

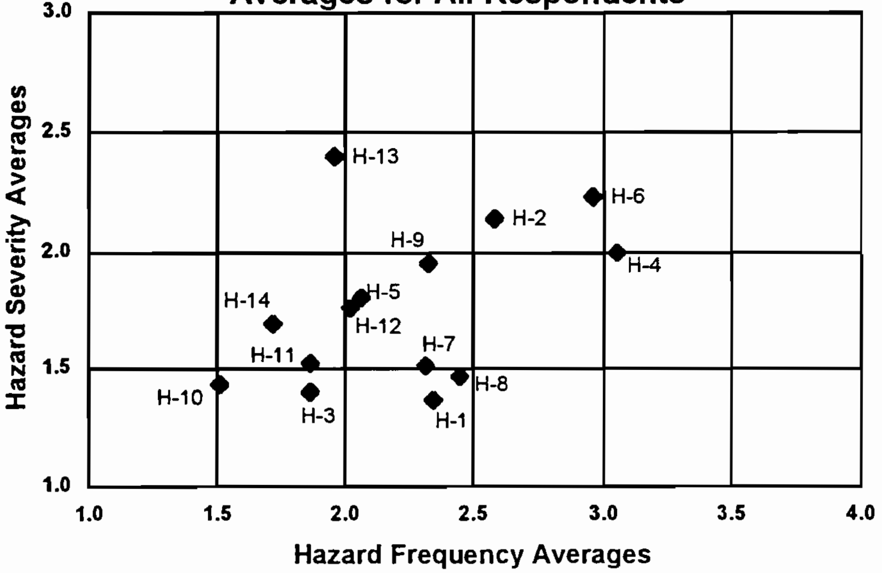
Table 4.4 Severity and Frequency Rankings for 14 Listed Hazards Based on All Respondents of the *Bicycle Riders Survey*

Severity Rank	Average Severity Rating*	H-#	Name	Average Frequency Ratings**	Frequency Rank
1	2.40	H-13	Wheel-trapping catch-basin grates and gutters	1.96	10
2	2.23	H-6	Potholes/ruts/wide cracks	2.96	2
3	2.14	H-2	Autos encroaching (or parked in) bike lanes	2.58	3
4	2.00	H-4	Debris/gravel in bike lanes/right lanes	3.06	1
5	1.95	H-9	Repaving using loose gravel	2.32	6
6	1.81	H-5	Oil patches near intersections and in bike lanes	2.06	8
7	1.76	H-12	Uneven manhole covers	2.02	9
8	1.69	H-14	Work zones poorly managed and signed	1.72	12
9	1.52	H-11	Uneven bridge expansion joints	1.86	11
10	1.51	H-7	Railroad/ trolley crossings	2.31	7
11	1.47	H-8	Raised lane markers	2.44	4
12	1.44	H-10	Signs too close to (or encroaching on) bike lanes	1.51	13
13	1.40	H-3	Bike paths/lanes blocked by overgrown vegetation	1.86	11
14	1.37	H-1	Asphalt ripples at intersections/bus stops	2.34	5

*Severity rating based on scale of 1 to 3 (3 most severe)

** Frequency rating based on scale of 1 to 4 (4 most frequent)

Figure 4.2 Hazard Frequency and Severity Averages for All Respondents



should be swiftly handled, whereas those in the lower left-hand corner could be handled as time and funds permit.

Comparing these results to those of the questionnaire survey, some differences can be noted, however the top four hazards (based on severity) of the *Bicycle Riders Survey* are ranked in the top twenty-five of the *Hazards to Cycling* questionnaire.

SUMMARY OF RESULTS

Many factors impact cyclists' safety, including the roadway and surrounding environment, the behavior of road users, and government agency policies. Government policies could influence bikers' safety by reducing or mitigating the dangers caused by the other factors. The study summarizes the results of the *Hazards to Cycling* questionnaire survey in Tables 4.5, 4.6, and 4.7. These tables categorize the hazards into three groups: actual hazards, potential concerns, and nuisances. The study determines and lists in Table 4.5 all of the hazards with a mean value of 5.5 or greater, which require discussion in any design or maintenance guidelines. Table 4.6 reports the hazards whose confidence intervals fall between 4.0 and 6.5 as potential concerns. While the remaining items found in Table 4.7 merit some interest, they generally pose little threat according to the surveyed cyclists. In each category, the tables rate the hazards according to severity. The study compares its findings from the accident study to the questionnaire survey regarding behaviors; Table 4.8 compares the ten most frequent contributing factors to bicycle-motor vehicle accidents and the top ten behavioral hazards from the questionnaire. The table indicates that cyclists view the accidents' major contributing factors as serious hazards. Six of the top seven factors from each list make the other study's top ten list, thus indicating consistent results.

Table 4.5 Hazards to Cycling

A. Pavement Conditions

1. Potholes, ruts, wide pavement cracks [7.07][1]
2. Slick/smooth pavement (when asphalt covers the surface aggregates completely it becomes slippery when wet) [6.59]
3. Cold weather combined with poor drainage resulting in ice patches [6.42]
4. Wide longitudinal pavement joints [6.28]
5. Dropoffs at pavement overlays parallel to the direction of travel [5.98]

B. Geometric Design

1. Roadway bottlenecks (narrow bridge lanes or sudden narrowing of roadway cross sections) [8.00]
2. Bike paths that are discontinued by a curb [7.63]
3. Bike paths with poorly designed ramps (e.g. sharp turns at the top or bottom of ramps, poor sight distance, etc.) [7.21]
4. Crossing major barriers: main roads, railways, canals, rivers [7.20]
5. Bike path/route on same roadway as a bus route (e.g. leapfrog between the buses and bicycles, buses enter the bike lane for bus stops) [7.15]
6. Narrow right lanes [7.00]
7. Narrow, unmarked shoulders [6.74]
8. Non-uniform design standards for cycle paths and lanes [6.64]
9. At-grade railroad crossings [6.48]
10. Narrow cycle paths [6.40]
11. Turning radius on horizontal curves at the bottom of a steep grade [6.38]
12. Frequent driveways [6.23]
13. Lack of lateral space for load-carrying cyclists [5.66]

C. Traffic Control and Conditions

1. High truck volumes [8.63]
2. High-speed or high-volume traffic [8.52]
3. Improper signal timing for cyclists (e.g. short green/amber durations) [6.58]
4. Bicycle insensitive signal detectors [6.56]
5. Curbside auto parking [6.44]
6. Raised lane markers [5.76]

---

[1] Mean value from the survey

Table 4.5 Hazards to Cycling (cont'd)

H. Motorists' Behavior

1. Driving under the influence [9.12]
2. Failure to yield right-of-way [8.69]
3. Not knowing or observing cyclists' right to use the road [8.65]
4. Right-turning motor vehicles crossing bike lanes [8.15]
5. Encroachment of automobiles into street space allocated to cyclists (e.g. motor vehicles must cross through the bike lane when parking, open car doors enter the bike lane, etc.) [7.38]

I. Policy/Enforcement

1. Traffic engineer untrained or unfamiliar with concerns of cyclists [8.04]
2. Lack of enforcement of the rules of the road for cyclists [7.38]
3. Cyclist education and training [7.20]
4. Bike paths and bike routes through crime-ridden locations [6.48]
5. Air Quality [6.44]
6. Pedestrians, joggers, etc. on exclusive bike lanes [6.00]
7. Lack of safe bicycle parking [5.62]

Table 4.6 Potential Concerns for Cyclists

A. **Pavement Conditions**

1. Poor drainage on cycle paths and streets in the areas that cyclists ride [5.43][1]
2. Uneven manhole covers [5.17]
3. Unpaved driveways (major source of sand and gravel on pavement) [4.94]

B. **Geometric Design**

1. Large roundabouts [5.44]

C. **Traffic Control and Conditions**

1. Street signs too close to the roadway or bike path [5.48]
2. Rumble strips [5.41]
3. Lack of signage devoted to bicycle routes and cyclists [5.22]
4. Inability of cyclists to see optically programmed signals [5.04]
5. Speed bumps [4.96]

D. **Other Design Elements**

1. Improper bridge railing height (if too short cyclist could flip over, if too high could restrict cylist's sight distance) [5.48]

E. **Bicycle Characteristics**

1. Lack of acceleration when turning left on permissive-only signals [5.43]

F. **Policy/Enforcement**

1. Unable to transport bikes on trains, trams, buses, and taxis [5.16]

---

[1] Mean value from the survey

Table 4.7 Nuisances to Cycling

A. Pavement Conditions

1. Stone paved roads [4.69][1]
2. Open drainage ditches across the street [4.66]
3. Oil leaks, particularly near intersections [4.56]
4. Temperature sensitive asphalt pavements in hot climates [4.35]
5. Differential pavement settlement, particularly at bridge connections [4.31]
6. Unsmooth patches (including hardened cement, tar, and other materials accidentally released onto the pavement surface) [4.30]
7. Asphalt ripples due to braking action, etc. [3.63]

B. Traffic Control and Conditions

1. Lack of separation for cyclists going at different speeds in bike lanes [4.43]
2. Friction reducing paints used in striping crosswalks and other pavement markings [4.30]
3. Nonstandard delineation for bike lanes (e.g. solid stripes, dashed stripes, grade separation, etc.) [4.00]

C. Other Design Elements

1. Stairways [5.00]

D. Roadway Maintenance/Upkeep

1. Vandalized signs and lights on bike paths [4.70]

E. Bicycle Characteristics

1. Difficulty of controlling speeds on downgrades [4.09]
2. Difficulty riding on uphill grades (e.g. zigzagging) [3.67]
3. Unstable at low speeds [3.65]

F. Cyclists' Behavior

1. Carriage of large, heavy, or bulky packages [4.81]

---

[1] Mean value from the survey

Table 4.8 A Comparison of Behaviors Between the Survey Data and the Accident Data

	Questionnaire Survey Data			Accident Study Data	
1.	Driving under the influence	9.12	1.	Failing to yield right of way - motorist	19.6%
2.	Failing to yield right of way - motorist	8.69	2.	Riding against traffic	17.1%
3.	Failing to accept the cyclists' right to use the road - motorist	8.65	3.	Bicyclist travelling in pedestrian areas	15.3%
4.	Failing to yield right of way - cyclist	8.41	4.	Failing to yield right of way - cyclist	13.6%
5.	Riding against traffic	8.27	5.	Disregard traffic control device - bicyclist	9.8%
6.	Right-turning motor vehicles in conflict with cyclists	8.15	6.	No light on bicycle at night	8.0%
7.	Reluctance to stop at intersections - cyclist	8.07	7.	Driving under the influence (D.U.I.)	6.8%
8.	Lack of safety equipment	7.38	8.	Improper passing or turning - motorist	6.5%
8.	Riding under the influence	7.38	9.	Cycling too close to parked car	4.7%
8.	Encroachment of cars into space allocated to bicyclists	7.38	10.	Improper passing or turning - cyclist	4.4%
			10.	Cyclist swerves unexpectedly	4.4%

CHAPTER V: HAZARD DETECTION AND MITIGATION

APPROACH

The objectives of this study have been to identify factors which constitute a hazard to cycling on urban and rural roadways and to propose and evaluate mitigation measures, especially those that could be accomplished as part of regular maintenance activities and procedures. A comprehensive list of potential cycling hazards was developed based on cyclist surveys and literature review. The list initially consisted of 86 hazards, which were grouped into nine broad categories for further analysis.

Questionnaire surveys were developed and used to identify the top hazards. Focus groups consisting of bicyclists as well as transportation professionals were formed and consulted to identify the top hazards to cycling. Individual bicyclists not associated with the focus groups were also surveyed. Accident data from state and local agencies in and outside Texas were used to supplement the information obtained from focus groups and cyclist surveys, as described in the previous chapters.

The above process led to the identification of nineteen major hazards that lend themselves to mitigation primarily through maintenance, or in some instances design measures. As explained in the previous chapter, a number of highly ranked hazards were behavioral or institutional in nature. However, only those that could be remedied by improving the physical infrastructure through design or maintenance practices were selected for further analysis; these include:

1. Surface irregularities such as potholes, ruts, and cracks
2. Sand, gravel, and debris on roadway surface
3. Catch-basins with parallel bar grates
4. Curb-opening catch-basins with steep entry slopes
5. Bicycle insensitive signal detectors
6. Short durations of amber and exclusive left-turn phases
7. Improperly designed rumble strips
8. Riding against traffic
9. Poor surface drainage
10. Curbside parking along bike routes
11. Crossing wide streets on a two-way stop sign
12. Cycling through roadway work-zones
13. Cycling along high-speed or high-volume roadways
14. Bike paths discontinued by a curb
15. Insufficient lighting

16. Roadside obstructions with inadequate vertical clearance
17. Poorly designed bicycle underpasses
18. Slippery-when-wet pavements
19. Poorly designed at-grade railroad crossings

The second phase of the study concentrated on finding feasible maintenance or, in some cases, design means to effectively mitigate the above hazards. The following section presents detailed description of these hazards as well as recommended mitigation measures and associated costs.

HAZARD MITIGATION: DESIGN AND MAINTENANCE SOLUTIONS AND COSTS

It would not be economically feasible to remedy all instances of the eighty-six hazards listed in Appendix A. In some cases, such as developing a network of exclusive bike routes, the cost would be prohibitive. In other cases the adverse impact of the remedial solution on motorized traffic might be too great. Prohibiting all curb-side parking or the right-turn on red maneuver are examples of the latter. In general the potential solutions can be classified, as shown in Table 5.1, in six groups in terms of cost and impact on other traffic. In terms of cost, they can be classified as *costly* or *relatively inexpensive*. They can also be grouped on the basis of adverse impact on other traffic into three categories, *beneficial to other traffic, minimum adverse impact on other traffic, or adverse impact on other traffic*. Problems that if addressed will be beneficial to both cyclists and motorists, i.e. groups A and B in Table 5.1, should clearly be given priority. Examples of such problems are filling potholes, removing unsmooth patches, improving drainage, or improving at-grade railroad crossings. Other solutions that are relatively inexpensive and pose only a minimal adverse impact on other traffic could also be addressed. These include solutions such as remarking lanes to create a wider outside lane. The nineteen problems selected, as listed earlier are believed to be in groups A, B, or C. A detailed discussion of these problems, their remedial solutions, and associated costs follow.

1. Surface Irregularities

The most common surface irregularities, which also pose the greatest risk to cycling include potholes (Figure 5.2), ruts, and wide longitudinal pavement cracks (Figure 5.1). These problems are examples of category A type problems as they are not only hazardous to cycling but also greatly compromise the integrity of the pavement structure and are relatively inexpensive to fix. Therefore, they should be immediately addressed. Roadways with regular bike traffic should especially be inspected more frequently.

Table 5.1 Classification of Remedial Solutions by Cost and Adverse Impact

	Inexpensive	*Costly*
Beneficial to other traffic	A	B
Minimum adverse impact on other traffic	C	D
Adverse impact on other traffic	E	F

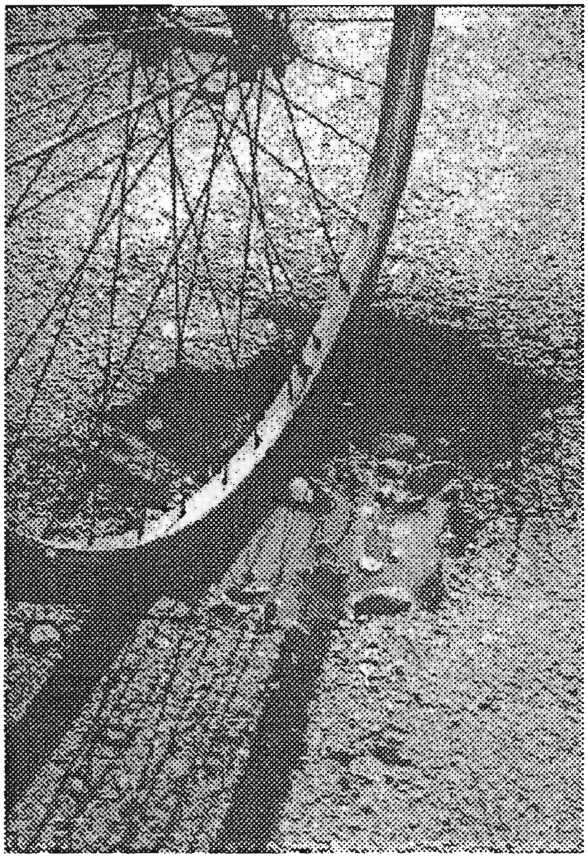


Figure 5.1 Potholes can Damage Bicycles and Cause Loss of Control

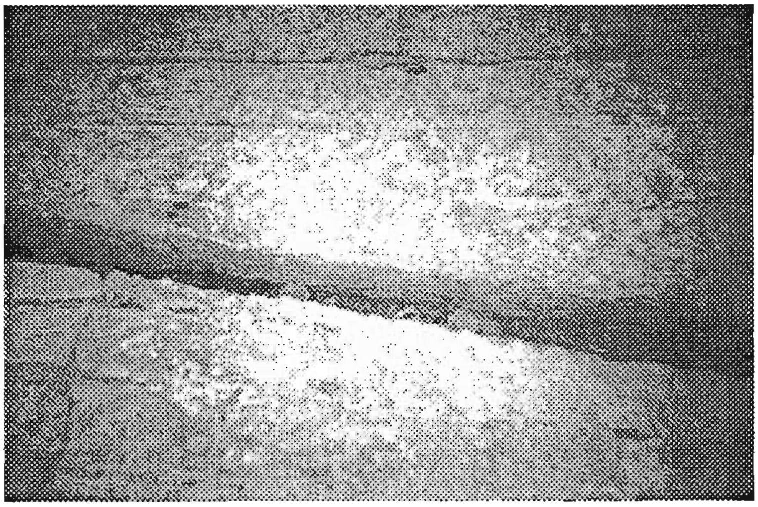


Figure 5.2 Pavement Cracks Wider than 7 mm can Trap Bicycle Tires

Table 5.2 Typical Costs for Various Surface Repairs

Typical Cost and Time (1993 $)

	Lower [1]	Upper	Function Codes [2]
Resurfacing (concrete) [3]	$ 5 /sq. yd.	$ 8 /sq. yd.	360
Resurfacing (asphalt)	$ 1.75 /sq. yd.	$ 250 /sq. yd.	110, 120 211, 212, 213
Sealing cracks (concrete)	$ 50 /yd.	$ 500 /yd.	320
Sealing cracks (asphalt)	$ 1.25 /ft.	$ 1.75 /ft	221, 222, 231 232, 233, 234
Repair spalling (concrete)	–	–	340
Filling potholes (asphalt)	$ 50 /hole	$ 500 /hole	241, 242
Pothole repair (asphalt)	0.5 person hr,	1 person hr,	–

[1] Cost and time estimate provided by workshop participants.

[2] Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT.

[3] Small scale resurfacing.

1.0 feet = 0.3048 meters

The solution procedures for these problems are well-established and include filling the potholes, resurfacing the rut area, and sealing the cracks. Currently, most TxDOT Districts seal pavement cracks wider than about 20mm. **This practice should be revised to include cracks 7 mm or wider to accommodate cyclists.** Table 5.2 provides unit cost estimates for these suggested solutions. These estimates are based on 1993 dollars and are extracted from the Texas Department of Transportation's Routine Maintenance Annual Report.

2. Sand, Gravel, and Debris on Roadway Surface

These problems can also be classified as category A problems as they are relatively inexpensive to address and are beneficial to motorists as well. Gravel, sand, or debris could substantially reduce surface skid resistance for all traffic. They could also increase frequency of incidents of broken windshields for motorists and flat tires for motorists and bicycles.

Sources of roadway debris, sand, and gravel include sanding operations to de-ice bridges and overpasses, unpaved driveways, runoff water, dirt and debris from commercial trucks, and accidents. A primary means of mitigating this problem is to institute a regular roadway sweeping program, particularly for designated bike routes and roadways expected to be frequented by cyclists. To date, many Texas cities have no systematic street sweeping program. Unpaved driveways, particularly along bike routes, should also be paved. When driveway permits are issued for warehouses, loading docks, and other facilities used by commercial trucks, truck wash areas could be required. Washing commercial trucks before they leave these locations would prevent dirt and debris from tracking onto the roadway.

Use of wide outside lanes 4.6 m to 4.9 m wide to where possible would afford cyclists, among other benefits, additional maneuverability to avoid debris. It should however be noted that when wide outside lanes are striped for a separate bicycle lane, motor vehicles would not drive on that part of the pavement and would instead brush roadway debris onto the bicycle lane. Therefore, if a wide outside lane is used, striping it for a designated bicycle lane is not recommended. Finally, a line of communication would need to be established through which cyclists and other road users could report roadway surface problems to the maintenance crew. Such a program has been successfully implemented in a number of cities, including Seattle and Dallas. The costs associated with the various treatments discussed above are shown in Table 5.3.

3. Catch-Basins with Parallel Bar Grates

Drainage catch-basins with bars parallel to the roadway travel path (Figure 5.3) are a serious hazard to cycling and must be remedied on a priority basis. The City of Dallas, for example, let a contract in March 1995 to replace such existing grates with a safer design similar to that shown in Figure 5.4. The replacement cost in the Dallas project averaged about $280 per grate replacement (Table 5.4). Additionally, TxDOT calls for a bicycle-safe grate with perpendicular slots on new designs.

Among the potential solutions is the retrofitting of such existing grates with both longitudinal and horizontal bars to minimum design spacing specifications. In such retrofit, hydraulic efficiency should not be overlooked. A more costly alternative (Table 5.4) is to replace the unsafe grates with a criss-cross or angled slot design (FHWA, 1993) In doing so, uniformity of slot orientation should be maintained to reinforce cyclists expectations of the hazards involved. These grates should be secured to the inlet structure/frame by tack welds or bolts to prevent "easy" removal but allow cleaning and maintenance of the drainage structure. One option is to design the grate with an attachment such as 13 mm diameter stainless steel five-sided bolts to prevent unauthorized removal. Alternatively, design specifications could discourage the use of grates on pavement surface in favor of curb-opening type inlets.

4. Curb-Opening Catch-Basins with Steep Entry Slopes

Curb-opening catch basins with steep slopes leading to the inlet throat pose a significant hazard to cycling (Figures 5.5 and 5.6). These inlets should be offset from potential bicycle wheel paths and should be designed with milder and longer slopes to the inlet throat. Recessed inlets are one solution to this problem (Figure 5.7). However, some recessed inlets may not be hydraulically efficient. Moreover, inlets should be recessed only when sidewalk space is not encroached (Figure 5.8). In new design, 450 mm to 600 mm of space should be allowed in the right-of-way between the sidewalk and the pavement edge for recessed inlets. Finally, recessing short inlets ($\leq$ 3 m) is generally a safe design. However, longer recessed inlets could pose a problem to motorists who may consider the curb as a delineator of the outside lane. In such cases vehicles could jump the curb at the end of the recessed inlet.

5. Bicycle Insensitive Signal Detectors

Pavement-embedded loop detectors for actuated signals are often not sensitive enough to detect bicycles. This is the case for both magnetic, magnetometer, and inductive loop technologies. Figure 5.9 presents a number of loop configurations with bicycle detection capability (FHWA, 1993). An alternative to loop detection is the use of cyclist activated push-buttons, which are common in Europe (Figure 5.10). However, the presence of such rigid obstacles near the pavement driving edge should be a concern regarding the motor-vehicle traffic safety. Table 5.5 presents typical costs of loop detector and push-button detector installations. Other potentially useful detection technologies include motion detectors or infrared beams which

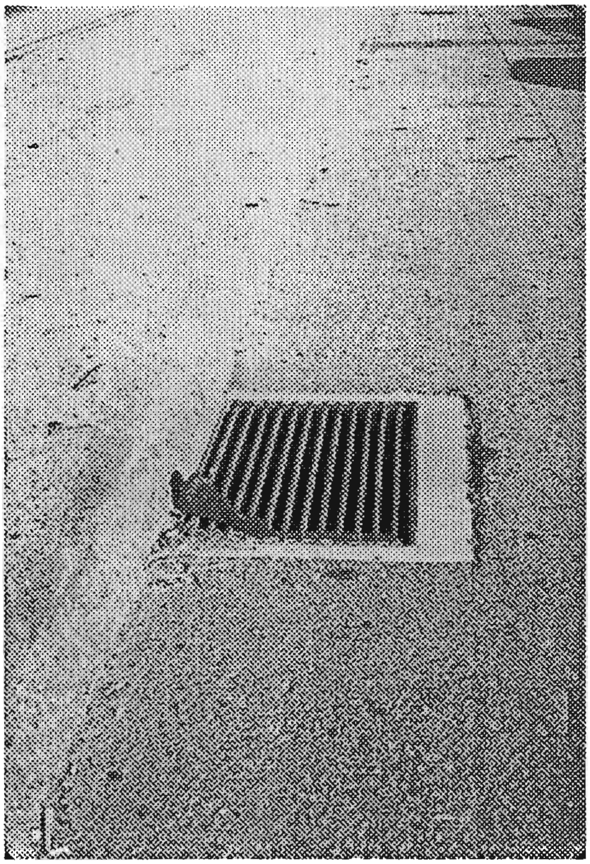
Table 5.3 Lane Widening and Surface Clean-up Unit Costs

Typical Cost (1993 $)			
	Lower [1]	Upper	Function Codes [2]
Widen lane (1 ft.) ≈ urban	$ 12,000 /mile	$ 21,000 /mile	245
Widen lane (1 ft.) ≈ rural	$ 10,000 /mile	-	245
Edge repair	–	-	270
Street Sweeping	$ 40 / mile	-	521, 522, 524
Surface driveways	$ 3.50 /sq. yd.	$ 4.50 /sq. yd.	593, 594

[1] Cost estimate provided by workshop participants.

[2] Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT.

1.0 feet = 0.3048 meters
1.0 miles = 1.61 kilometers



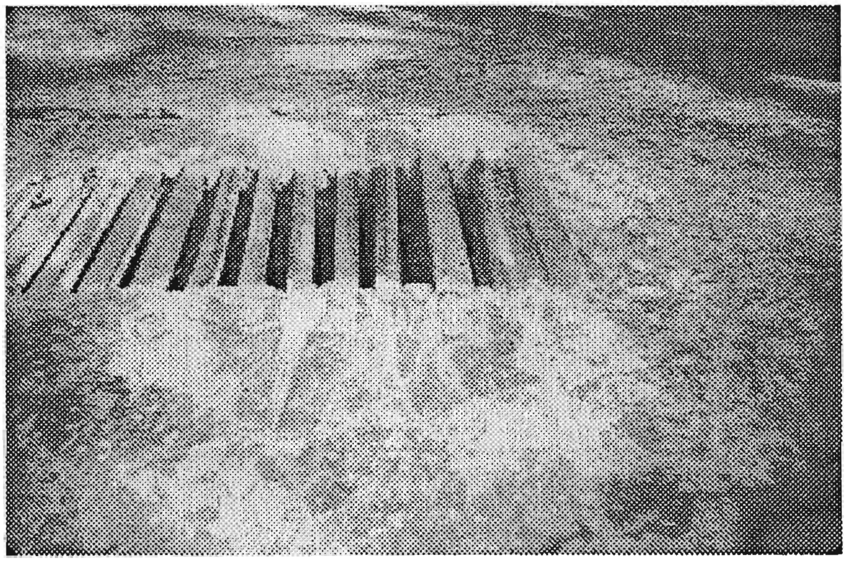


Figure 5.3 Two Examples of Wheel-trapping Parallel-bar Grates

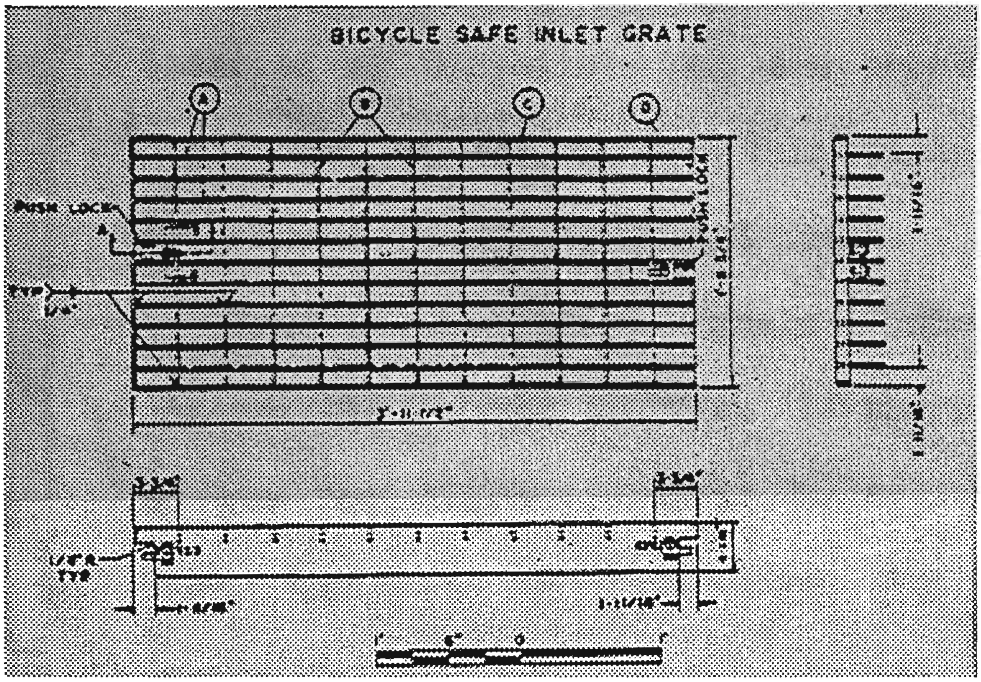


Figure 5.4 Example of a Bicycle-safe Inlet Grate

Table 5.4 Unit Costs and Man Hours Associated with Drainage and Inlet Grates

Typical Cost (1993 $)			
	Lower [1]	Upper	Recent Cost [2]
Replace grate ($ / grate)	$ 200	$ 300	$ 280
Replace grate (person-hour)	–	2	–
Realign grate (person-hour)	1	4	–
Grate inlet ($ / grate)	$ 240 ea.	$ 280 ea.	–
Grate inlet (person-hour)	0.5	1	–

[1] Cost estimate provided by workshop participants (includes labor and material).

[2] Dallas District March 1995 contract.

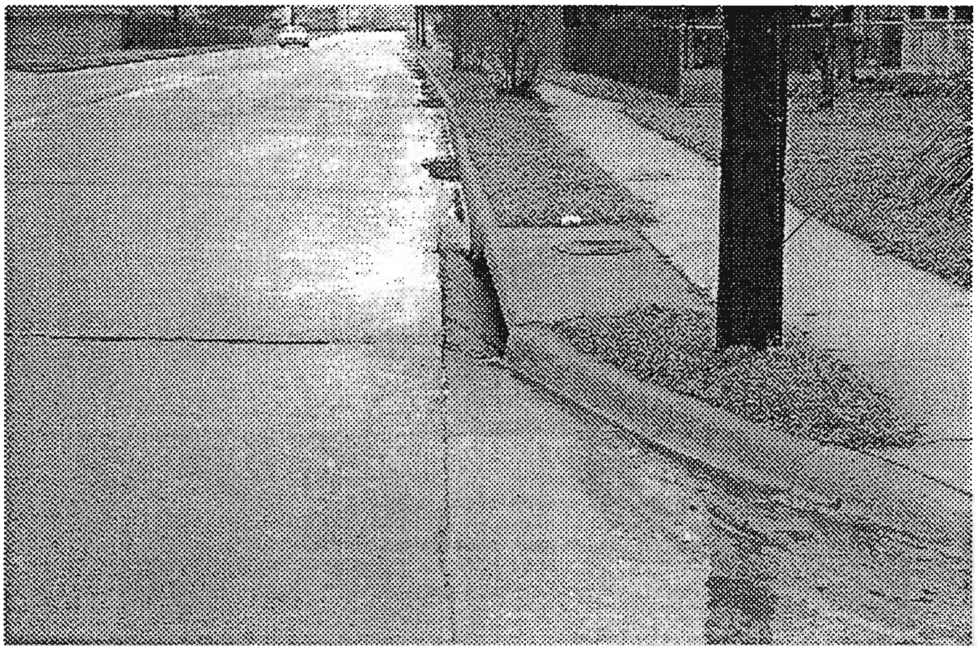


Figure 5.5 Example of an Inlet with a Steep Slope Leading to the Throat

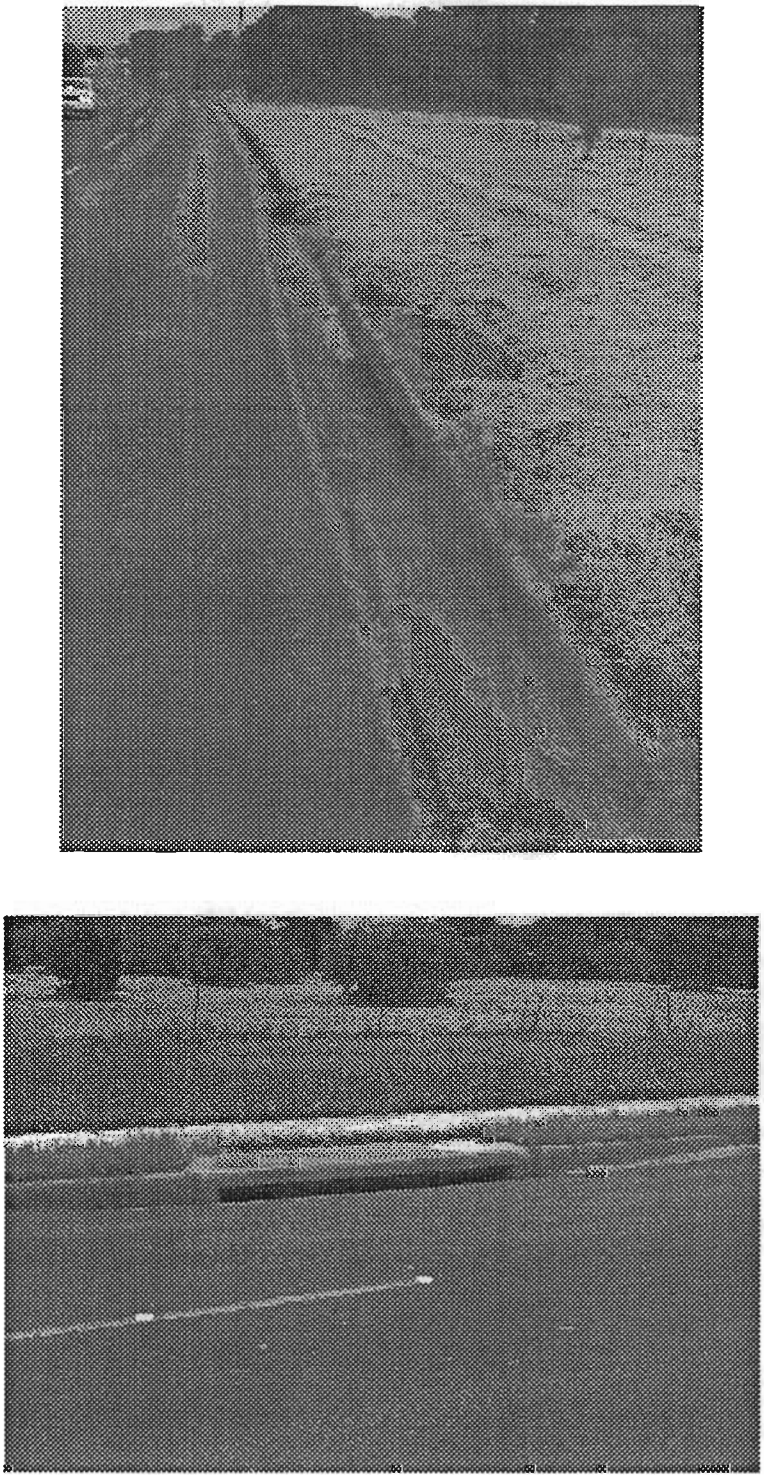
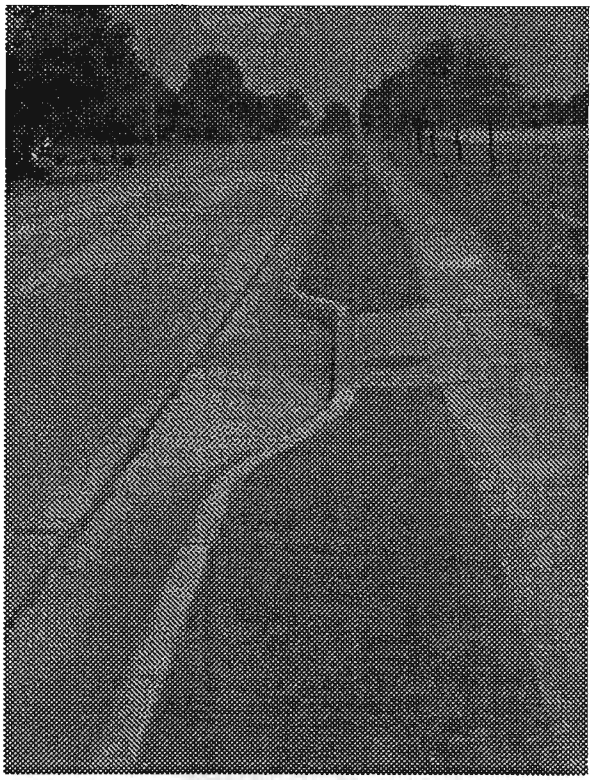


Figure 5.6 Another Example of an Inlet with a Steep Slope Leading to the Throat



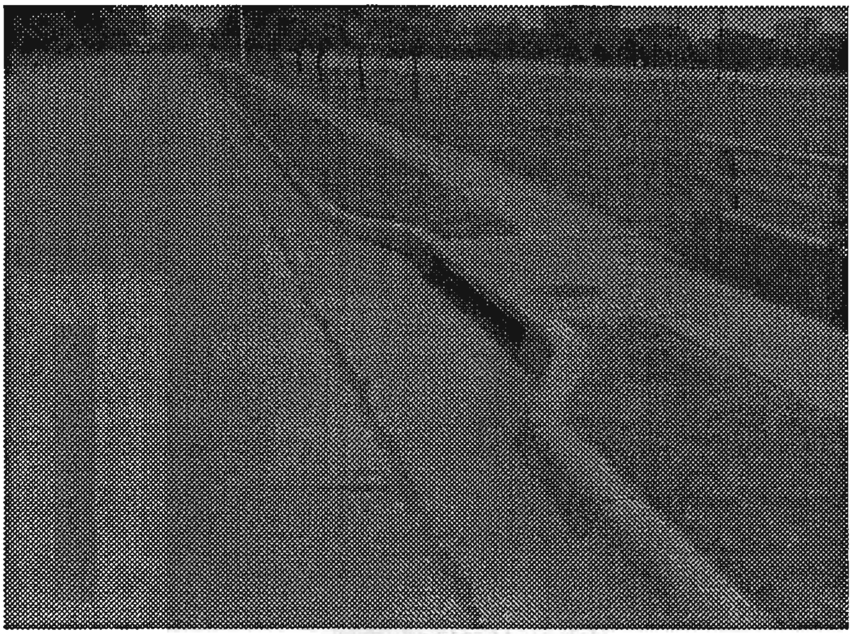


Figure 5.7 A Recessed Inlet that does not Encroach on the Sidewalk Space

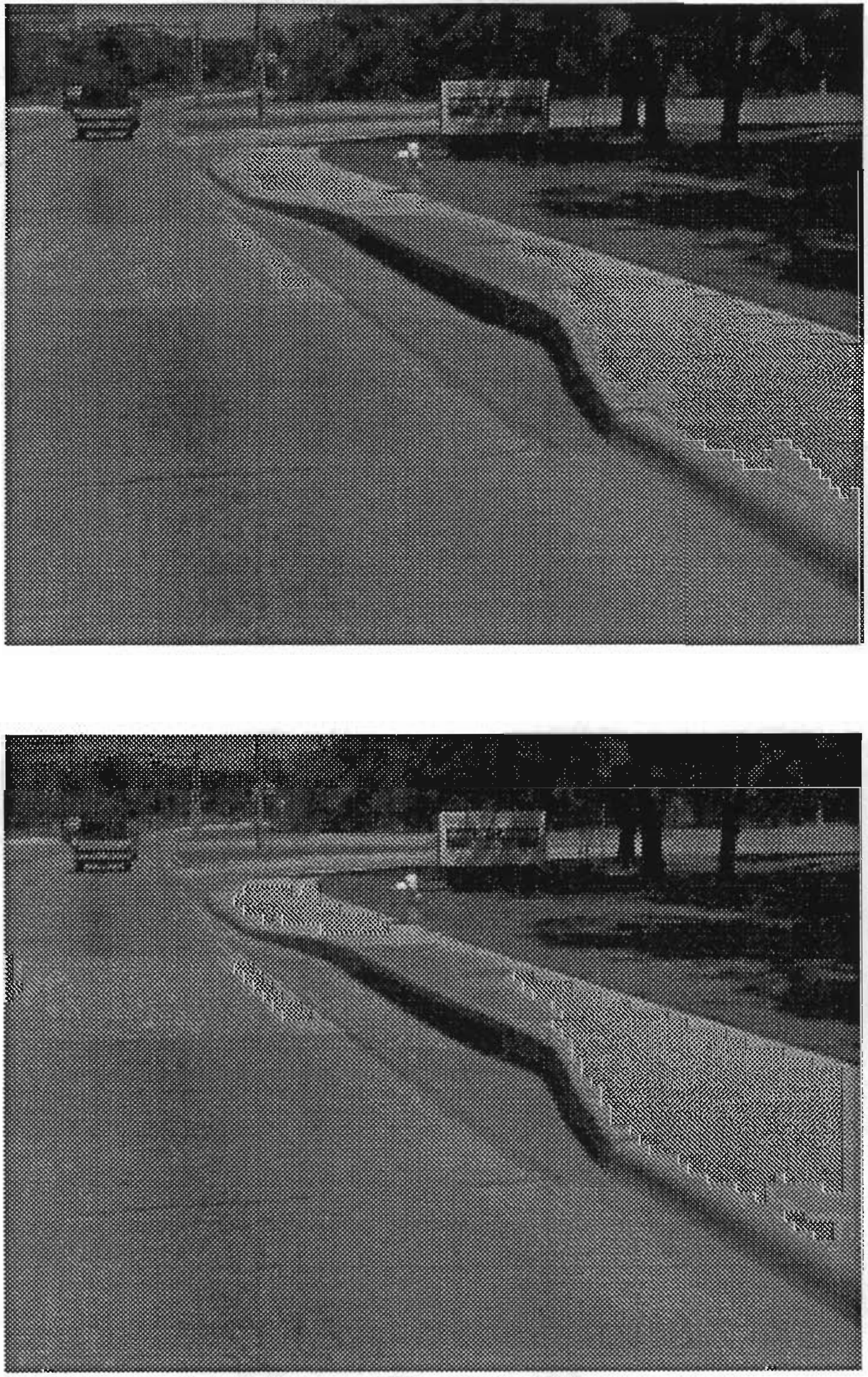


Figure 5.8 A Recessed Inlet with a Gentle Slope, but Encroaching on the Sidewalk

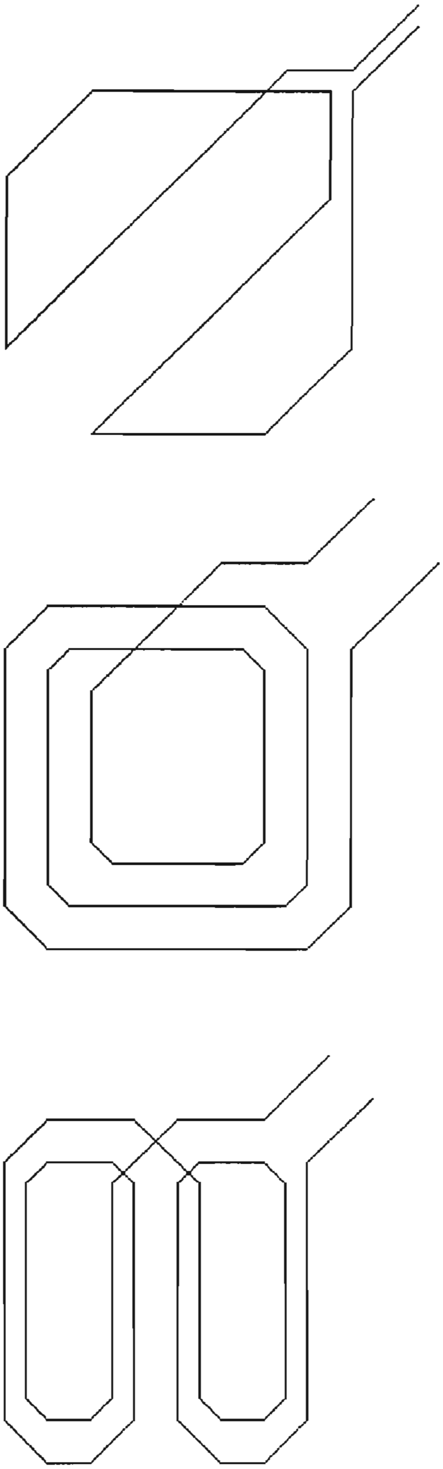


Figure 5.9 Loop Types for Bicycle Detection

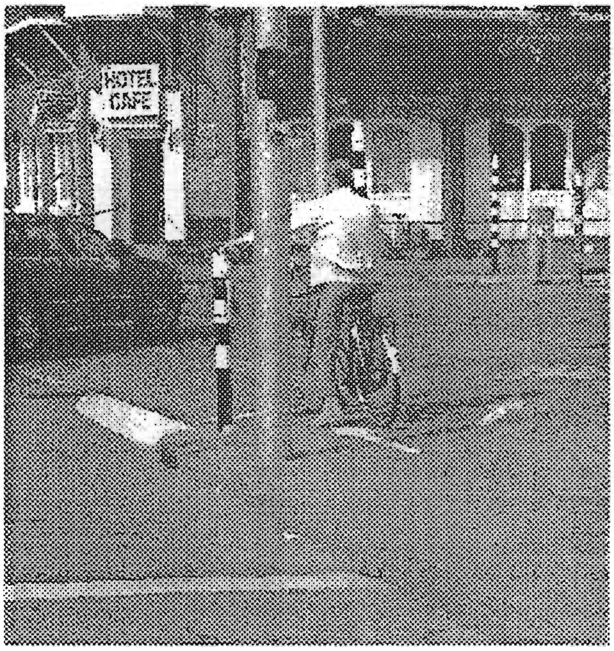


Figure 5.10 A Push-button System for Cyclists

Table 5.5 Cost and Labor for Detector Installation

Typical Installation Cost and Time (1993 $)

	Lower	Upper
Loop Detector (cost) [1]	$ 4 /ft.	$ 6 /ft.
Loop Detector (time)	2 person-days	3 person-days
Push-button (installed)	$ 300	–

[1] Cost estimate includes equipment and installation.

1.0 ft = 0.3048 m

could activate a signal once crossed. The rate of false activations due to non-vehicular movements in the detection field (e.g. pedestrians, birds, etc.) should be a concern in the use of such detectors.

6. Short Durations of Amber and Exclusive Left-Turn Phases

Due to its limited acceleration characteristics, the gap requirement for a cyclist to cross a priority stream of vehicles could be substantially greater than motorists' requirements. A cyclist averaging 15 km/h, which is typical for standing starts, travels only 21 meters in 5 seconds of amber. This is approximately 5 meters less than the outside-to-outside curb width of a six-lane thoroughfare. Taylor in his research on yellow time requirements for bicycles (Taylor, 1993) has determined that the fifteenth percentile acceleration for bicycles is only 0.3 m/s^2.

While the remedy is seemingly in increasing the amber length to accommodate cyclists, there are practical limits on how long amber durations can be. The Institute of Transportation Engineers, for example, recommends the amber length not to exceed 5 seconds (ITE, 1992). This recommendation is closely followed by most traffic engineers as longer amber lengths greatly increase rear-end and right-angle collisions. A practical means of reducing yellow time accidents for cyclists is to provide as long an all-red clearance interval as local policies permit, hence avoiding unusually long yellow intervals (Wachtel & Pelz, 1995). Therefore, at locations where extending the yellow phase is not an option, an all-red phase of 1 to 2 seconds is generally an acceptable traffic engineering practice. Table 5.6 presents estimated manpower estimates for retiming a signalized intersection.

Low bicycle acceleration capabilities create similar problems for left-turning vehicles at permissive as well as exclusive left-turn phases (Figures 11, 12). However, unlike the amber time, no safety-motivated upper bound is placed on left-turn phases. Therefore, retiming signals to provide longer left-turn phases for accommodating cyclists should be considered. However, it should be emphasized that any signal re-timing actions should carefully balance the potentially conflicting interests of cyclists and other classes of road users, especially since longer clearance times and left-turn phases are likely to result in overall capacity loss and possible delay increases to other users.

7. Improperly Designed Rumble Strips

Rumble strips are pavement grooves or raised buttons laid out laterally across driving lanes or shoulders. Once driven over, they generate a jiggling sensation and noise, which warns drivers that they are leaving the road or they are approaching a low speed limit area such as a tollbooth. Rumble strips constructed with raised buttons are often referred to as "jiggle bars". Figure 5.13 shows typical jiggle bars along the outside shoulder of a freeway.

When jiggle bars are used in shoulder areas, an effective bicycle accommodation is to provide 1.2 m to 1.8 m wide channels along the outside edge of the shoulder (Figure 5.13). This includes providing a clear open path through jiggle bars used at exit and entrance gores as well as for intersection channelization. Table 5.7 lists the typical costs of removing raised buttons as well as pavement sanding and restriping, which may be necessary when jiggle bars are removed.

A more traditional rumble strip is one constructed through pavement groves laterally across the pavement. A variety of designs in terms of the groove width, depth, and spacing exist. While some of these designs represent a rough and uncomfortable ride for cyclists, other designs are tolerable. Field studies of a number of designs were conducted to assess the relative discomfort to cyclists of a number of common and experimental designs in Texas. In the latter part of this chapter, the results of this study are discussed in detail.

8. Riding Against Traffic

This problem is particularly prevalent near schools, where children often tend to ride against traffic. This dangerous behavior partly results from the common misconception about the risk of being rear-ended by motor vehicles. Bicycle accident data show that cyclists being rear-ended is an uncommon occurrence, whereas riding against traffic is the cause of a relatively much higher percent of automobile-bicycle accidents (Mattingly, 1994).

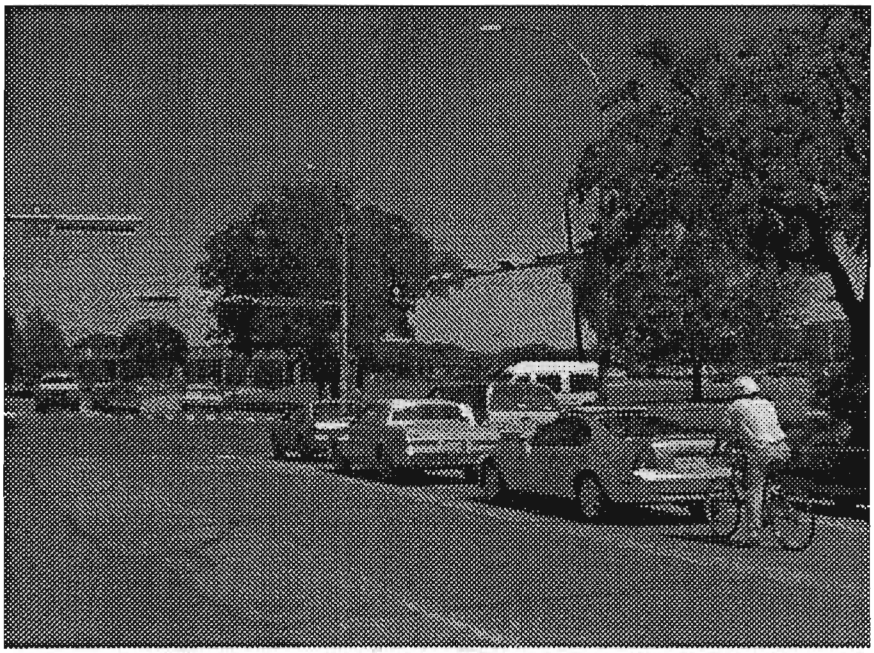
Educating the public about dangers of riding against traffic as well as rules of the road related to bicycling in general will be beneficial. Classrooms, print media, radio and television public service announcements, and defensive driving and driver's license handbooks are examples of the educational tools available.

A traffic engineering tool which could prove beneficial is the installation of "wrong way" signs, such as shown in Figure 5.14, near school zones and at other locations where such movements are anticipated. An even more effective treatment will be "Right Way" signs to be installed in tandem with the Wrong Way signs, i.e. each Wrong Way sign could be a two-sided sign where the other side shows the Right Way message. Costs associated with installation of signs are provided in Table 5.8.

9. Poor Surface Drainage

Poor surface drainage results in reduced skid resistance and accelerated pavement deterioration, particularly in cold climates. These problems affect both motorized and bicycle traffic. In addition, cyclists riding through puddles of standing water (e.g. Figure 5.15) would have little idea on how deep the standing water may be. There is also the splashing water effect

Figure 5.11 Bikes Take Longer to Clear Intersection due to Low Acceleration



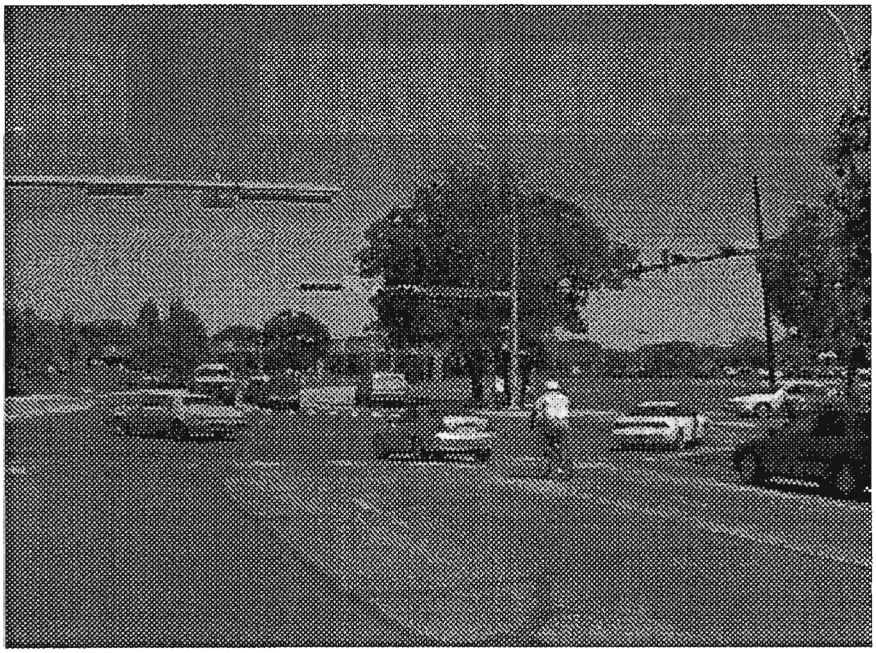


Figure 5.12 Exclusive Left-turn Phase should be Longer to Accommodate Bikes

Table 5.6 Labor Costs for Retiming Traffic Signals

Typical Time to Reprogram Controllers		
	Lower	Upper
Reprogram Controller (local)	–	2 person-hours
Reprogram Controller (central)	–	0.25 person-hours

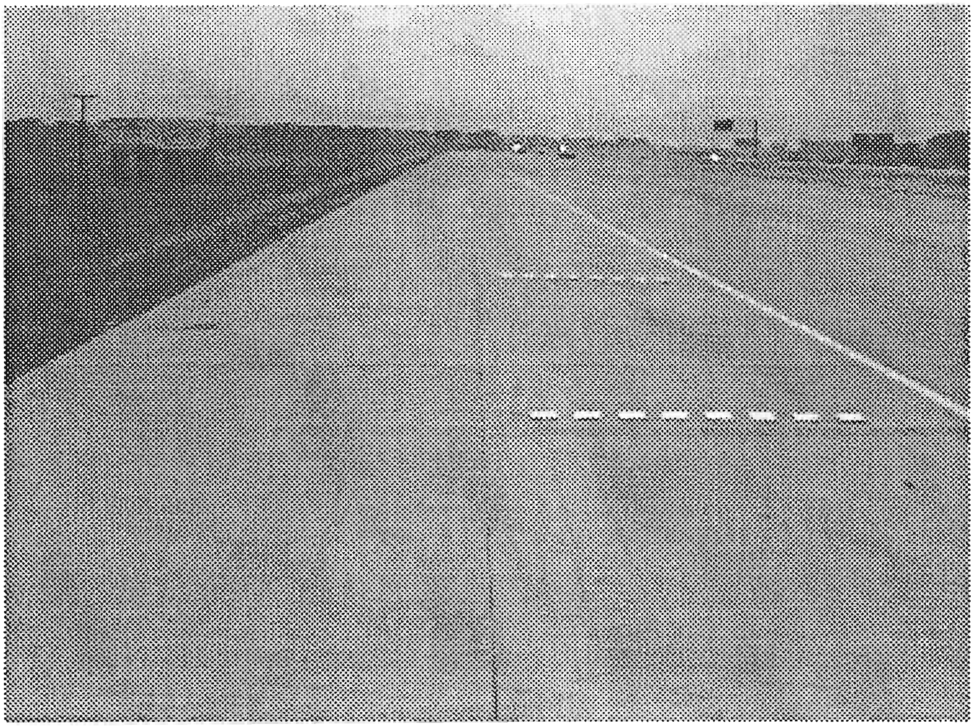


Figure 5.13 Provide a Clear Path Along Outside Edge of Shoulder

Table 5.7 Unit Costs for Removal or Installation of Rumble Strips and Jiggle Bars

	Typical Cost (1993 $)		
	Lower [1]	Upper	Function Codes [2]
Remove button	18 ¢ / button	40 ¢ / button	713,715
Remove 4" stripe	50 ¢ / ft.	–	715
Sandblast	10 ¢ / ft.	–	711
Paint	15 ¢ / ft.	–	710,713
Thermoplastic	30 ¢ / ft.	–	712
Restripe pavement	$ 1 / ft.	$ 2 / ft.	710,711,712,715
Install buttons / jiggle bars	$ 1 / button	$ 5 / button	750

[1] Cost estimate provided by workshop participants.

[2] Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT.

1.0 feet = 0.3048 meters

Figure 5.14 One Possible Design of a "Wrong Way" Sign for Bicyclists

Table 5.8 Unit Costs for Installation of Traffic Signs

Typical Costs (1993 $)			
	Lower [1]	Upper	Function Codes [2]
Install sign (1 pole)	$ 200	$ 500	732,733,734
Aluminum sign	$ 17 /sq. ft.	–	–

[1] Cost estimate provided by workshop participants.

[2] Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT.

1.0 feet = 0.3048 meters

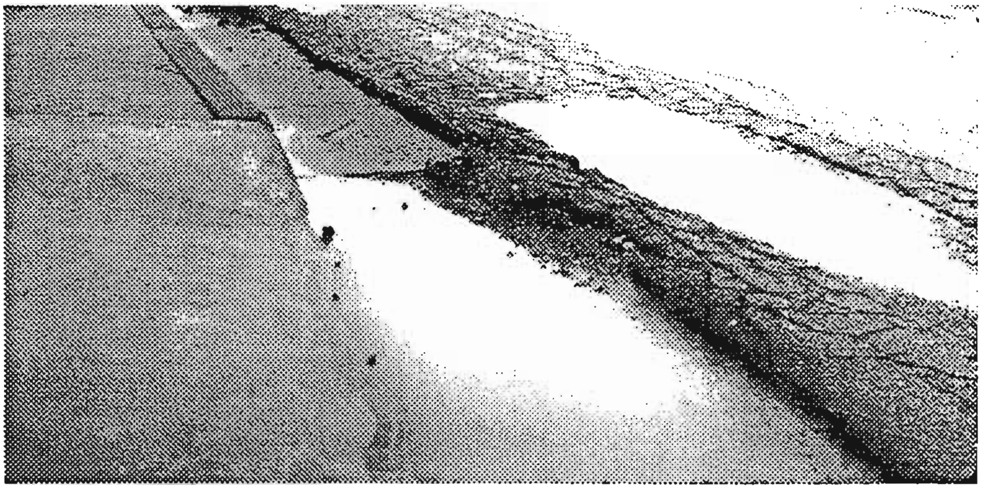


Figure 5.15 Water Puddles due to Poor Drainage in Bike Path

Table 5.9 Typical Resurfacing Costs and Time Requirements

Typical Resurfacing Time & Costs (1993 $)	Lower [1]	Upper	Function Codes [2]
Cost (per lane mile)	$ 20,000	$ 40,000	110,120
Cost (per sq. yard)	$ 200	$ 250	821,822,823
Time (person-days / lane-mile)	4	8	–
Install under-drains	–	–	130
Install curb and gutter	–	–	485

[1] Cost estimate provided by workshop participants.

[2] Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT.

from passing traffic. Although most remedies for poor surface drainage are fairly expensive, for the above reasons remediation of such problems should be a top priority item.

All such problem areas should be identified and patched or resurfaced. Patching, while a less expensive remedy, could often lead to more problems if not done properly. These include uneven riding surfaces and seepage of water into the subsurface pavement layers. Where possible resurfacing should be considered. Resurfacing cost estimates are provided in Table 5.9.

Installations of under-drains and curb and gutter may also be necessary to prevent the recurrence of drainage problems. Gutters should be designed as an integral part of the outside driving lane, without longitudinal joints. Also as a design issue, designers should consider roadway cross-slope and longitudinal grade in combination to provide proper drainage.

10. Curb-Side Parking Along Bike Routes

Curb-side parking along bike routes is a serious problem to cyclists. Not only motorists would have to cross the path of cyclists to park but also cyclist's path could be encroached on by opening doors. This is a fairly difficult problem to address, particularly when considering the potential adverse impact on motorized traffic. Possible solutions include:

1. Provide dedicated bike lanes to the left of the parking lane
2. Widen the driving lane adjacent to the parking lane to 4.6 m to 4.9 m
3. Remove the parking lane on one side and widen the outside lane on the other side
4. Prohibit curb-side parking

Major concerns in implementing any of these solutions are the right-of-way acquisition cost and the adverse impact on motorized traffic. Right-of-way cost becomes a significant factor when existing roadway width is not sufficient for restriping and maintaining minimum lane widths. Table 5.10 provides costs associated with restriping as well as pavement widening.

11. Crossing Wide Streets on a Two-Way Stop Sign

Due to the limited acceleration of bicycles, as discussed in item 6 above, crossing wide streets on two-way stop sign is a particularly difficult maneuver. If the two-way stop sign is along a path regularly used by cyclists, consideration should be given to signalizing the intersection. Alternatively, a refuge island wide enough to shadow a cyclist could be provided. Providing such an island is generally expensive and subject to right-of-way availability. In such instances signalization may be a less expensive solution. Table 5.11 provides cost estimates for signalizing an intersection. These estimates do not include the operational costs associated with additional motorist delay due to installation of signals. Such adverse impacts could be very expensive.

Table 5.10 Costs Associated with Pavement Restriping and Widening

Typical Costs (1993 S)			
	Lower [1]	Upper	Function Codes [2]
Remove 4" stripe	50 ¢ / ft.	–	715
Sandblast	10 ¢ / ft.	–	711
Paint	15 ¢ / ft.	–	710,713
Thermoplastic	30 ¢ / ft.	–	712
Widen street (1 ft. width / mile)	$ 12,000	$ 21,000	245
Land value (urban) / sq. ft.	$ 5	$ 10	–

[1] Cost estimate provided by workshop participants.

[2] Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT.

1.0 feet = 0.3048 meters
1.0 miles = 1.61 kilometers

Table 5.11 Costs and Time Requirements for Installation of Traffic Signals

Typical Signalization Costs and Time (1993 $)

	Lower[1]	Upper	Function Codes[2]
Costs (T intersection)	$ 20,000	$ 40,000	–
Costs (X intersection)	$ 25,000	$ 50,000	743
Time (person-days)	6	9	–

[1] Cost estimate provided by workshop participants (includes labor and material).

[2] Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT.

Figure 5.16 Barriers and Fences Guide Bikes Through a Construction Zone

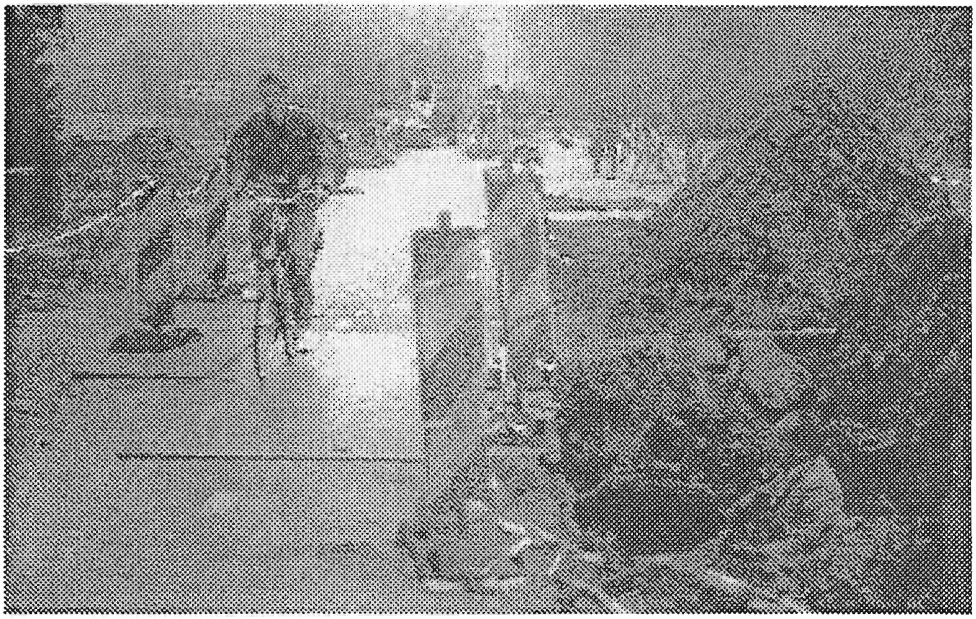


Figure 5.17 Smooth Road Surface Maintained with Planks in a Construction Zone

12. Cycling Through Roadway Workzones

Workzones are particularly inhospitable to cyclists. Not only are geometric widths generally more restricted, but also a workzone is a major source of debris. Preferably, cyclists should be detoured away from workzones when feasible. If doing so would mean very long detours, a separate bike lane through the workzone should be erected. Such lanes should be properly signed and protected by means of barriers. An example is shown in Figure 5.16. Removable planks could also be used to maintain smooth debris-free surfaces through workzones (e.g. Figure 5.17). When neither detours nor dedicated lanes are feasible, consideration should be given to prohibiting bicycle traffic through workzones.

13. Cycling Along High-Speed or High-Volume Roadways

Cycling through roadways carrying a high volume and/or high speed traffic is highly stressful to cyclists (I.T.E., 1993). Roadways with a curb lane peak hourly volume greater than 325 vphpl and average speeds of 64 km/h or greater can be classified as high speed/high volume roadways, producing high stress levels of 4 to 5 on a 1-5 scale (NCTCOG, 1995). While presenting a stressful condition (e.g. Figures 18, 19), these roadways generally constitute the most direct paths to cyclists' destinations.

Remedial solutions include widening the outside lanes to 4.6 m or 4.9 m in urban areas and providing exclusive separated bike paths in rural conditions. Exclusive bike paths in rural areas are considerably less expensive per square meter than contiguous roadways designed for 40-ton vehicles (Table 5.12).

14. Bike Paths Discontinued By A Curb

Bicyclists should generally be discouraged from using sidewalks. Riding on sidewalks could result in serious conflict with pedestrians. Children, however, have a tendency to ride on sidewalks, particularly near school areas. At times, sidewalks in these and other locations have a curb ramp at one end while the other end is discontinued by a curb. In general, such situations should be avoided as they are in direct conflict with Americans with Disabilities Act requirements. Table 5.13 summarizes costs associated with constructing curb ramps.

15. Insufficient Lighting

Roadways that are expected to accommodate cyclists at night should be well-lit. The height and spacing of light fixtures is critical, however. Light poles that are spaced too far apart create strobes (Figure 5.20) that are also hazardous to nighttime cycling.

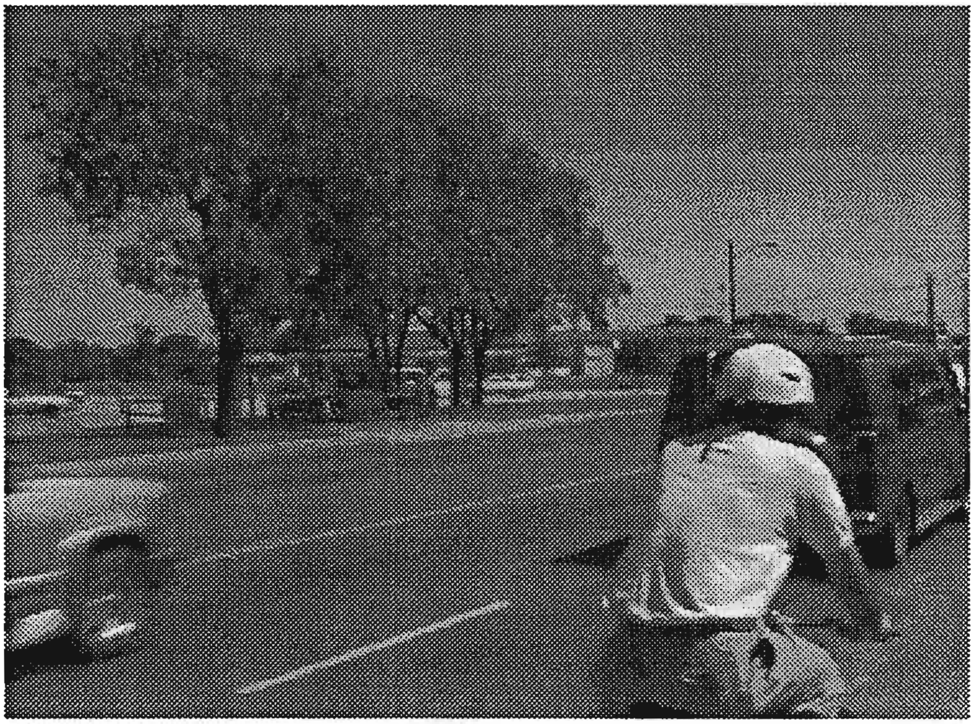


Figure 5.18 Riding in High-speed Traffic can be Stressful

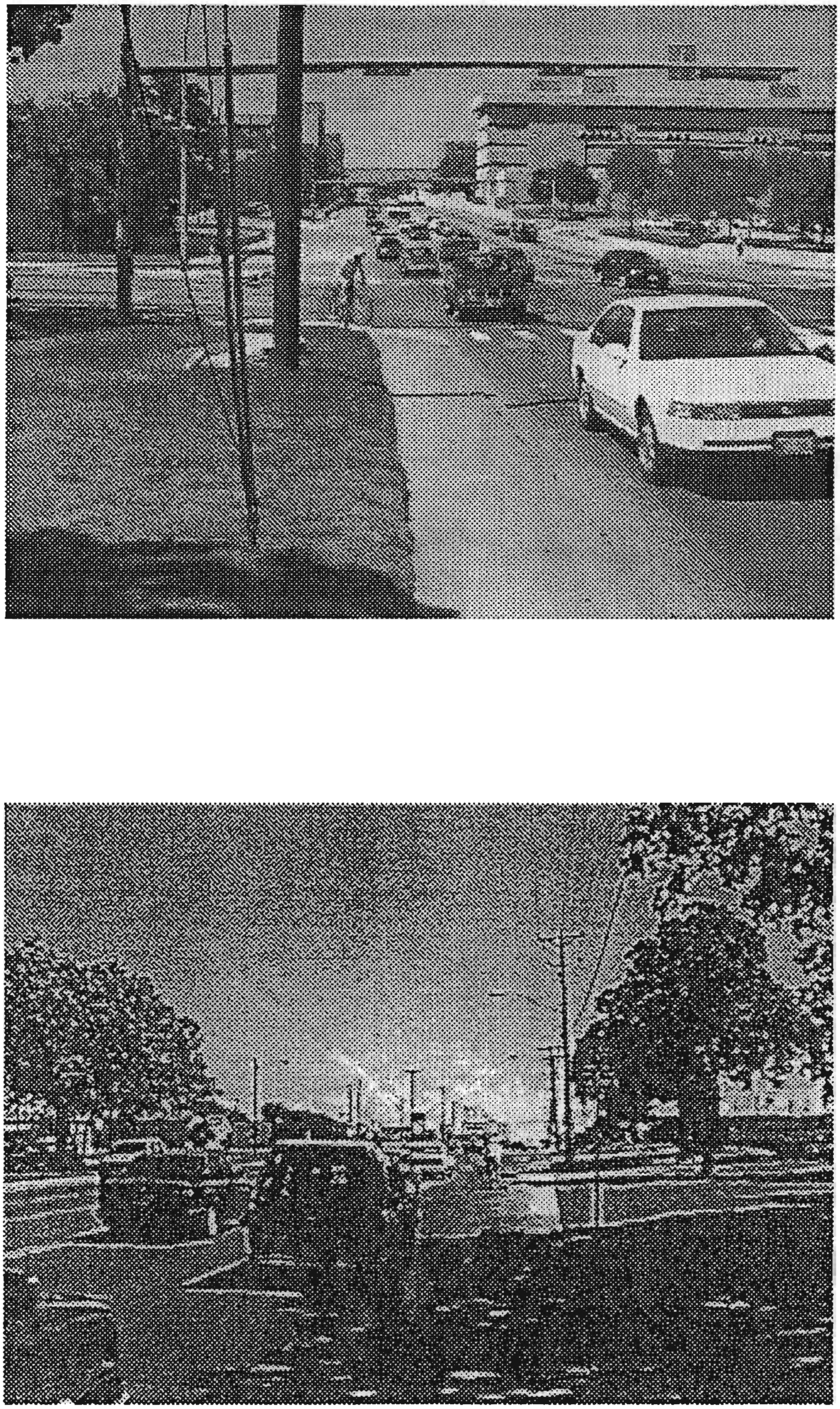


Figure 5.19 Riding in High-volume Traffic can be Stressful and Dangerous

Table 5.12 Roadway Widening Costs and Labor

Typical Cost and Time (1993 $)			
	Lower [1]	Upper	Function Codes [2]
Widen street ≈ urban (1 ft. / mile)	$ 12,000	$ 21,000	245
Widen street ≈ rural FM (1 ft. / mile)	$ 10,000	–	245
Time (person-days / mile)	4	8	–

[1] Cost estimate provided by workshop participants.

[2] Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT.

1.0 feet = 0.3048 meters
1.0 miles = 1.61 kilometers

Table 5.13 Unit Costs for Construction of Wheelchair Ramps at Curbs

Typical Ramp Costs (1993 $)	Lower [1]	Upper
Ramp from curb to pavement (per feet of curb)	$ 3	$ 4
Ramp from curb to pavement (per sq. yd.)	$ 35	-

[1] Cost estimate provided by workshop participants.

1.0 feet = 0.3048 meters

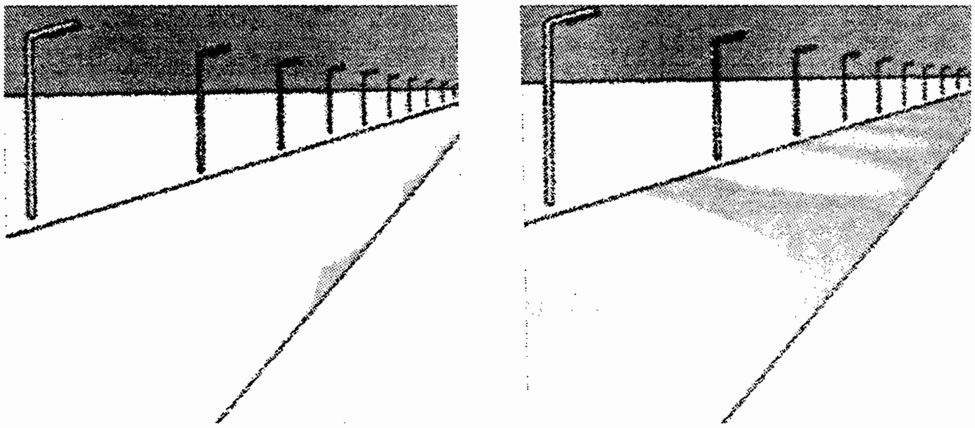


Figure 5.20 Strobe Effects (figure on the right) should be Avoided by Optimizing Light Fixture Spacing to Provide a Uniform Light Intensity (figure on the left)

Table 5.14 Typical Street Lighting Costs and Labor

Typical Lighting Cost and Time (1993 $)			
	Lower [1]	Upper	Function Codes [2]
Street lighting ≈ cost / mile	$ 33,000	–	742
Street lighting ≈ cost / pole	$ 1,500	$ 2,000	–
Street lighting ≈ person-days / pole	4	6	–

[1] Cost estimate provided by workshop participants (includes labor and material).

[2] Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT.

1.0 feet = 0.3048 meters

An acceptable lighting treatment is sodium lights spaced on 12-meter poles at 75 m-90 m with 250 watts. This arrangement will provide sufficient lighting for two lanes. Therefore, on a two lane street, light fixtures will be needed only on one side of the roadway. Table 5.14 provides typical costs for street lighting.

16. Roadside Obstructions with Inadequate Vertical Clearance

The most common roadside objects that could restrict vertical clearance to cyclists include traffic signs that are too short and overgrown tree branches. Mitigation measures should include quick identification of such cases, relocation of signs that are too short, and regular trimming of trees and other overgrown vegetation, particularly along bike paths.

To implement such measures, an inspection program should be initiated to identify all signs lower than 2.1 m and to replace or relocate them so that they no longer pose a problem. Another project to be considered is an "Adopt-A-Bikepath" program. In this program bicycle groups and other interested entities help in maintenance of a bike path by regularly inspecting the paths and reporting such hazards as badly placed signs, overgrown vegetation, etc. Regular trimming of trees and other vegetation along streets and bike paths should also be implemented. Table 5.15 summarizes the person-hours of effort required for trimming.

17. Poorly Designed Bicycle Underpasses

Common problems related to underpasses for cyclists include narrow widths, insufficient lighting, and sharp entrance/exit horizontal curves. Several State Guidelines (e.g. Arizona, North Carolina) specify 3.1 meters minimum widths for bike path underpasses. However, experience with these underpasses shows that 3.1 meters can be dangerously narrow (Elliott, 1995). Entering from bright sunlight into a tunnel, cyclists tend to shy away from the dark interior walls and move towards the center of the path. Moreover, many underpasses have long and/or curved entry approaches (e.g. Figure 5.21), and cyclists gain speed going down into the underpass. Oncoming cyclists also gain speed as the approach in the other direction for the climb out. This is the recipe for a common accident scenario where cyclists using an underpass approach each other at high speed, one blinded by the darkness, the other blinded by the light, and both riding near the center line.

Mitigation measures should therefore include sufficient underpass lighting (at least 150 kw). The width of the underpass should be a minimum bike path width plus 0.6 m of lateral clearance on each side, or bikepath width plus 1.2 m. Where such widths are not attainable, a minimum width of 3.6 m should be provided.

Table 5.15 Labor Needs for Right-of-Way Maintenance Activities

	Typical Time		
	Lower [1]	Upper	Function Codes [2]
Trim tree (person-hours/tree)	2	3	552
Remove signs	–	–	580,581,734
Install signs	–	–	732,733
Adopt-A-Highway	–	–	525

[1] Time estimate provided by workshop participants.

[2] Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT.

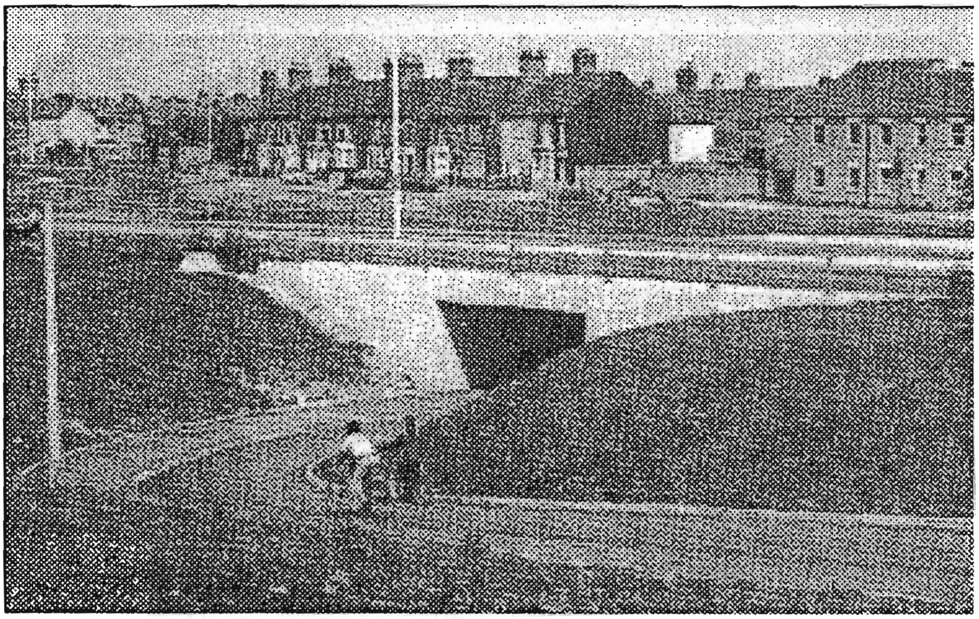


Figure 5.21 Hazardous Sharp Curve at the Bottom of a Hill Leading to a Dark Underpass

Table 5.16 Cost and Labor for Installation of Light Fixtures for Underpasses

Typical Cost and Time (1993 $)			
	Lower [1]	**Upper**	**Function Codes** [2]
Install light fixture (sodium vapor)	$ 200 each	$ 300 each	–
Install light fixture	$ 450 each	$ 500 each	–
Install light fixture ≈ (person days)	2	4	–
Flashing becons	–	–	739

[1] Cost estimate provided by workshop participants (includes labor and material).

[2] Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT.

While sharp, steep entrance ramps to underpasses should be avoided in new designs, such existing ramps could be somewhat rectified through caution signs and flashing beacons. Signs such as "Caution, Tunnel Ahead". "Slow", or "Ride to Right" should be installed upstream of the underpass entrance. Furthermore, tunnel ceiling and walls should be painted white and daytime illumination in tunnels should be increased, especially at tunnel entrances (may need to lower illumination levels at night to decrease contrast with the dark (Elliott, 1995). Table 5.16 shows typical costs for lighting fixtures and installation.

18. Slippery-When-Wet Pavements

Slippery-when-wet pavements could be due to a variety of sources. Main causes include motor oil spillage-especially near intersections, improper asphalt mix design resulting in asphalt bleeding, polished pavement surface texture, and friction reducing paint used in pavement marking.

Locations where reduced pavement friction is particularly problematic are at horizontal curves, downhill grades, and immediately upstream of intersection stop lines. Every effort should be made to identify the locations and the causes of pavement slipperiness at these critical areas. Mitigation measures vary depending on the cause of friction loss. They include use of thermoplastic material for pavement marking, slurry seal (sand-asphalt) or seal coat to provide texture, and grooving rigid pavements at the time of laying the pavement to enhance skid resistance. Table 5.17 provides cost estimates for some of the above solutions.

19. Poorly-Designed At-Grade Railroad Crossings

The combination of high tire pressure, high suspension stiffness, short wheelbase, and high center of gravity make bicycles difficult to control when the rider hits even a small surface bump or depression. One such condition is an at-grade railroad crossing, which could easily cause loss of control of bicycles. The problem is further aggravated if the railroad crossing is not at a right-angle to the roadway it crosses, as a bicycle tire could easily be trapped by the flangeway.

Typical remedies include use of rubberized railroad crossing with flangeway fillers (e.g. Figure 5.22) or the use of concrete pads. This allows the railroad crossing to be level with the pavement surface without significant gaps between the railbed and the rail. Use of the rubberized railroad crossing treatment should be coordinated with railroad companies and should be limited to low-speed, lightly traveled tracks. On high-speed trunk railway lines, trains risk derailment at locations where fillers are used as fillers do not compress fast enough (FHWA, 1993). The use of concrete pads is preferred over rubberized treatment by cyclists (FDOT, 1995) because the rubber is compressed over time in the locations where car tires typically ride over them, creating an

Table 5.17 Unit Costs for Various Pavement Maintenance Activities

Typical Costs (1993 $)			
	Lower [1]	Upper	Function Codes[2]
Milling	–	–	252
Groove rigid (per sq. yd.)	> $ 1	–	–
Asphat bleeding	–	–	260
Remove layer ≈ flexible (sq. yd.)	$ 1	–	232
Slurry seal (per ton)	$ 140	–	231

[1] Cost estimate provided by workshop participants.

[2] Routine Maintenance Annual Report: Fiscal Year 1993. TxDOT

1.0 feet = 0.3048 meters

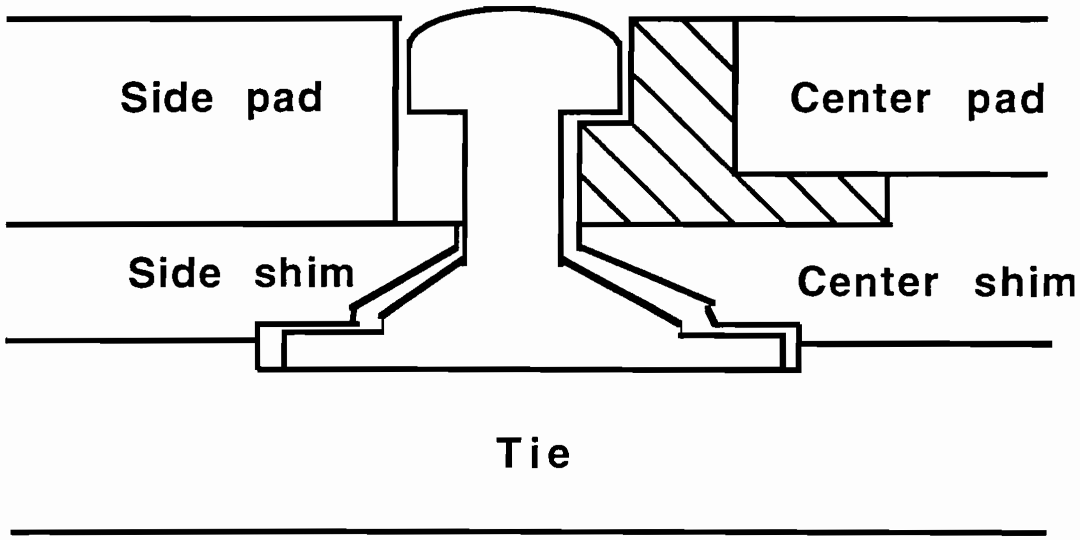


Figure 5.22 Rubberized Flangeway Filler Strip

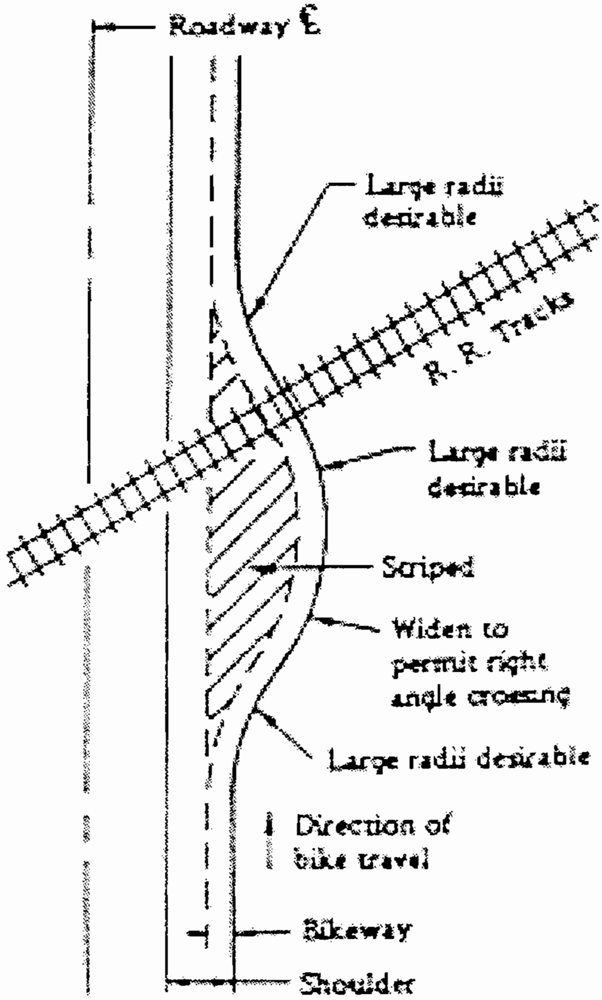


Figure 5.23 Crossing a Railroad Track at a Right Angle

uneven riding surface. Finally, at crossings which are not at a right angle, a designated bicycle crossing lane which intersects the track at a right angle should be provided (Figure 5.23).

RATING RUMBLE STRIPS

As an extension to the original scope of study, different type of rumble strips were investigated to determine the relative comfort level they offered to bicyclists.

Types of Rumble Strips

Four different types of rumble strips were studied for the purpose of relatively ranking them on a comfort scale (defined in the next section). The rumble strips shall be identified as Type 1 through Type 4. Types 1, 2, and 3 are rumble strips formed by alternating strips of flush plain pavement surface followed by depressed strips created by gouging out a small amount of the pavement surface and subsurface (all dimensions are provided). Type 4 rumble strips are conventional square buttons placed end to end.

Rumble strip Type 1 and Type 2 are located on SH 1183 just north of the junction with SH 287. SH 1183 is a rural road running North-South through Ennis. The rumble strips are located on the south-bound lane, just north of the intersection with SH 287. Rumble strip Type 1 is located about 100 meters north of the intersection; rumble strip Type 2 is located about 200 meters north of the intersection (Figure 5.24). Rumble strips of Type 3 are located on the DFW Airport Tollway, immediately upstream of all toll gates. Rumble strips of Type 4 can be normally found on outside shoulders of Interstate Highways; they are also used extensively for traffic channelization markers on city streets.

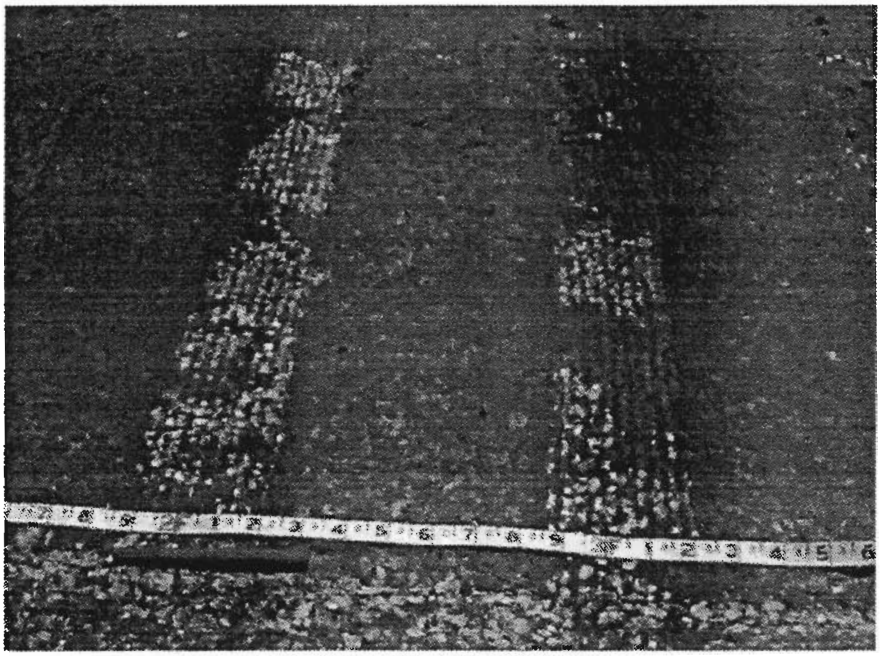
Specifications of the Rumble Strips

Type 1: 198 mm wide plain flush pavement followed by a 107 mm wide depressed stripe. The depressions are approximately 2.5 mm deep. This pattern is repeated to create the rumble strip. (Figure 5.24)

Type 2: 183 mm wide plain flush pavement followed by a 122 mm wide depressed stripe. The depressions are approximately 5.0 mm deep. This pattern is repeated to create the rumble strip. (Figure 5.25)

Type 3: 457 mm wide plain flush pavement followed by a 152 mm wide depressed stripe. The depressions are approximately 5.0 mm deep. This pattern is repeated to create the rumble strip. (Figure 5.26)

Figure 5.24 Overview of the Two Rumble Strips, Type 1 and Type 2, on SH 1183 at Ennis



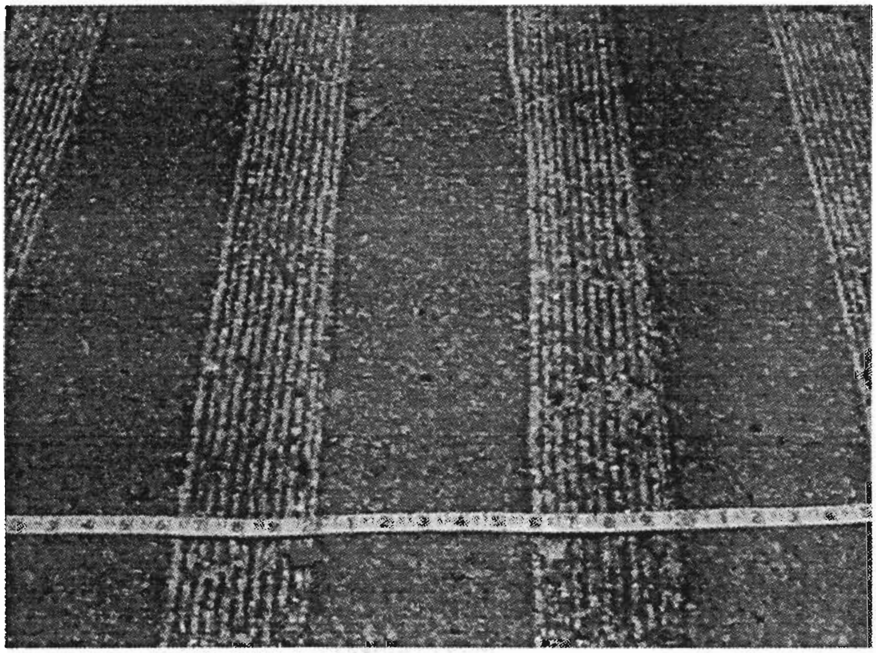
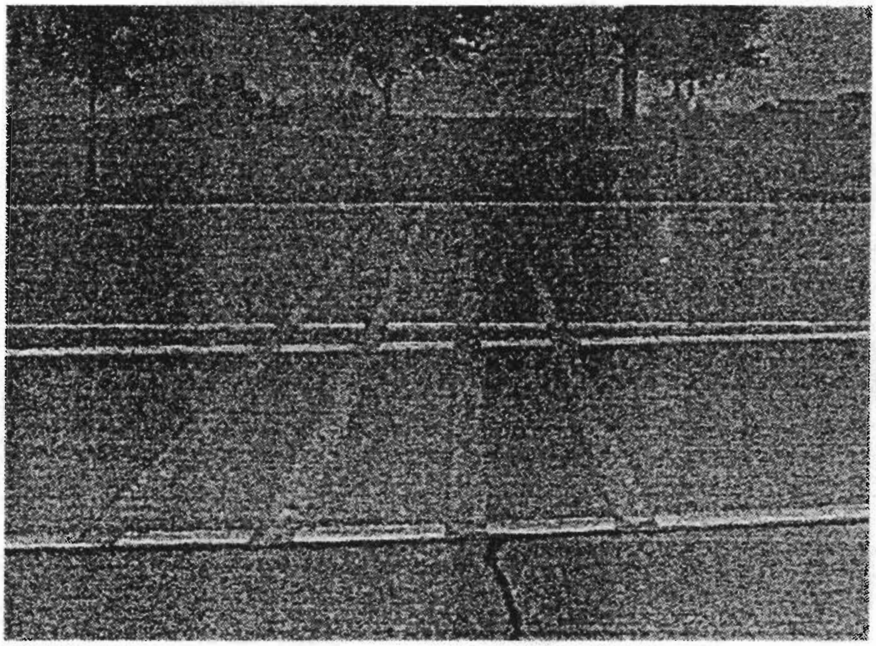


Figure 5.25 Closeup of the Two Rumble Strips Tested at Ennis. Top: Rumble Strip Type 1, Bottom: Rumble Strip Type 2



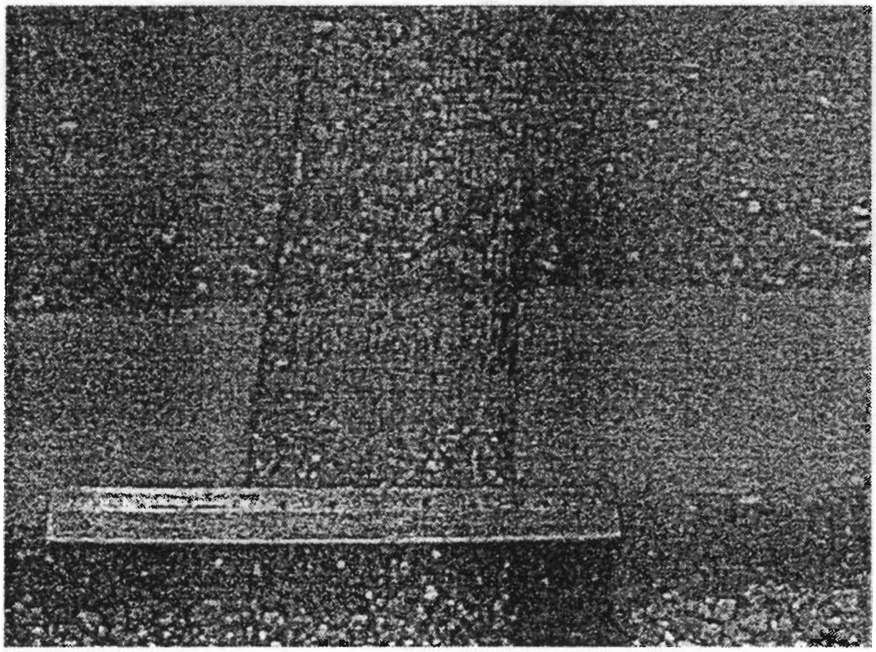


Figure 5.26 Two Views of the Rumble Strips Located Upstream of Tollbooths on the Dallas-Fort Worth Airport Tollway

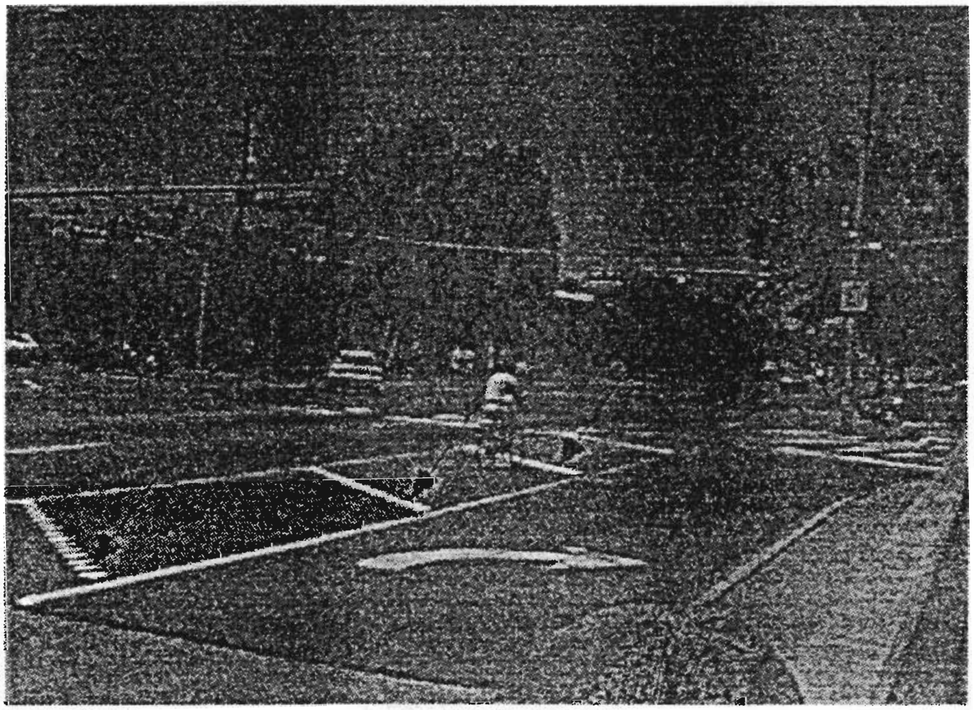


Figure 5.27 Arrows Point to the Conventional Rumble Strip Formed by the use of Raised Buttons

Type 4: 150 mm x 150 mm square buttons, 35 mm high at one end and 25 mm high at the other end. These have been placed at a distance of 200 mm center to center. (Figure 5.27)

The Rating Experiment

A team of 5 bicyclists (4 males, 1 female) were asked to repeatedly drive over a rumble strip and rate the comfort level of the ride on a scale of 1 (1 = least comfortable ride), to 10 (10 = most comfortable ride). Each rider rated the comfort level of the rumbles strips while riding a touring bike, and subsequently, a mountain bike (Figures 5.27, 5.28, 5.29, 5.30). The speed of the bicyclists for each of their runs was slow to intermediate (8 to 16 km/h). To prevent a bias in the ratings, the scores received from each rider was kept confidential from other riders.

The rumble strip comfort scores for touring bikes are listed in Table 5.18; those for mountain bikes are listed in Table 5.19.

Results of the Experiment

As can be seen from Tables 18 and 19, rumble strip Type 3 was consistently rated as providing the smoothest and most comfortable ride in 9 out of a possible 10 choices. It could be reasoned that is so because in Type 3, the flush strips are much wider than the flush strips to be found in Type 1 and Type 2. The feeling and perception of a smooth ride seems to be linked to the width of the smooth surface, and not necessarily the depth and width of the depression (within the given limits). It is recommended that till more extensive research is done in this matter, rumble strips of Type 3 be used in all areas where there is a significant amount of bike traffic.

CLOSURE

A comprehensive list of hazards to cycling was compiled from the literature and through surveys of bicyclists. In all, one hundred thirty-one hazards were identified. Eighty-six of the hazards were rank ordered in terms of the degree of risk, as determined from accident studies and focus group discussions involving both cyclists and engineering professionals.

Nineteen of the top ranking hazards were determined to be of the type to be addressed through maintenance or design activities. Potential solutions to these hazards were identified through literature search and focus group discussions with TxDOT design and maintenance engineers. A number of recommended solutions were developed and their associated costs were estimated.

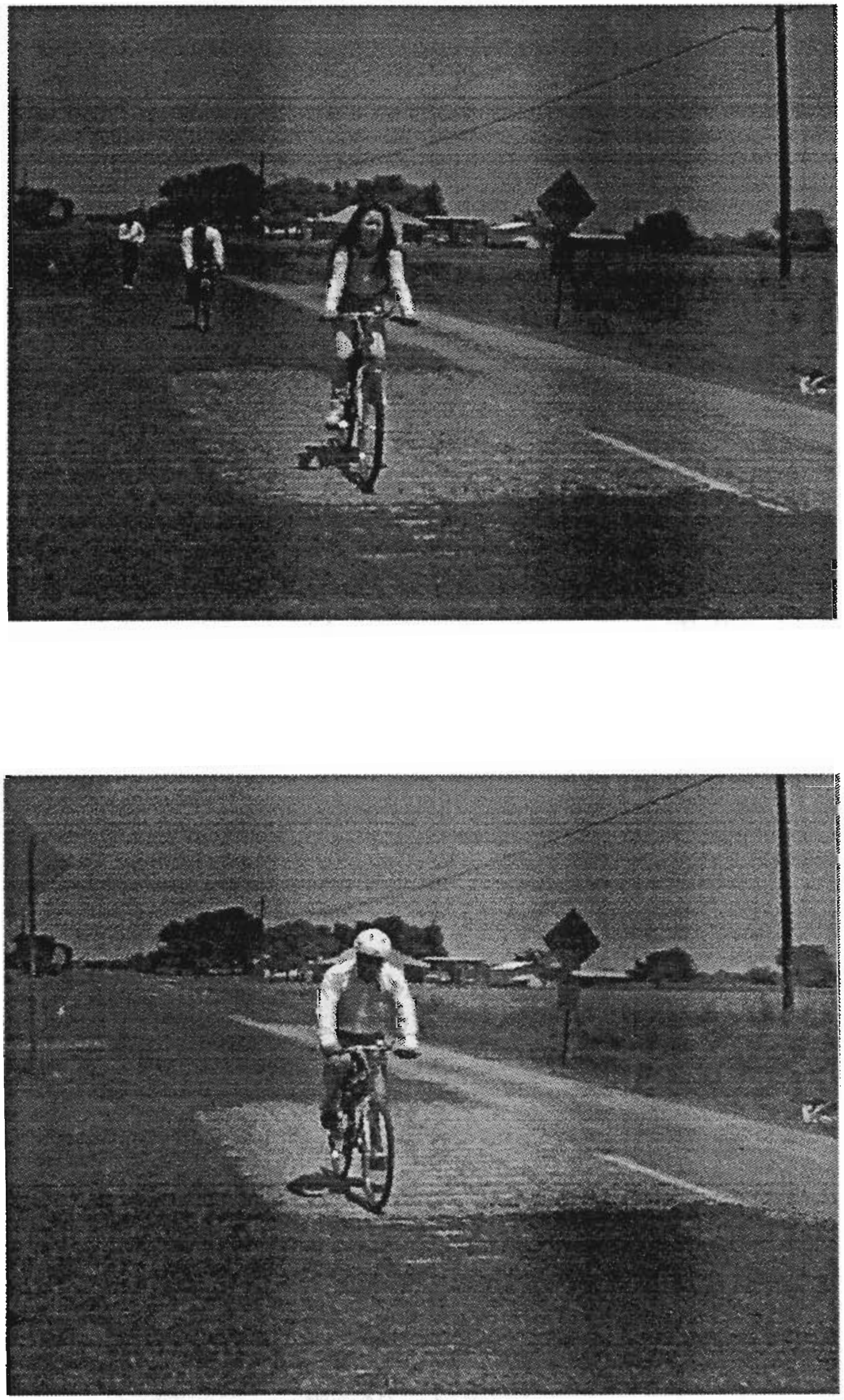


Figure 5.28 Members of the Test Group Riding Their Bikes Over the Rumble Strips on SH 1183 at Ennis

Figure 5.29 Members of the Test Group Ride Their Bikes Over a Rumble Strip on the Dallas-Fort Worth Airport Tollway

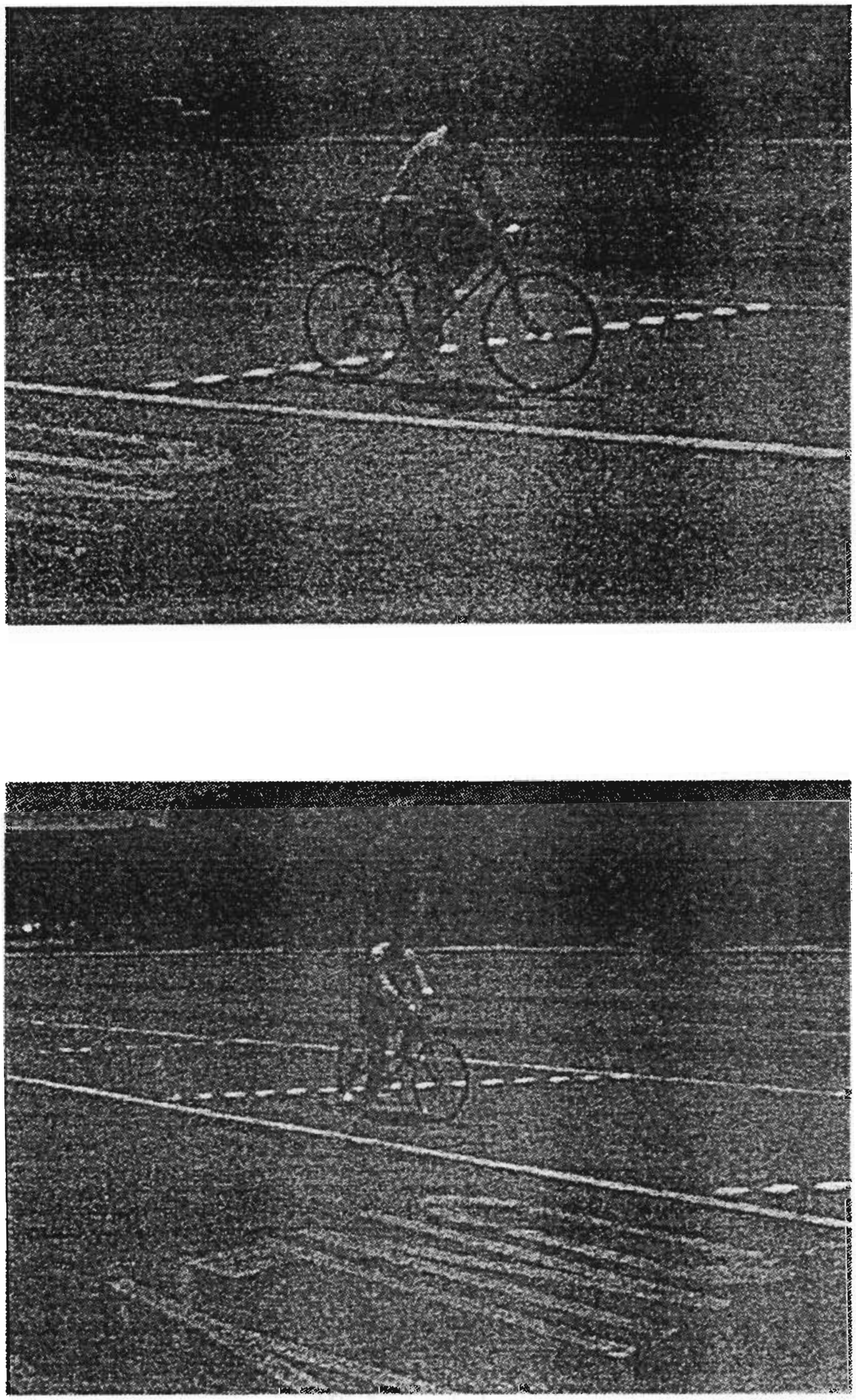


Figure 5.30 Members of the Test Group Riding Their Bikes Over a Conventional Rumble Strip Comprised of Square Buttons

Table 5.18 Rumble Strip Rankings. Relative ranking of the four different types of rumble strips as scored by five cyclists riding a touring bike. The scores are on a scale of 1 to 10 (10 representing the smoothest and most comfortable ride).

Comfort Rating of Rumble Strips on a Touring Bike

	Cyclist 1	*Cyclist 2*	*Cyclist 3*	*Cyclist 4*	*Cyclist 5*	*Mean Score*
Type 1	4	4	5	5	7	5.0
Type 2	1	2	3	2	5	2.6
Type 3	7	7	7	6	6	6.6
Type 4	2	4	5	4	6	4.2

Table 5.19 Rumble Strip Rankings. Relative ranking of the four different types of rumble strips as scored by the same five cyclists riding a mountain bike.

Comfort Rating of Rumble Strips on a Mountain Bike

	Cyclist 1	*Cyclist 2*	*Cyclist 3*	*Cyclist 4*	*Cyclist 5*	*Mean Score*
Type 1	6	6	7	8	9	7.2
Type 2	4	4	5	5	6	4.0
Type 3	8	8	9	7	8	8.0
Type 4	4	5	7	6	7	5.8

CHAPTER VI: CONCLUSIONS AND RECOMMENDATIONS

SUMMARY OF FINDINGS

This study seeks to identify potential hazards to cyclists, to rank order the hazards in terms of their perceived and actual degree of risk, and propose mitigation actions to address these hazards. Of particular concern to this study are mitigation actions that can be incorporated into an agency's regular maintenance activities; however, in almost all cases, there are corresponding considerations that are better addressed at the design stage, and these are pointed to as well. Through literature search, focus groups with cyclists, cyclists' responses to questionnaire surveys, actual field observation, and a review of accident studies, the principal hazardous situations encountered by bicyclists are determined and rank-ordered in this report. In general, behavioral factors contribute to most motor vehicle-bicycle accidents and rank highly among cyclists' concerns; however, available accident studies have failed to investigate the potential contributing factors associated with the roadway and its environment. As previously discussed, most bicycle crashes do not involve a motor vehicle; the most common bicycle crash types are multi-bike, bike-pedestrian, and single bike (Ferrara, 1980). Responses received to the various surveys described in this report overwhelmingly indicate single bike accidents resulting from loss of control as the primary type of accident experienced by responding bicyclists. Frequently, these crash types, like most, develop from a mixture of behavioral factors, roadway design, and roadway conditions. Many of the hazardous factors found in the roadway or its surrounding environment can be corrected or improved.

Although many physical elements contribute to the dangers facing cyclists, it appears that those with perhaps greatest impact may be readily remedied through carefully executed maintenance programs, often in conjunction with existing programs and procedures. The main requirement is for maintenance crews to be aware of the hazardous nature of these elements, and of the agency's responsibility and/or intent to remedy conditions that are hazardous to bicyclists, even when these may not be of particular concern to automobiles. In addition, even problems whose main solution is likely to involve redesign could be detected during routine maintenance if the maintenance crews knew what to look for. Table 6.1 lists the top ten items for maintenance crews to look for during maintenance activities and suggests possible solutions to each problem. This table provides a basis for maintenance guidelines; maintenance crews can undertake additional improvements after mastering these ten detection and mitigation tasks. All factors hazardous to cycling that deal with the roadway and its environment need correction and improvement.

To further facilitate the task of the agency's maintenance staff, a special purpose implementation manual has been prepared as a companion to this report. The manual is amply illustrated with examples of things to look for, and specific guidelines to the extent possible with regard to the specifics of size, shape, and location of hazards. In addition, it describes countermeasures, along with estimates of the cost of these actions.

While maintenance activities are critical to enhancing the safety of the roadway environment for cyclists, it is important to keep the connection to design in mind. Design practices prevent some problems from developing in the first place, and are the most cost-effective way to correct existing dangers. By carefully considering the cyclists' needs during planning and design, the planner can help create an effective network of facilities that provide bicyclists with mobility in a safe environment. When considering the design of bicycle facilities, one might invoke the old adage that the cost of building something right the first time is usually considerably less than the cost of correcting a mistake. Of course, facility designs intended for vehicles cannot be considered as "mistakes"; they are simply not effective for the broadening mix of traffic that wishes and is permitted to share the right of way. Design guidelines need to deal with both new construction and retrofits. To improve the roadways and road networks for cyclists as part of a multimodal transportation system environment, designers and planners need to improve existing facilities and to ensure that all new construction avoids such design pitfalls.

Development of bike "friendly" road and bicycle networks begins by improving existing facilities. The development of solutions to correct bicycle hazards helps in both mitigation and design. Although solutions do not exist for every hazard, the literature review presents many ideas for solving some of the dangerous situations facing cyclists. Using this information, the study develops a comprehensive list of hazards and their corresponding mitigation (Table 6.2). This table proposes general mitigating solutions to each major hazard area. Of course, solutions may need to be adapted to best fit specific situations. Clearly, governments are likely to implement inexpensive solutions first. In the companion implementation manual, additional information is provided on the relative costs of various mitigation actions in light of current TxDOT and other agencies' experience. These were obtained during a focus group of TxDOT maintenance professionals, as well as from direct contacts with various agencies.

This study has compiled many low cost mitigation approaches to solve the hazardous conditions facing cyclists. Each hazard's ranking and its corresponding mitigation cost identify the most cost-effective solutions to the bicycle hazards.

Table 6.1 Top Ten Items to Look for During Maintenance

	Hazard		Solutions
1a.	Wheel-trapping catch basins	1a.	Recess catch basins into the curb
1b.	Grates with parallel bars in the direction of travel	1b.	Replace grates with bicycle-safe drainage grates (Fig. 2.13) Warn cyclists with striping, signs, and/or flashers Add temporary crossbars
1c.	Gutters	1c.	Keep catch basins, grates, gutters out of cyclists' paths
2.	Sand, gravel, and other debris on the pavement (including debris swept into bike lanes from adjacent motor vehicle lanes)	2.	Identify locations for sweepings and develop a frequent sweeping schedule
3.	Roadway bottlenecks, such as those occuring at bridges	3.	Identify and report bottlenecks Warn cyclists with striping, signs, and/or flashers
4a.	Potholes 6 inches or more across	4a.	Patch or repair immediately
4b.	Ruts and wide pavement cracks more than 1/2 inch wide	4b.	Patch or repair immediately
4c.	Wide longitudinal pavement joints more than 1/2 inch wide	4c.	Patch or repair immediately Consider putting in place a 4.5 foot monolithic concrete curb and gutter
5.	Bike paths that are discontinued by a curb	5.	Identify and replace with a curb ramp; provide signage
6.	Bike paths with poorly designed ramps	6.	Improve or replace ramps Identify and place appropriate warning signs (e.g. reduced speed)
7.	Overgrown vegetation blocking bike paths/lanes	7.	Regular maintenance and spot improvement program to keep vegetation 3 feet away from the road edge
8.	Slick/smooth pavement - pavement surfaces where the aggregate is entirely covered by asphalt	8.	Add small lateral grooves to the pavement to improve drainage and traction Resurface with a rough surface
9.	Poorly managed work zones	9.	Consider cyclists through the work zone or provide an alternate route
10.	Unleashed dogs and other stray animals	10.	Call animal control

Table 6.2 Cycling Hazards and Possible Solutions

HAZARDS	MITIGATIONS
1. Driving under the influence	A. Education and enforcement
2. Failure to yield right-of-way - motorist	A. Education and enforcement
3. Not knowing or observing the cyclists' right to use the road	A. Education
4. High truck volumes	A. Provide a suitable alternate route
	B. Restrict trucks along bike routes
	C. Increase bike space (2 m suggested by Florida DOT between trucks and bikes)
5. High speed or high-volume traffic	A. Traffic-calming*
	B. Provide a suitable alternate route
6. Wheel-trapping catch-basins, grates, and gutters	A. Replace parallel bar grates with other types of grates
	B. Recess the catch-basins into the curb
	C. Keep grates, catch-basins, and gutters away from the cyclists' paths
	D. Until replacement add crossbars
	E. Warn cyclists with striping, signs, and flashers
7. Failure to yield right-of-way - cyclist	A. Education and enforcement
8. Riding against traffic	A. Education and enforcement
	B. Add signage
9. Sand, gravel and other debris on the pavement	A. Schedule frequent sweeping (at least every 10 days)
	B. Control bottle disposal by deposit laws
	C. Carefully clean locations after collisions
10. Right-turning motor vehicles crossing bike lanes	A. Discontinue bike lanes before intersections
	B. Move the bike lane to the left of a right-turn only lane
	C. Widen right-turning-lane and turning lane
	D. Signage " Yield to Bicycle"
	E. Alter signalization
	F. Provide grade separation
	G. Education
11. Reluctance to decelerate or stop at crossing	A. Education and enforcement
12. Traffic engineer untrained or unfamiliar with concerns of cyclists	A. Education

* Traffic calming
1. Modify the layout of streets to slow traffic speeds
2. Claim space from motor vehicles for pedestrians, bikes, and greenery
3. Use chicanes, speed plateaus, ramps, and carriageway narrowing

Table 6.2 (Continued)

HAZARDS	MITIGATIONS
13. Roadway bottlenecks	A. Widen the bridge or intersection to the same width as the roadway
	B. Provide a suitable alternate route
	C. Provide signage to warn cyclists
14. Debris swept into the bike lanes from motor vehicle lanes	A. Scheduled frequent sweeping
15. Bike paths that are discontinued by a curb	A. Add a curb ramp
16. Lack of safety equipment	A. Education and enforcement
17. Lack of enforcement of the rules of the road for cyclists	A. Enforce traffic laws equally among cyclists and motorists
18. Riding under the influence	A. Education and enforcement
19. Encroachment of cars into street space allocated for bicyclists	A. Prohibit parking in and alongside a bike lane
	B. Create alternative standing areas
	C. Create protected lanes
	D. Enforcement
20. Bike paths with poorly designed ramps	A. Redesign the ramps (improve sight distance and reduce grades)
	B. Place warning signs
21. Crossing major barriers	A. Build underpasses or bridges
22. Cyclist education and training	A. Licensing requirements
23. Turning left from the right lane	A. Education and enforcement
24. Bike path/route on same roadway as a bus route	A. Limit bus frequency
	B. Disperse bus stops
	C. Provide bike lane to the left of bus lane
25. Potholes, ruts, wide pavement cracks	A. Patch or repair
	B. Warn cyclists
26. Narrow right lanes	A. Restripe for a wider outside lane
	B. Mark a shoulder along the side of the roadway
	C. Bike lane
	D. Policies to discourage motor vehicle traffic
27. Non-uniform design standards for cycle paths and lanes	A. Develop standardized design guidelines
28. Slick/smooth pavement	A. Stricter construction guidelines
	B. Small lateral grooves on the pavement
29. Improper signal timing	A. Improve signal timing to account for bicycle operation characteristics

Table 6.2 (Continued)

HAZARDS	MITIGATIONS
30. Bicycle insensitive signal detectors	A. Place detectors in the areas that cyclists ride
	B. Mark the pavement to delineate the detector or the most sensitive locations on the detector
	C. Replace with bicycle sensitive detectors
	Type D, quadropole in bike lanes
	Type Q, diagonal quadropole for shared road
	Type A, standard loop detects over wires
	D. Add push-button for bike crossing
31. Poorly managed work zones	A. Provide cyclists with a safe path around or through the work zone
	B. Signage
32. Bike paths and bike routes through crime-ridden locations	A. Provide a suitable alternate route
	B. Add sufficient lighting
	C. Widen underpasses
	D. Thin out dense vegetation
33. At-grade railroad crossings	A. Provide crossings at right-angles to the rails for cyclists
	B. Improved signing and pavement marking
	C. Build the road surface up to track level
	D. Build an undercrossing
	E. Rubberized crossing mats and flanges (not for high speed train movements)
34. Curbside auto parking	A. Prohibit auto parking along bike routes or lanes
	B. Clearly place stripes on both sides of a bike lane
35. Stray animals, unleased dogs	A. Enforcement
	B. Animal Catchers Patrol
36. Air quality	A. Provide separated facilities
	B. Use traffic-calming* to limit the number of cars using the roadway
	C. Encourage use of alternative-fuel vehicles
	D. Reduce congestion
37. Cold weather and resulting ice patches	A. Improve drainage
38. Narrow cycle paths	A. Widen the cycle path
	B. Place warning signs
	C. Stripe a yellow centerline
39. Insufficient lighting	A. Add additional lighting

Table 6.2 (Continued)

HAZARDS	MITIGATIONS
40. Turning radii on horizontal curves at the bottom of a steep grade	A. Increase the radii of the curves at the base of steep grades
	B. Curve widening
	C. Provide signage
	D. Rerouting
	E. Lane relocation
41. Large gap requirements when crossing streets	A. Provide a signal for bicyclists
	B. Build an underpass or an overpass for cyclists
	C. Construct a median refuge for cyclists
42. Wide longitudinal pavement joints	A. Patch or repair
	B. Completely rebuild
	C. For bike lanes, install monolithic concrete curbs (approx. 5 feet wide)
	D. To prevent cracks caused by tree roots, install 12 inch metal root barriers at pavement edges
	E. Eliminate in new construction
43. Metal grate bridge decks	A. Use a different type of bridge deck
	B. Provide a suitable alternate route
	C. Provide a separate surface for bike lane
44. Frequent driveways	A. Limit the frequency of driveways present along bike routes and lanes
	B. Require driveways be paved for approximately 15 feet
45. Turning left on protected left-turn phases that are too short	A. Improve signal timing
46. Pedestrians, joggers, etc. on exclusive bicycle lanes	A. Enforcement
	B. Provide separate paths for pedestrians and joggers
47. Pavement overlay drop-offs parallel to travel	A. Improve the quality of maintenance by training of the maintenance crews
	B. Keep drop-offs less than 3/8 inch high
48. Unpruned trees	A. Scheduled and spot maintenance to keep tree branches at least 3 feet from the pavement edge
49. Raised lane markers	A. Limit the use of raised pavement markers, use paint markings
	B. Warn cyclists
50. Turning right from left of exclusive bus lanes	A. Allow bicyclists to use the bus lane
51. Exceeding design speed on downhill grades	A. Post speed advisory signs
	B. Improve design guidelines

Table 6.2 (Continued)

HAZARDS	MITIGATIONS
52. Lack of adequate sight distance	A. Remove sight distance obstacles
	B. Lower speed limit and provide warning signs
	C. Reconstruct to allow for longer, better sight distance
53. Lack of lateral space for load-carrying cyclists	A. Widen bicycle facilities
54. Lack of safe bicycle parking	A. Require bicycle parking facilities
	B. Use lighting and environmental protection at parking installations
55. Overgrown vegetation on bike paths	A. Scheduled and spot maintenance
56. Bridge expansion joints	A. Use bicycle-safe expansion joints

RECOMMENDATIONS AND SUGGESTIONS FOR FUTURE WORK

This study has achieved its objectives of identifying the principal elements of the roadway environment that pose the greatest hazard to bicyclists, and that could be addressed through an agency's regular maintenance activities. This was accomplished both by identifying the key hazards, as well as those symptoms that maintenance crews should look for on a routine basis. In addition, a continuum of countermeasures and mitigation actions have been identified, with their associated costs and expected level of effort. As noted, many of these pertain to unexpected obstacles that bicyclists encounter in constrained mixed-traffic environments, preventing them from adequate action to avoid these obstacles, or exacerbating any lapse of attention on their part. To successfully implement the recommendations of the study, a key element is raising the awareness level of maintenance crews regarding bicycles and related hazards; this provided the motivation for preparing the companion implementation manual in conjunction with this study. Other activities should be considered in this regard, such as use of videotaped material to directly convey to maintenance crews what the bicyclists' experience was in that particular case. Some of the video footage obtained as part of this study could be used as a starting point for this purpose; however, the production of such material was outside the scope of the present study, but should be considered now that the data is readily available.

It is clear that behavioral factors play a predominant role in bicycle safety. This study has provided an important starting point in terms of characterizing bicyclist behavior in the presence of hazardous spots, as well as in various demanding traffic conditions. However, much remains to be done in this regard, including additional observation of bicyclists in various environments and situations, and the development of a comprehensive behavioral framework that would serve as the basis for the design of countermeasures and safety enhancements.

Finally, it is important to recognize that maintenance is only one link, albeit a critical one, in the chain of agency activities that affect the condition of the roadway infrastructure and physical planning and design stages is becoming increasingly important, and is ultimately required for the longer term integration of bicycles in the modal mix that the infrastructure is intended to serve. In addition to the physical and operational characteristics of bicycles, behavioral considerations are of primary importance, in terms of bicyclist preferences for different types of facilities, determinants of bicycle use, and human factors aspects of bicycle operator performance.

REFERENCES

AASHTO (1991) *Guide for the Development of Bicycle Facilities.*

Adams, G. (1994) Comments from Roadway Hazards for Bicyclists Survey. University of Texas at Arlington

Badgett, S.I., Niemeier, D. A., and Rutherford, G. S. (1993) Bicycle Commuting Deterrents and Incentives: A Survey of Selected Companies in the Greater Seattle Area. *73rd Annual Meeting, Transportation Research Board,* Washington DC: 940802

Baker, S. P., Li, G., Fowler, C. & Dannenburg, D.L. (1993) *Injuries to Bicyclists: A National Perspective.* St. James, NY: The Snell Memorial Foundation

Betz, J., Dustrude, J., and Walker, J. (1993) Intelligent Bicycle Routing in the United States. *Transportation Research Record* 1405: 21-27

Caine, B. T. and Siegel, R. L. (1975) The Second Most Frequent Mode of Transportation. *Proceedings of the Fourth National Seminar on Planning, Design, and Implementation of Bicycle and Pedestrian Facilities,* New Orleans LA: 41-53

Cheng, E. Y-C., Gonzalez, E., Christensen, M. O. (1994) Application and Evaluation of Rumble Things on Highways. ITE 1994, Compendium of Technical Papers, ITE

Cross, K. D. (1980) *Causal Factors of Non-Motor Vehicle Related Accidents.* Santa Barbara Bicycle Safety Project, Santa Barbara, CA

Cross, K. D. and Fisher, G. (1977) *A Study of Bicycle/Motor Vehicle Accidents: Identification of Problem Types and Countermeasure Approaches.* NHTSA, U.S. Department of Transportation

CROW (1993) *Sign Up for the Bike Design Manual for a Cycle-Friendly Infrastructure.*

Center for Research and Contract Standardization in Civil and Traffic Engineering - The Netherlands

Daecher, C.W. (1975) A Guide for Municipalities for Bicycle Planning. *Proceedings of the Fourth National Seminar on Planning, Design, and Implementation of Bicycle and Pedestrian Facilities,* New Orleans LA: 117-171

DeRobertis, M. M. and Levine, C.R. (1994) BICYCLE TRAFFIC ENGINEERING, What Every Traffic Engineer Should Know. *ITE 1994 Compendium of Technical Papers.*

Dubin, J. A. and Rivers, R. D. (1990) *SST Reference Manual, Version 2.0*

Dubin, J. A. and Rivers, R. D. (1988) *SST Users Guide, Version 2.0*

Elliott, M. (1995) *Newsletter of the American Society of Civil Engineers Human Power Transportation Commitee.*

Ferrara, T. C. (1980) Techniques for Traffic Planning as Related to Bicycles. *ITE Journal* 50:12

Florida Bicycle Facilities Planning and Design Manual, 1982, Florida DOT, Tallahassee, Fl

Florida Department of Transportation (1993) *Bicycle/Pedestrian Program, Estimates*

Forester J (1983) *Bicycle Transportation.* Boston, MA: MIT Press

Gårder, P. (1994) Bicycle Accidents in Maine: An Analysis. *73rd Annual Meeting, Transportation Research Board,* Washington DC: 940328

Ginzton, A. (1975) Poor Parking-Detrimental to Bicycling Growth. *Proceedings of the Fourth National Seminar on Planning, Design, and Implementation of Bicycle and Pedestrian Facilities,* New Orleans LA: 300-307

Hollern, M. (1992) *1992 Oregon Bicycle Plan.* Oregon Department of Transportation

Hope, D. A. (1992) Community Cycling Manual--Planning and Design Guide. *Transportation Research Record* 1294: 50-51

Huber, T. (1994) Developing Guidelines for Co-use of Roadways by Bicycles and Buses. *Pro Bike/Pro Walk 94 Resource Book, Eighth International Symposium on Bicycling and Walking*. Bicycle Federation of America and Pedestrian Federation of America: A-7

Hudson, M. (1982) *Bicycle Planning: Policy and Practice.* London: The Architectural Press

Hunter, B. (1994) Pedestrian and Bicyclist Crash Types in the 1990's: New Thoughts on the Cross and Snyder/Knoblauch Studies and Ways to Use Data in Your Community. *Pro Bike/Pro Walk 94 Resource Book, Eighth International Symposium on Bicycling and Walking*. Bicycle Federation of America and Pedestrian Federation of America: E-2

Institute of Transportation Engineers. (1992) *Traffic Engineering Handbook.* Prentice Hall, Inc. 4th Ed.

ITE Special Task Force. (1990) *Recommended Guidelines for the Design and Application of Speed Humps-Proposed Recommended Practice*. Institude of Transportation Engineers.

Kraft, W. H. (1976) *Proceedings of the Fourth National Seminar on Planning, Design, and Implementation of Bicycle and Pedestrian Facilities.* New York, NY: American Society of Civil Engineers

Lowe, M. D. (1989) *The Bicycle: Vehicle for a Small Planet.* Worldwatch Institute

Lucero, L. L. (1975) Issues and Answers in Bikeway System Development. *Proceedings of the Fourth National Seminar on Planning, Design, and Implementation of Bicycle and Pedestrian Facilities,* New Orleans LA: 54-65

MacKay, J. (1994) Bicycle Facility Signing and Pavement Markings *Pro Bike/Pro Walk 94 Resource Book, Eighth International Symposium on Bicycling and Walking*. Bicycle Federation of America and Pedestrian Federation of America: A-10

McClintock, H. (1992) *The Bicycle and City Traffic.* London: Belhaven Press

Noland, R. (1994) excerpt from *Transportation.* University of Texas at Arlington E-mail

North Carolina Bicycle Facilities Planning and Design Guidelines. (Jan. 1994), North Carolina DOT, Raleigh, NC

NCTCOG Bicycle and Pedestrian Transportation Task Force. (1995) *Bicycle and Pedestrian Facilities Planning and Design Manual.* North Central Texas Council of Governments

O'Connor, J. T. (1975) Walking and Biking in the Traffic Mix. *Proceedings of the Fourth National Seminar on Planning, Design, and Implementation of Bicycle and Pedestrian Facilities,* New Orleans LA: 435-442

State of Oregon Bicycle Master Plan. (May 1988), Oregon DOT, Salem, OR.

Ronki, M. and McAllister, W. (1990) *Bicycle / Motor Vehicle Accident Summary,* Oregon Department of Transportation

Ronkin, M. and McAllister, W. (1992) *Bicycle / Motor Vehicle Accident Summary,* Oregon Department of Transportation

Ronkin, M., O'Connor, M., and Oliver, T. (1994) Bike Lanes on Arterial Streets: Case Studies from Corvallis, Tempe and Phoenix *Pro Bike/Pro Walk 94 Resource Book, Eighth International Symposium on Bicycling and Walking.* Bicycle Federation of America and Pedestrian Federation of America: A-9

Stutts, J. C., Hunter, W. W., Tracy, T., Wilkinson III, W.C. (1992) *Pedestrian and Bicyclist Safety: A Review of Key Program and Countermeasure Developments During the 1980's,* NHTSA, U.S. Department of Transportation

Sorton, A. (1993) Lecture on Legal Liability and Bicycle Facilities for the Bicycle Planning and Facility Workshop in Arlington, Texas.

Sorton, A. (1993) Program of Instruction for the Bicycle Planning and Facility Workshop. The Traffic Institute, Northwestern University, Evanston, Illinois

Sorton, A. & Walsh, T. (1994) Bicycle Stress Level as a Tool to Evaluate Urban and Suburban Bicycle Compatibility. *Transportation Research Record* 1438.

Taylor, D. (1993) Analysis of Traffic Signal Clearance Interval Requirements for Bicycle-Automobile Mixed Traffic. *Transportation Research Record* 1405: 13-20

Thom, R.G. and Clayton, A.M. (1993) Accident Data Requirements for Improving Cycling Safety. *Transportation Research Record* 1405: 1-6

Thom R. G. and Clayton, A. M. (1992) Low-cost Opportunities for Making Cities Bicycle Friendly Based on a Case Study Analysis of Cyclist Behavior and Accidents. *71st Annual Meeting, Transportation Research Board,* Washington DC

Unrein, D., et al. (1992) *1992 Oregon Bicycle Plan*, Oregon Department of Transportation

U.S. Consumer Product Safety Commission. (1994) *Bicycle Use and Hazard Patterns in the United States.* Washington D.C.

U.S. Department of Transportation. (1995) *Bicycle Safety-Related Research Synthesis.* Federal Highway Administration.

U. S. Department of Transportation. (1988) *Manual on Uniform Traffic Control Devices.* Federal Highway Administration.

U. S. Department of Transportation. (1994) *The National Bicycling and Walking Study: Transportation Choices for a Changing America.* Federal Highway Administration.

U. S. Department of Transportation. (1994) *The National Bicycling and Walking Study: Current Planning Guidelines and Design Standards Being Used by State and Local Agencies for Bicycle and Pedestrian Facilities (Case Study No. 24).* Federal Highway Administration.

Wachtel, A. Forester, J. & Pelz, D. (1995) Signal Clearence Timing for Bicyclists. *ITE Journal. 65(3).*

Wilkinson, W. C., III, Clarke, A., Epperson, B. and Knoblauch, R. (1994) *Selecting Roadway Design Treatments to Accommodate Bicycles.* U.S. Department of Transportation. Federal Highway Administration

Williams, A. F. (1976) Factors in the Initiation of Bicycle-Motor Vehicle Collisions. *American Journal of Diseases of Children* 130

Williams, J. (1988) Bike Forum Technical Note Series. *Bike Centennial*

Williams, J. "Improving Local Conditions for Bicycling," Bike Centennial, Missoula, MT

Wortman, R. H. (1975) Bikeway hazards. *Proceedings of the Fourth National Seminar on Planning, Design, and Implementation of Bicycle and Pedestrian Facilities*, New Orleans LA: 320-325

Ying, L. J. (1987) Management of Bicycling in Urban Areas. *Transportation Quarterly* 41:4

APPENDIX A

COMPREHENSIVE LIST OF HAZARDS

List of Bicycle Hazards

Bike Characteristics

- Bicycle defect or failure (e.g., tire blows, chain breaks)
- Difficult to control speeds on downgrades
- Difficult to ride on uphill grades (e.g., zigzagging)
- Exclusive left-turn phase too short
- Inadequate sight distance at crossings
- Lack of acceleration when turning left (especially on permissive-only signals)
- Large gap requirements (especially while crossing wide streets)
- Unstable at low speeds

Cyclist Behavior

- Carrying unstrapped bulky packages (in hands or on the handlebars)
- Exceeding design speeds on downhill grades (especially in residential areas)
- Failure of another cyclist to yield right-of-way
- Failure to signal movements
- Failure to yield right-of-way
- Following a bicycle too closely
- Following a motor vehicle too closely
- Inexperience in using equipment (e.g. gear-shifting, toe-clip usage)
- Installing unbalanced panniers (saddlebags)
- Lack of safety equipment
- Lapse of rider's attention
- Misjudging intentions of other cyclists
- Not maintaining a straight or predictable path
- Problem releasing feet from toe-clips
- Reckless riding of nearby cyclists
- Reluctance to decelerate or stop at crossings
- Riding against traffic ("wrong-way riding")
- Riding at night
- Riding on the sidewalk
- Riding too fast
- Riding under the influence
- Turning left from the right lane or bike lane
- Turning right from left of exclusive bus lanes
- Weaving in and out between parked cars

Environmental Conditions

- Fog
- Rain
- Severe inclement weather (hurricanes, tornadoes, snow and sand storms)
- Snow
- Sun rising or setting (dawn or dusk)
- Wind

Geometric Design

- At-grade Railroad crossings
- Bike path/route on same roadway as a bus route
  (e.g. leapfrog between the buses and bicycles, buses enter the bike lane for bus stops, etc.)
- Bike paths that are discontinued by a curb
- Bike paths with poorly designed ramps (e.g. sharp turns at the top or bottom of ramps, poor sight distance, etc.)
- Crossing major barriers (e.g., main roads, railways, canals, rivers)
- Cycle paths too narrow
- Frequent driveways
- Lack of lateral space for load-carrying cyclists
- Large roundabouts
- Narrow right lanes / no bike lanes
- Narrow, unmarked shoulders
- Non-uniform designs for bike lanes/paths
- Oblique right turns (drivers often do not signal and do not slow down for the turn)
- Right-turn channelization (use of pork chop islands causes drivers not to slow down sufficiently)
- Roadway bottlenecks / squeeze points (e.g., narrow bridges, sudden narrowing of roads)
- Sidewalks without curb-cuts
- Striped right-turn lane (rightmost position of cyclist is now unclear)
- Too small a turning radius on a horizontal curve (especially at the bottom of steep grades)
- Unexpected (reverse) crown on a horizontal curve
- Wide curb radii (the larger a radius $\Rightarrow$ a higher speed turn)

Motorist Behavior

- Driving under the influence
- Encroachment of autos in space for bikes (e.g., opening car doors, parking cars in bike lanes)
- Failure to yield right-of-way
- Lapse of driver's attention
- Left-turning vehicle crossing path of cyclist
- Motorist error
- Motorist following cyclist too closely
- Motorist honking horn / yelling at cyclist
- Not knowing / observing cyclist's right to use road
- Right-turning vehicle crossing path of cyclist

Other Design Elements

- Blind corners (poor sight distance)
- Bridge expansion joints
- Cattle guards
- Improper bridge railing height (if too short cyclists could flip over it, if too high it could restrict sight distance)
- Insufficient lighting
- Metal-grate bridge decks
- Stairways
- Wheel-trapping catch-basin grates and gutters

Pavement Conditions

- Asphalt ripples due to braking action, etc.
- Cold weather and poor drainage ⇒ ice patches
- Debris in bike lanes swept from auto lanes (especially at turns)
- Differential pavement settlement (especially at bridge connections)
- Drop-offs (at overlays) in the direction of travel
- Hot weather & asphalt ⇒ soft asphalt patches
- Newly chip-coated roads
- Non-flush manhole covers
- Oil leaks, particularly near intersections and where cars park
- Open drainage ditches across the street
- Poor drainage on cycle paths / lanes (puddles of water may cover other hazards)
- Potholes / ruts / wide pavement cracks
- Rough road surface (especially on shoulders where a large aggregate is used)
- Slick / smooth pavement (especially when wet)
- Steel plates on roadway
- Stone paved roads
  (cobblestones / tiles are both subject to shifting and cracking, plus these are extremely slippery when wet)
- Unpaved driveways (source of sand and gravel on pavement)
- Unpaved / gravel road
- Unsmooth patches (e.g., hardened cement, tar on surface)
- Wide, longitudinal pavement joints

Policy & Enforcement

- Air quality
- Bike paths through high-crime neighborhoods
- Harassment by police officers
- Insufficient cyclist education and training
- Insufficient motorist education and training
- Jaywalking pedestrians
- Lack of enforcement of road rules for cyclists and drivers
- Lack of safe / proper bike parking
- Pedestrians/joggers/skaters on bike paths/lanes
- Persons throwing objects (e.g., bottles) at cyclists
- Stray animals & dogs not on leashes
- Traffic engineers unfamiliar with cyclists' concerns
- Unable to transport bike on public transit (e.g., bus, ferry, taxi, train, tram, trolley car)

Roadway Maintenance

- Debris in bike lanes swept from auto lanes (especially at turns)
- Overgrown vegetation / Unpruned trees (e.g., blocking bike path / lane, hiding signs, limiting sight distance)
- Poorly managed and signed work zones
- Unswept debris on pavement
- Vandalized signs and lights on bike paths

Traffic Control Elements

- Bike insensitive signal detectors
- Cars parked too close to intersections
- Curbside auto parking (especially in bike lanes)
- Friction reducing paints for roadway markings (e.g., used in striping crosswalks)
- Heavy bike traffic
- High-speed or high-volume auto traffic
- High truck volumes
- Improper signal time for cyclists (e.g., short green/amber times)
- Inability to see optically programmed signals
- Lack of speed separation for cyclists in bike lanes
- Lack of signage devoted to bike traffic
- Nonstandard delineation for bike lanes (solid stripes, dashed stripes, grade separation)
- Non-uniform design standards (difference in designing cycle paths and lanes)
- Raised lane markers
- Rumble strips
- Signs too close to roadway
- Speed bumps

APPENDIX B

U.T.-AUSTIN BICYCLE RIDERS SURVEY

Bicycle Riders Survey

TBC ___ ___ ___ ___

If you ride a bicycle, please fill out this survey form for an ongoing University of Texas research study. Most respondents take between 10 and 15 minutes to completely fill out this survey form. Your participation in this survey will help identify, manage and reduce hazards faced by bicyclists, and make our city streets more bike-friendly. Please return the completed survey in the pre-addressed Campus Mail envelope provided. Campus Mail boxes are located in the lobbies of almost every building on campus. Please answer all questions to the best of your knowledge and recollection. Surveys will be treated anonymously, and all responses will be kept strictly confidential. We truly appreciate your time and effort in responding to this survey. Thank you!

For the purpose of this survey, we define:
Touring bikes = bicycles with thin tires
Mountain bikes = bicycles with wide tires

1. Types of **bicycles you ride** and **number of years** you have ridden them:
   Touring bikes: ______ years   Mountain bikes: ______ years
   Other peda-cycles (please specify): ______________________ years

2. Indicate the **bicycle types** (Touring = T, Mountain = M, Other = O) that members of your household **other than yourself** ride; circle the corresponding age group of the rider:

Age:	under 13	13 to 17	18 to 24	25 to 34	35 to 49	50 to 65	over 65
Bike:	______	______	______	______	______	______	______

3. Check the types of **training** you have received for riding **a bicycle**:
   Learned as a child ______________   Saw a film/video ______________
   Taught yourself as an adult ______________   Read an article/pamphlet ______________
   Trained by other bicyclists ______________   Read a book/monograph ______________
   Formal training (month/year): ______________________________

4. Check how frequently you use the appropriate **equipment when you ride...**

	...a Touring Bike				...a Mountain Bike			
Equipment	Never	Seldom	Often	Always	Never	Seldom	Often	Always
Helmet								
Gloves								
Glasses/eye protection								
Rear-view mirror								
Bright/reflective markings								
Front lights (night use only)								
Rear lights (night use only)								
Other:								

5. Please provide an estimate of the average **weekly bicycle-miles** you ride for the following activities:
   Shopping / Errands ______________   Work ______________
   Social activities / Recreation ______________   School ______________
   Exercise / Training ______________   Other ______________

6. Please provide an estimate of the average **weekly auto-miles** you drive for the following activities:
   Shopping / Errands ______________   Work ______________
   Social activities / Recreation ______________   School ______________

7. Check the activities for which you use **mass transit** (either occasionally or regularly) for travel to:
   Shopping / Errands ______________   Work ______________
   Social activities / Recreation ______________   School ______________

Social activities / Recreation____________ School__________

8. Check the street environments in which you do most of your bicycle riding:

	Auto traffic	Bike traffic	Pedestrian traffic
Streets with little or no	_____	_____	_____
Streets with moderate	_____	_____	_____
Streets with heavy	_____	_____	_____

Bike paths with light / moderate / heavy traffic. (Circle all applicable.)

9. Number of **months each year** you don't ride a bicycle because of bad weather: ____months.

10. What **percent of your total** bicycle-riding is done during the evening/night hours? ________%

11. In the last 2 years, indicate the **number of citations** received for a traffic violation while:
riding a bicycle:______________ driving an auto:____________

12. In the last 2 years, indicate the **number of accidents** involved in (regardless of fault) while:
riding a bicycle:______________ driving an auto:____________

13. Describe 3 situations that make you feel unsafe or uncomfortable while riding a bicycle.

14. While riding a bicycle, have you ever been in a situation where you **narrowly missed getting involved in an accident**? Please describe briefly the circumstances, and mention all "hazards" which may have contributed (in part or whole) to the "almost-accident".

15. On the basis of your riding experience, indicate how frequently you have encountered some of the problems (or roadway "hazards") listed below, and how severe a threat you find them to be from the point of view of safety. Please check appropriate boxes in the table below.

	Frequency of Occurrence				Severity of the Problem		
List of	rare	seldom	often	very common	problem is just annoying	likely to cause minor accident	likely to cause serious accident
1. Asphalt ripples at intersections / bus stops							
2. Autos encroaching (or parked in) bike lanes							
3. Bike paths/lanes with overgrow vegetation							
4. Debris / gravel in bike lanes / right lane							
5. Oil patches near intersections and in bike lanes							
6. Potholes, ruts, wide cracks							
7. Railroad / trolley crossings							
8. Raised lane markers							
9. Repaving using loose gravel							
10. Signs too close to (or encroaching on) bike							
11. Uneven bridge expansion							
12. Uneven manhole							
13. Wheel-trapping catch-basin grates and							
14. Work zones poorly managed and							
Others:							

16. In the table on page 5, please provide some information about bike accidents/collisions/falls you can recall (no off-trail accidents please!) Two examples illustrate how to fill in your responses.

a. Based on the definitions below, assign a Code # to the accident: (11-17)

Code #	Accident Type
11	Collision with an animal
12	Collision with another bike
13	Collision with a motorized vehicle
14	Collision with a pedestrian (including skaters etc.)
15	"Solo" accident or fall caused while evading one of the above
16	"Solo" accident or fall caused by losing control of bike
17	Other (please specify in column i)

b. The month and year the accident occurred. (m/y)

c. Using the Bike Accident Severity (BAS) scale defined below, assign BAS # for injury to rider, and a BAS # for damage to bike. (0 - 5, 0 - 5)

BAS#	Injury to Rider	BAS#	Damage to Bike
0	No physical injuries	0	No damage
1	Minor scrapes	1	Cosmetic scratches
2	A few bruises/cuts	2	Bike requires some adjustments
3	Outpatient at clinic/hospital	3	Mechanic required to fix bike
4	Hospitalization	4	Bike needs extensive repairs
5	Critical injuries	5	Bike unrepairable

d. Type of bike you were riding at the time of the accident (Touring/Mountain/Other) and the speed of the bike at the time of the accident (Slow/Intermediate/Fast)

e. Whether or not a police report was filed (Y/N) and whether or not an insurance claim was filed (Y/N)

f. Whether or not human error (by you or some one else) contributed to the accident (Y/N)

g. Whether or not the design and condition of the road/street-facilities contributed to the accident (Y/N)

h. Regardless of fault, whether or not you could have avoided the accident (Y/N)

i. List all hazards (or causes) that, directly or indirectly, led to the accident.

Example I: Bike runs over a nail causing the rider to loose control and fall (16). It happened in September 1993 (9/93). The rider had no injuries (0), and the bike had to be taken to a shop for a new tire (3). It was a touring bike (T) travelling fast (F). No police report was filed (N), and no insurance claim was filed (N). There was no human error involved (N), street conditions caused the accident (Y), and the accident was unavoidable (N). Primary hazards were: debris in bike lane, ruts, and an uneven pavement surface. The entry for Ex. I in the table becomes:
(16, 9/93, 0, 3, T, F, N, N, N, Y, N, debris in bike lane, uneven surface, ruts)

Example II: Bike gets hit by a car coming out of a driveway (13) in January 1994 (1/94). The bike rider had to visit a hospital as an outpatient (3), and the bike was rendered unrepairable (5). It was a mountain bike (M) travelling at intermediate speeds (I). A police report was filed (Y) but no insurance claim was filed (N). Human error caused the accident (Y), and street design/maintenance was not a factor (N). The rider felt that with quick evasive maneuvers, the accident could have been avoided (Y). Causes of the accident were: motorist error, poor visibility, lapse of rider's attention. Thus, Ex. II becomes:
(13, 1/94, 3, 5, M, I, Y, N, Y, N, Y, motorist error, poor visibility, lapse of rider's attention)

Table for Q. 16

	a	b	c		d		e		f	g	h	
Number	Accident Type Code #	Month & Year	Rider Injury BAS #	Bike Damage BAS #	Bike Type (Touring / Mountain / Other)	Bike Speed (Slow / Intermediate / Fast)	Police Report Filed ?	Insurance Claim Filed ?	Human error contributed to accident ?	Street design / maintainence contributed to accident ?	Bike rider could have avoided the accident ?	
#	11-17	m/y	0-5	0-5	t/m/o	s/i/f	y/n	y/n	y/n	y/n	y/n	List of hazards or other causes of the accident :
Ex I	16	9/93	0	3	T	F	N	N	N	Y	N	Debris in bike lane, uneven surface, ruts.
Ex II	13	1/94	3	5	M	I	Y	N	Y	N	Y	Motorist error, poor visibility, lapse of rider's attention.

Accident Type	Code
Collision with an animal	11
Collision with another bike	12
Collision with a motorized vehicle	13
Collision with a pedestrian / skater	14
Solo accident while evading collision	15
Solo accident after losing control	16
Other (please specify)	17

Rider Injury	BAS	Bike Damage
No injuries	0	No damage
Minor scrapes	1	Cosmetic scratches
Bruises/cuts	2	Needs adjustment
Outpatient	3	Mechanic required
Hospitalization	4	Extensive repairs
Critical injury	5	Unrepairable

This last set of questions are for demographic classification purposes.

17. Gender: F / M ________ 18. Occupation: ______________________________

19. City, State: ______________________________

20. Your age: 13 to 17 18 to 24 25 to 34 35 to 49 50 to 65 over 65

21. Number of people in your household (including yourself): ____________

22. Gross annual income of your household:
under $15,000 $30,000 to $45,000 $60,000 to $75,000
$15,000 to $30,000 $45,000 to $60,000 over $75,000

23. Number of automobiles (cars, vans, pick-up trucks etc.) in your household: ________

24. Is there a readily accessible transit service available in your community? Yes / No

Any additional anecdotes, experiences, or general comments about hazards for bicyclists you would like to share are welcome!

We appreciate your time and effort spent on this survey. If you've already filled out this survey before, please pass it on to a fellow bicyclist. Please return the completed survey in the accompanying Campus Mail envelope addressed to:

The Bike Project
Department of Civil Engineering
51700

Please use Campus Mail boxes located in the lobbies of most buildings on campus. Additional copies of this form, along with a self-addressed and stamped return envelope can also be requested from the above address. An email version of this survey can be requested from:

bike@alpha1.ce.utexas.edu

Send email to the above account with the word REQUEST in the Subject field.

APPENDIX C

SUMMARY OF SELECTED SURVEY STATISTICS

Statistics Compiled from the *Bicycle Riders Survey*

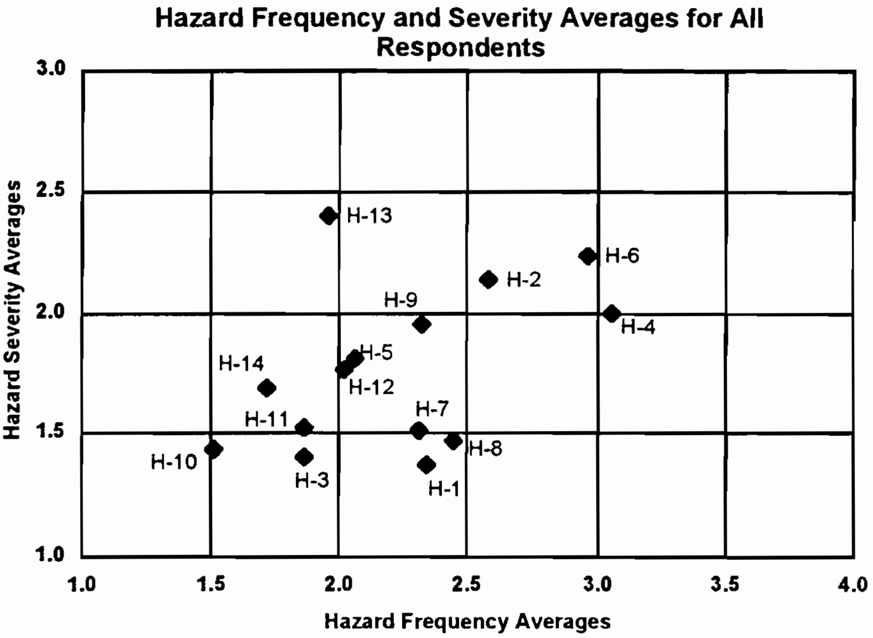
Hazard Statistics

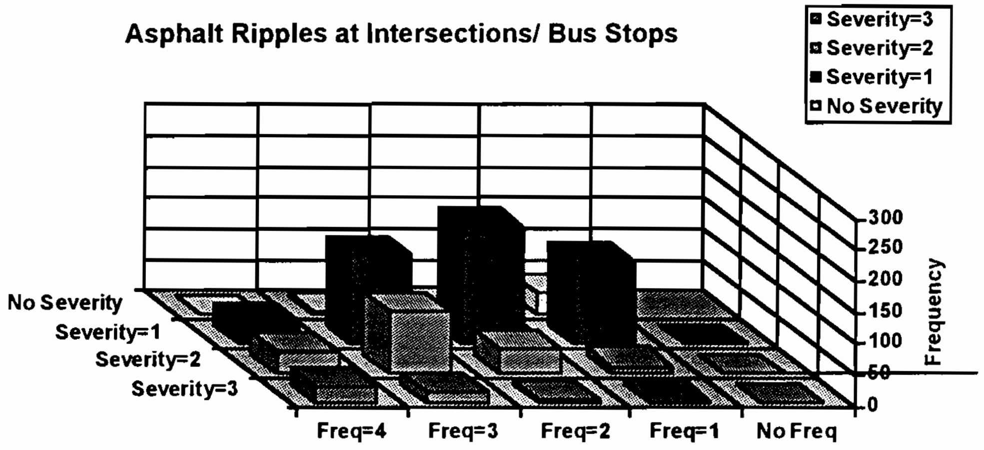
Table C.1 Hazard Frequency and Severity Perceptions of All Respondents

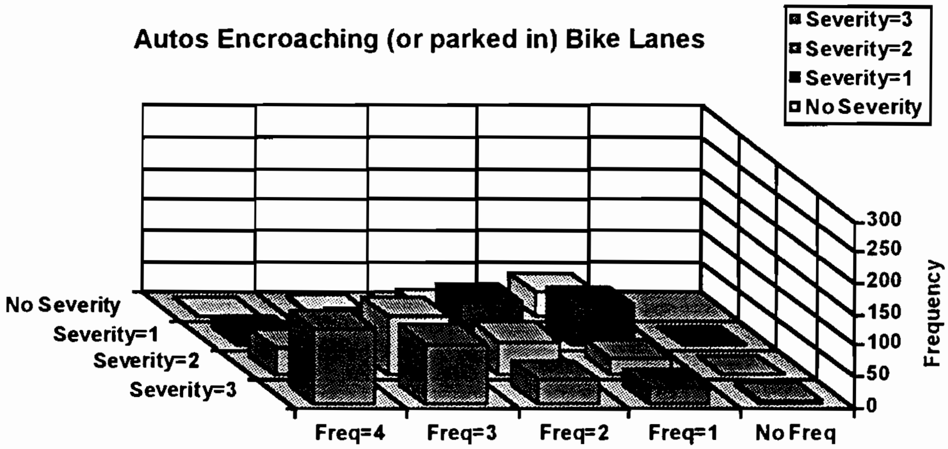
(based on the number of valid observations)

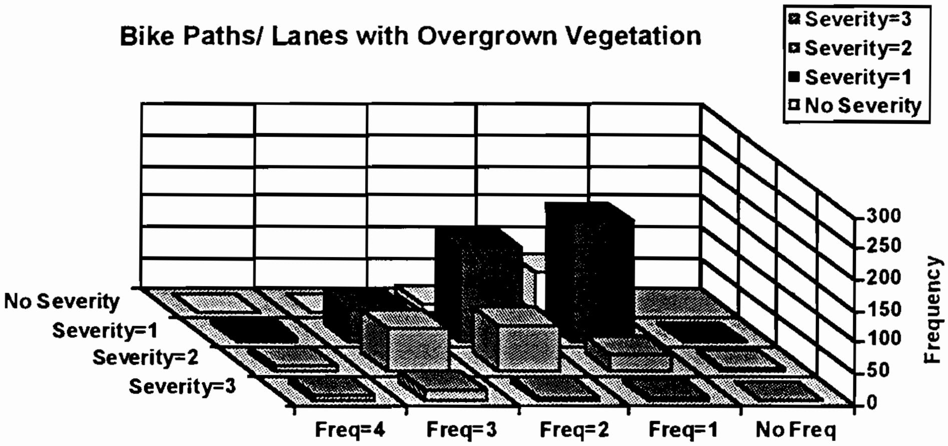
Frequency Scale:	Severity Scale:
1 = rare	1 = problem is just annoying
2 = seldom	2 = likely to cause a minor accident
3 = often	3 = likely to cause a serious accident
4 = very common	

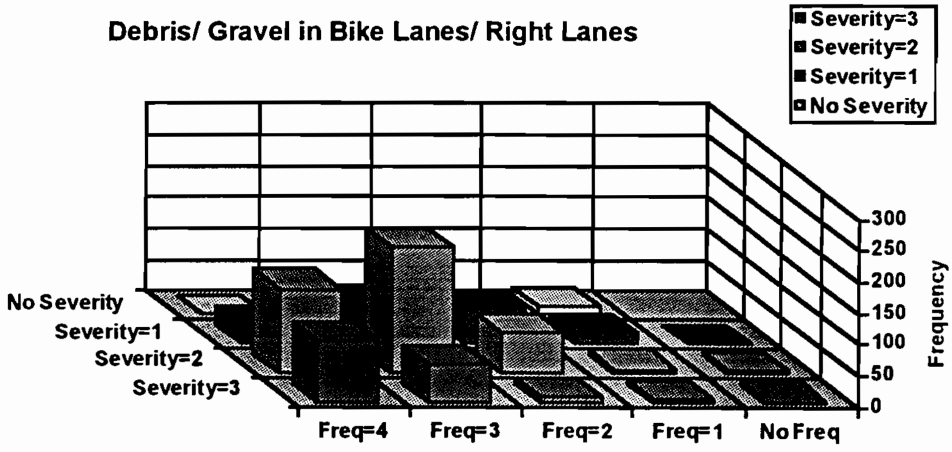
List of Problems	Average Frequency	Average Severity
1. Asphalt ripples at intersections/bus stops	2.34	1.37
2. Autos encroaching (or parked in) bike lanes	2.58	2.14
3. Bike paths/lanes with overgrown vegetation	1.86	1.40
4. Debris/gravel in bike lanes/right lanes	3.06	2.00
5. Oil patches near intersections and in bike lanes	2.06	1.81
6. Potholes, ruts, wide cracks	2.96	2.23
7. Railroad/trolley crossings	2.31	1.51
8. Raised lane markers	2.44	1.47
9. Repaving using loose gravel	2.32	1.95
10. Signs too close to (or encroaching on) bike lanes	1.51	1.44
11. Uneven bridge expansion joints	1.86	1.52
12. Uneven manhole covers	2.02	1.76
13. Wheel-trapping catch-basin grates and gutters	1.96	2.40
14. Work zones poorly managed and signed	1.72	1.69



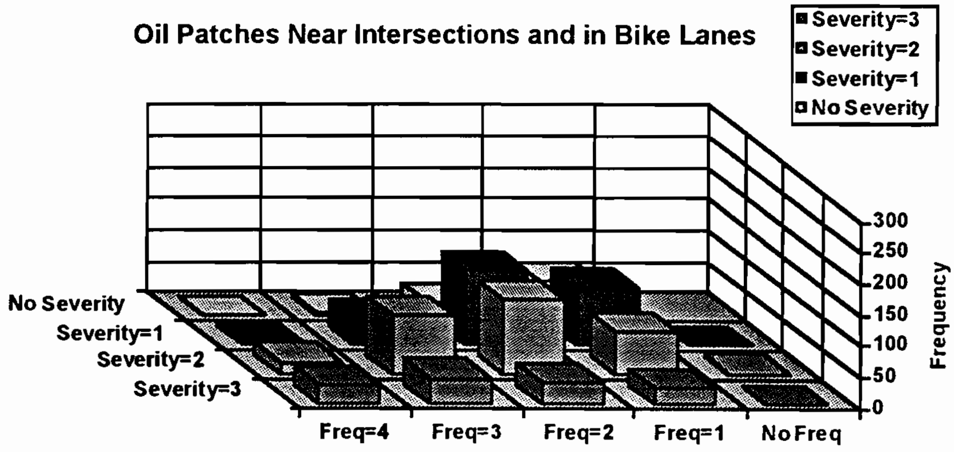

Asphalt Ripples at Intersections/ Bus Stops


Autos Encroaching (or parked in) Bike Lanes

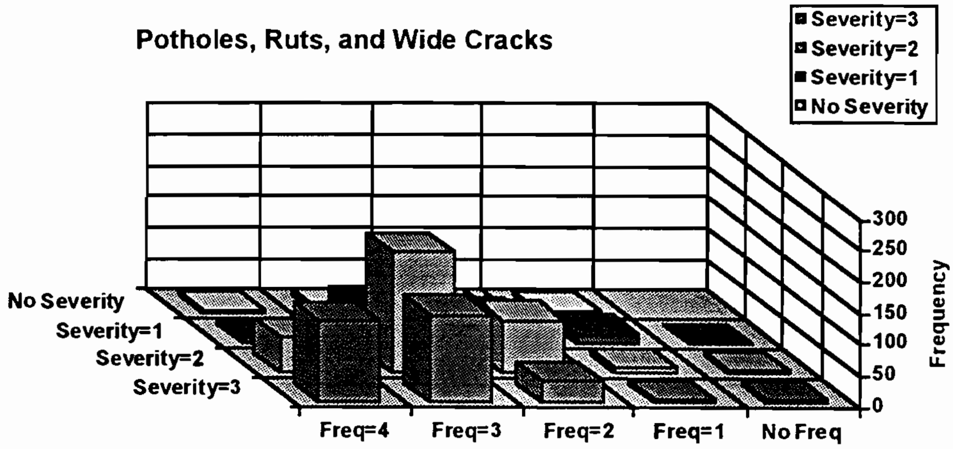

Bike Paths/ Lanes with Overgrown Vegetation



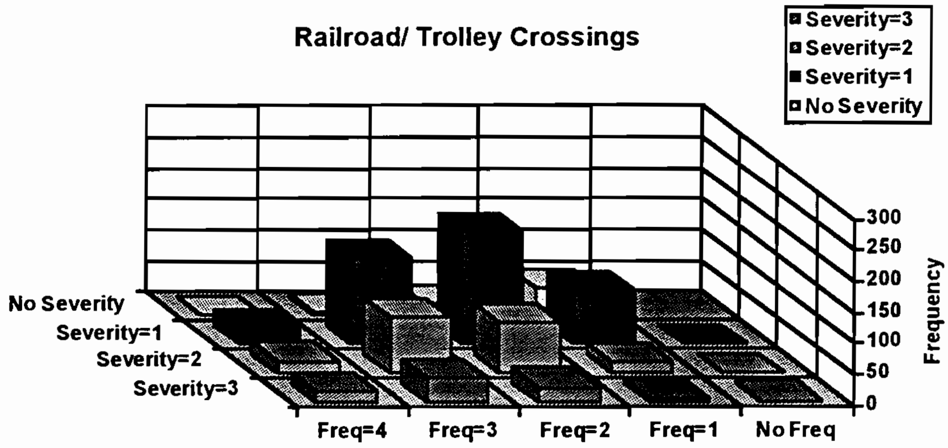
Debris/ Gravel in Bike Lanes/ Right Lanes



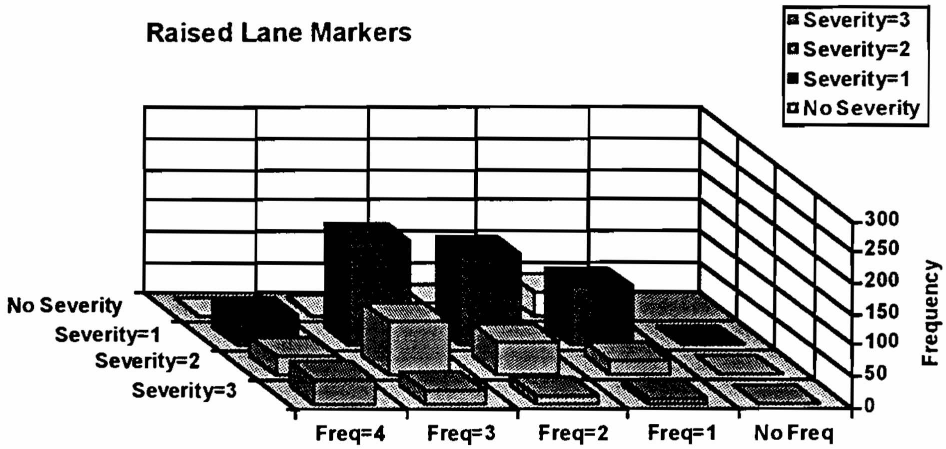
Oil Patches Near Intersections and in Bike Lanes



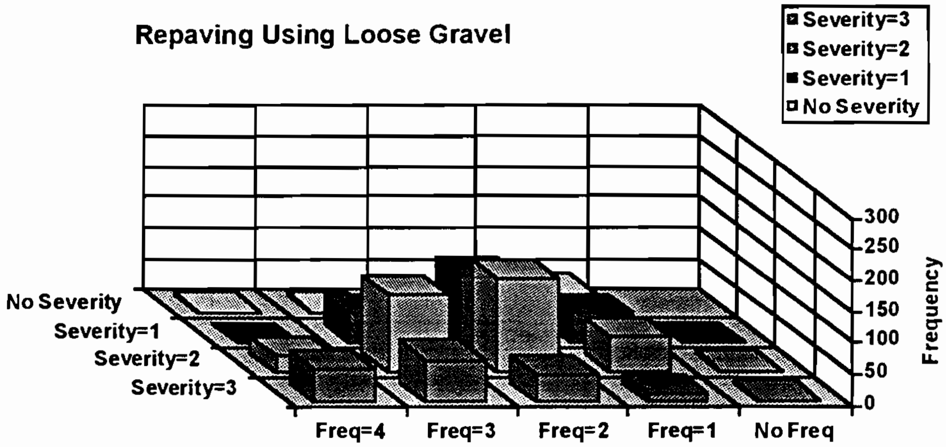
Potholes, Ruts, and Wide Cracks



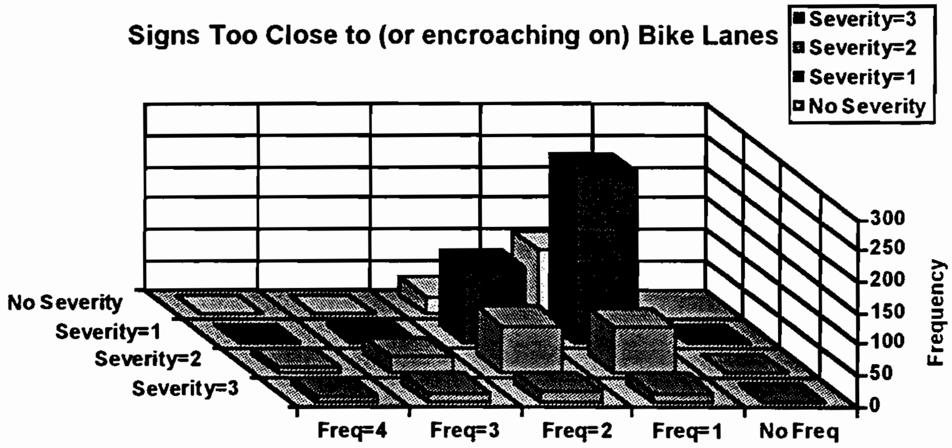
Railroad/ Trolley Crossings



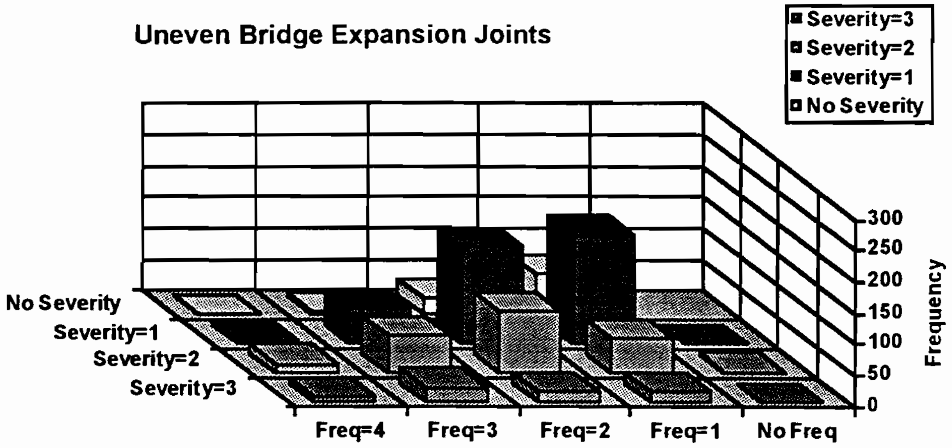
Raised Lane Markers



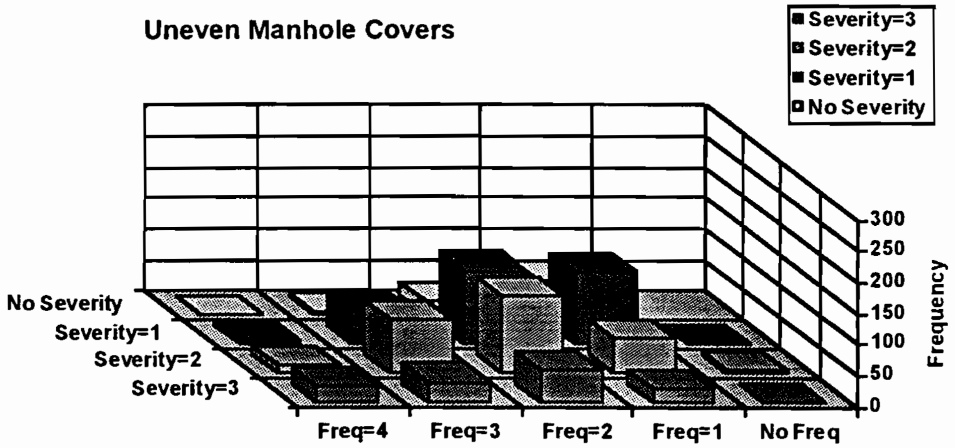
Repaving Using Loose Gravel



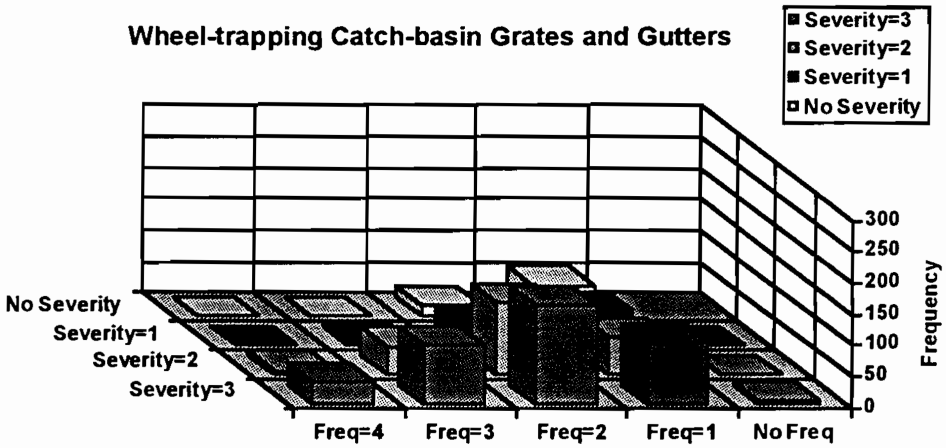
Signs Too Close to (or encroaching on) Bike Lanes



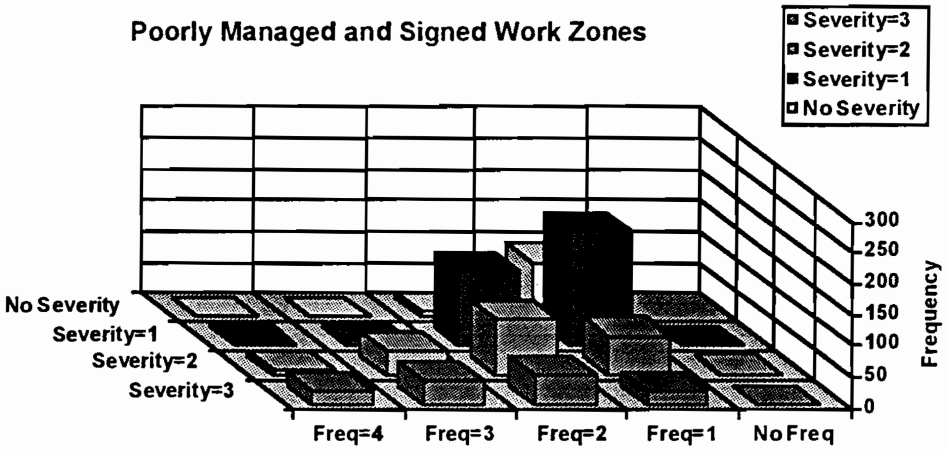
Uneven Bridge Expansion Joints



Uneven Manhole Covers



Wheel-trapping Catch-basin Grates and Gutters



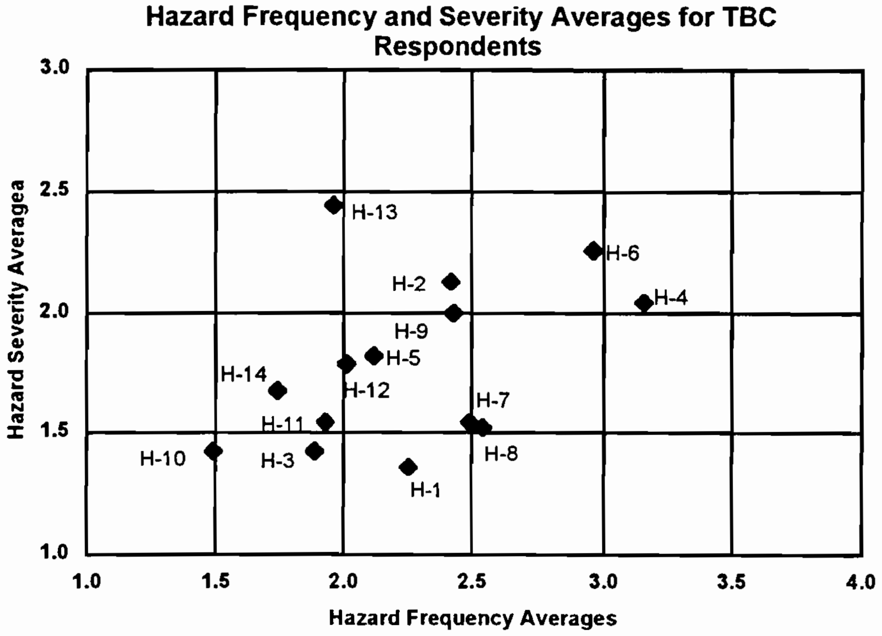
Poorly Managed and Signed Work Zones

Table C.2 Hazard Frequency and Severity Perceptions of TBC Respondents

(based on the number of valid observations)

Frequency Scale:	Severity Scale:
1 = rare	1 = problem is just annoying
2 = seldom	2 = likely to cause a minor accident
3 = often	3 = likely to cause a serious accident
4 = very common	

List of Problems	Average Frequency	Average Severity
1. Asphalt ripples at intersections/bus stops	2.34	1.37
2. Autos encroaching (or parked in) bike lanes	2.58	2.14
3. Bike paths/lanes with overgrown vegetation	1.86	1.40
4. Debris/gravel in bike lanes/right lanes	3.06	2.00
5. Oil patches near intersections and in bike lanes	2.06	1.81
6. Potholes, ruts, wide cracks	2.96	2.23
7. Railroad/trolley crossings	2.31	1.51
8. Raised lane markers	2.54	1.52
9. Repaving using loose gravel	2.42	2.00
10. Signs too close to (or encroaching on) bike lanes	1.49	1.43
11. Uneven bridge expansion joints	1.92	1.55
12. Uneven manhole covers	2.01	1.79
13. Wheel-trapping catch-basin grates and gutters	1.96	2.44
14. Work zones poorly managed and signed	1.74	1.68



APPENDIX D

U.T. - ARLINGTON
HAZARDS TO CYCLING QUESTIONNAIRE

Dear Bicycle Rider:

The Civil Engineering Department of The University of Texas at Arlington is conducting a research project for the Texas Department of Transportation (TxDOT). We are trying to identify and rank order the hazards that cyclists face on a daily basis on city streets. TxDOT will use this ranking of bicycle hazards to establish guidelines for improving roads for cyclists. We would appreciate it if you could take a minute to subjectively rank the bicycle hazards on the attached list.

To do this, you must assess how hazardous you believe the described situation or obstacle is when cycling. A value of ten (10) corresponds to most dangerous while a one (1) will be least dangerous. If you do not understand a particular item, feel free to leave it blank. You may include any additional comments or ideas that you may have while filling this questionnaire. After finishing the questionnaire, please return it in the accompanying pre-paid envelope or return it via campus mail to:

Dr. Sia Ardekani or Steve Mattingly
Department of Civil Engineering
Box 19308

If you have any questions, please call Steve Mattingly (214) 596-6514.

Thanks for your help,

Steve Mattingly

Steve Mattingly, GRA

HAZARDS TO CYCLING

		Ranking (1-10)*
A.	**PAVEMENT CONDITIONS**	
1.	Potholes, ruts, wide pavement cracks	
2.	Unsmooth patches (including hardened cement, tar, and other materials accidentally released onto the pavement surface)	
3.	Uneven manhole covers	
4.	Dropoffs at pavement overlays parallel to the direction of travel	
5.	Wide longitudinal pavement joints	
6.	Open drainage ditches across the street	
7.	Asphalt ripples due to braking action, etc.	
8.	Differential pavement settlement, particularly at bridge connections	
9.	Stone paved roads	
10.	Slick/smooth pavement (when asphalt covers the surface aggregates completely it becomes slippery when wet)	
11.	Temperature sensitive asphalt pavements in hot climates	
12.	Unpaved driveways (major source of sand and gravel on pavement)	
13.	Oil leaks, particularly near intersections	
14.	Poor drainage on cycle paths and in streets in the areas that cyclists ride	
15.	Cold weather combined with poor drainage resulting in ice patches	
B.	**GEOMETRIC DESIGN**	
16.	Non-uniform design standards for cycle paths and lanes	
17.	Narrow right lanes	
18.	Narrow cycle paths	
19.	Narrow, unmarked shoulders	
20.	Roadway bottlenecks (narrow bridge lanes or sudden narrowing of roadway cross sections)	
21.	Lack of lateral space for load-carrying cyclists	
22.	Crossing major barriers: main roads, railways, canals, rivers	
23.	At-grade railroad crossings	
24.	Frequent driveways	
25.	Turning radius on horizontal curves on the bottom of a steep grade	
26.	Bike path/route on same roadway as a bus route (e.g leapfrog between the buses and bicycles, buses enter the bike lane for bus stops)	
27.	Bike paths with poorly designed ramps (e.g. sharp turns at the top or bottom of ramps, poor sight distance, etc.)	
28.	Bike paths that are discontinued by a curb	
29.	Large roundabouts	

---

*10 represents most hazardous conditions

		Ranking (1-10)
C.	TRAFFIC CONTROL AND CONDITIONS	
30.	Bicycle insensitive signal detectors	
31.	Inability of cyclists to see optically programmed signals	
32.	Improper signal timing for cyclists (e.g. short green/amber durations)	
33.	Street signs too close to the roadway or bike path	
34.	Speed bumps	
35.	Rumble strips	
36.	Raised lane markers	
37.	Friction reducing paint used in striping crosswalks and other pavement markings	
38.	Lack of separation for cyclists going at different speeds within bike lanes	
39.	Nonstandard delineation for bike lanes (e.g. solid stripes, dashed stripes, grade separation, etc.)	
40.	Lack of signage devoted to bicycle routes and cyclists	
41.	Curbside auto parking	
42.	High-speed or high-volume traffic	
43.	High truck volumes	
D.	OTHER DESIGN ELEMENTS	
44.	Metal grate bridge decks	
45.	Bridge expansion joints	
46.	Improper bridge railing height (if too short cyclist could flip over, if too high could restrict cylist's sight distance)	
47.	Wheel-trapping catch-basin grates and gutters	
48.	Insufficient lighting	
49.	Stairways	
E.	ROADWAY MAINTENANCE/UPKEEP	
50.	Sand, gravel, broken glass, and other debris on pavement (particularly at turns)	
51.	Debris swept into the bike lanes from adjacent motor vehicle lanes	
52.	Vandalized signs and lights on bike paths	
53.	Poorly managed work zones	
54:	Overgrown vegetation on bike paths	
55.	Unpruned trees	
56.	Stray animals, dogs not on leash	
F.	BICYCLE CHARACTERISTICS	
57.	Unstable at low speeds	
58.	Difficulty of controlling speeds on downgrades	
59.	Difficulty in riding uphill grades (e.g. zigzagging)	

APPENDIX E

SUMMARY OF THE QUESTIONNAIRE RESPONSES

TABLE E.1 SUMMARY OF HAZARDS TO CYCLING SURVEY RESPONSES

Hazards	Number of Responses	Average Ratings	Standard Deviation	Min. mean at a 90% Confidence	Max. mean at a 90% Confidence
1. Potholes, ruts, wide pavement cracks	27	7.07	2.58	6.23	7.92
2. Unsmooth patches	27	4.30	2.00	3.64	4.95
3. Uneven manhole covers	27	5.17	2.56	4.32	6.01
4. Pavement overlay dropoffs parallel to travel	27	5.98	2.68	5.10	6.86
5. Wide longitudinal pavement joints	23	6.28	2.60	5.35	7.21
6. Open drainage ditches across the street	22	4.66	2.15	3.87	5.45
7. Asphalt ripples due to braking action	27	3.63	1.74	3.06	4.20
8. Differential pavement settlement	26	4.31	1.93	3.66	4.95
9. Stone paved roads	24	4.69	2.24	3.91	5.47
10. Slick/smooth pavement	23	6.59	2.25	5.78	7.39
11. Temperature sensitive asphalt pavements in hot climates	23	4.35	2.22	3.56	5.15
12. Unpaved driveways	27	4.94	2.37	4.17	5.72
13. Oil leaks	24	4.56	2.24	3.78	5.35
14. Poor drainage	27	5.43	2.53	4.60	6.26
15. Cold weather and resulting ice patches	25	6.42	2.79	5.46	7.38
16. Non-uniform design standards for cycle paths and lanes	25	6.64	2.71	5.71	7.57
17. Narrow right lanes	23	7.00	2.27	6.19	7.81
18. Narrow cycle paths	25	6.40	2.59	5.51	7.29
19. Narrow, unmarked shoulders	23	6.74	2.64	5.79	7.68
20. Roadway bottle necks	24	8.00	2.25	7.21	8.79
21. Lack of lateral space for load-carrying cyclists	22	5.66	2.43	4.77	6.55
22. Crossing major barriers	25	7.20	2.21	6.44	7.96
23. At-grade railroad crossings	21	6.48	2.46	5.55	7.40
24. Frequent driveways	22	6.23	2.09	5.46	6.99
25. Turning radius on horizontal curves at the bottom of a steep grade	21	6.38	2.38	5.49	7.28
26. Bike path/route on same roadway as a bus route	20	7.15	2.17	6.31	7.99
27. Bike paths with poorly designed ramps	24	7.21	2.12	6.47	7.95
28. Bike paths that are discontinued by a curb	23	7.63	2.14	6.87	8.40
29. Large roundabouts	18	5.44	2.81	4.29	6.60
30. Bicycle insensitive signal detectors	25	6.56	2.83	5.59	7.53
31. Inability of cyclists to see optically programmed signals	23	5.04	2.71	4.07	6.01
32. Improper signal timing	26	6.58	2.45	5.76	7.40

TABLE E.1 (CONTINUED)

Hazards	Number of Responses	Average Ratings	Standard Deviation	Min. mean at a 90% Confidence	Max. mean at a 90% Confidence
33. Street signs too close to the roadway or bike path	23	5.48	2.84	4.46	6.50
34. Speed bumps	26	4.96	2.74	4.04	5.88
35. Rumble strips	22	5.41	2.35	4.55	6.27
36. Raised lane markers	25	5.76	2.92	4.76	6.76
37. Friction reducing paints	23	4.30	2.27	3.49	5.12
38. Lack of speed separation for cyclists	23	4.43	2.24	3.63	5.24
39. Non-standard delineation for bike lanes	22	4.00	2.30	3.16	4.84
40. Lack of signage devoted to bicycle routes and cyclists	23	5.22	2.60	4.29	6.15
41. Curbside auto parking	26	6.44	2.55	5.59	7.30
42. High speed or high-volume traffic	27	8.52	1.83	7.92	9.12
43. High truck volumes	24	8.63	2.08	7.90	9.35
44. Metal grate bridge decks	23	6.26	2.85	5.24	7.28
45. Bridge expansion joints	22	5.55	2.44	4.65	6.44
46. Improper bridge railing height	23	5.48	2.48	4.59	6.37
47. Wheel trapping catch basin grates and gutters	23	8.43	1.69	7.83	9.04
48. Insufficient lighting	25	6.40	2.71	5.47	7.33
49. Stairways	22	5.00	3.10	3.86	6.14
50. Sand, gravel, and other debris on the pavement	26	8.19	2.20	7.45	8.93
51. Debris swept into the bike lanes from motor vehicle lanes	24	7.71	2.17	6.95	8.47
52. Vandalized signs and lights on bike paths	23	4.70	2.46	3.82	5.58
53. Poorly managed work zones	24	6.50	2.61	5.59	7.41
54. Overgrown vegetaton on bike paths	24	5.58	2.22	4.81	6.36
55. Unpruned trees	24	5.79	2.38	4.96	6.62
56. Stray animals, unleashed dogs	25	6.44	2.52	5.58	7.30
57. Unstable at low speeds	23	3.65	2.31	2.82	4.48
58. Difficulty controlling speeds on downgrades	23	4.09	2.06	3.35	4.83
59. Difficulty riding uphill grades	24	3.67	2.03	2.95	4.38
60. Lack of adequate sight distance	24	5.71	2.11	4.97	6.45
61. Large gap requirements when crossing streets	23	6.35	2.08	5.60	7.09
62. Lack of acceleration when turning left	23	5.43	2.61	4.43	6.44
63. Turning left on protected left-turn pases that are too short	25	6.00	2.76	5.06	6.94
64. Failure to yield right of way - cyclist	27	8.41	2.11	7.71	9.10

TABLE E.1 (CONTINUED)

Hazards	Number of Responses	Average Ratings	Standard Deviation	Min. mean at a 90% Confidence	Max. mean at a 90% Confidence
65. Exceeding design speed on downhill grades	26	5.73	2.85	4.78	6.69
66. Reluctance to decelerate or stop at crossings	27	8.07	1.90	7.45	8.70
67. Carriage of large, heavy, or bulky packages	26	4.81	2.62	3.93	5.68
68. Lack of safety equipment	26	7.38	2.57	6.52	8.25
69. Turning right from left of exclusive bus lanes	25	5.68	2.91	4.68	6.68
70. Turning left from the right lane	26	7.19	2.86	6.24	8.15
71. Not maintaining a straight predictable path	27	6.93	2.45	6.12	7.73
72. Riding against traffic	26	8.27	2.23	7.52	9.02
73. Riding under the influence	25	7.38	3.08	6.33	8.43
74. Right-turning motor vehicles crossing bike lanes	26	8.15	1.97	7.49	8.82
75. Failure to yield right-of-way - motorist	27	8.69	1.92	8.05	9.32
76. Encroachment of cars into street space allocated for bicyclists	24	7.38	2.34	6.56	8.19
77. Not knowing or observing the cyclists' right to use the road	27	8.65	1.80	8.06	9.24
78. Driving under the influence	25	9.12	1.80	8.51	9.73
79. Lack of enforcement of the rules of the road for cyclists	26	7.38	2.43	6.57	8.20
80. Cyclist education and training	25	7.20	2.91	6.20	8.20
81. Traffic engineer untrained or unfamiliar with concerns of cyclists	25	8.04	1.75	7.44	8.64
82. Lack of safe bicycle parking	26	5.62	2.92	4.64	6.59
83. Pedestrians, joggers, etc. on exclusive bicycle lanes	24	6.00	2.14	5.25	6.75
84. Unable to transport bikes on trains, trams, buses, and taxis	25	5.16	3.11	4.10	6.22
85. Bike paths and bike routes through crime-ridden locations	23	6.48	2.81	5.47	7.48
86. Air quality	25	6.44	3.01	5.41	7.47

APPENDIX F

SUMMARY OF THE ACCIDENT STUDIES

TABLE F.1 ACCIDENT DATA

		Texas DPS - 1988		Texas DPS - 1989		Texas DPS - 1990		Texas DPS - 1991	
		Total	Percentage*	Total	Percentage*	Total	Percentage*	Total	Percentage*
Speed over limit/too fast for conditions		68	4.8%	54	4.2%	42	3.6%	56	5.6%
Speed under limit - unsafe		201	14.3%	166	13.0%	153	13.1%	108	10.8%
Fail to yield ROW to vehicle	Total	502	35.6%	400	31.3%	335	28.7%	299	30.0%
	Motorist	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Bicyclist	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Disregard traffic control device	Total	66	4.7%	73	5.7%	57	4.9%	51	5.1%
	Motorist	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Bicyclist	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Improper passing or turn:	Total	21	1.5%	21	1.6%	17	1.5%	27	2.7%
	Motorist	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Bicyclist	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Unsafe lane change:	Motorist	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Bicyclist	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Bicyclist riding against traffic flow		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Wrong way driving		30	2.1%	16	1.3%	14	1.2%	13	1.3%
Following too closely	Total	4	0.3%	14	1.1%	19	1.6%	16	1.6%
	Motorist	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Bicyclist	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Overtake & pass insufficient clearance		7	0.5%	9	0.7%	10	0.9%	12	1.2%
Illegal passing		24	1.7%	35	2.7%	45	3.9%	35	3.5%
Improper parking/start from parked pos.		14	1.0%	11	0.9%	2	0.2%	5	0.5%
Drive under influence (D.U.I.)		90	6.4%	73	5.7%	80	6.9%	76	7.6%
No light on bicycle at night		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Inattentive driving		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Failure to have control		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Bicyclist travelling in Ped. areas		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Cyclist too close to parked car		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Cyclist swerves unexpectedly		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Other violations		382	27.1%	408	31.9%	393	33.7%	300	30.1%
Total Violations		1409	100.0%	1280	100.0%	1167	100.0%	998	100.0%
Unknown or other cause		2310	n/a	2062	n/a	1713	n/a	1734	n/a
Total Accidents		3719	n/a	3342	n/a	2880	n/a	2732	n/a

* Percentage calculated based on total violations.

TABLE F.1 (CONTINUED)

		Texas DPS - 1992		Texas DPS - Avg. 1988-92	
		Total	Percentage*	Total	Percentage*
Speed over limit/too fast for conditions		38	3.8%	51.6	4.4%
Speed under limit - unsafe		123	12.2%	150.2	12.8%
Fail to yield ROW to vehicle	Total	339	33.7%	375.0	32.0%
	Motorist	n/a	n/a	n/a	n/a
	Bicyclist	n/a	n/a	n/a	n/a
Disregard traffic control device	Total	53	5.3%	60.0	5.1%
	Motorist	n/a	n/a	n/a	n/a
	Bicyclist	n/a	n/a	n/a	n/a
Improper passing or turn:	Total	23	2.3%	21.8	1.9%
	Motorist	n/a	n/a	n/a	n/a
	Bicyclist	n/a	n/a	n/a	n/a
Unsafe lane change:	Motorist	n/a	n/a	n/a	n/a
	Bicyclist	n/a	n/a	n/a	n/a
Bicyclist riding against traffic flow		n/a	n/a	n/a	n/a
Wrong way driving		11	1.1%	16.8	1.4%
Following too closely	Total	12	1.2%	13.0	1.1%
	Motorist	n/a	n/a	n/a	n/a
	Bicyclist	n/a	n/a	n/a	n/a
Overtake & pass insufficient clearance		17	1.7%	11.0	0.9%
Illegal passing		41	4.1%	36.0	3.1%
Improper parking/start from parked pos.		7	0.7%	7.8	0.7%
Drive under influence (D.U.I.)		76	7.5%	79.0	6.7%
No light on bicycle at night		n/a	n/a	n/a	n/a
Inattentive driving		n/a	n/a	n/a	n/a
Failure to have control		n/a	n/a	n/a	n/a
Bicyclist travelling in Ped. areas		n/a	n/a	n/a	n/a
Cyclist too close to parked car		n/a	n/a	n/a	n/a
Cyclist swerves unexpectedly		n/a	n/a	n/a	n/a
Other violations		267	26.5%	350.0	29.9%
Total Violations		1007	100.0%	1172.2	100.0%
Unknown or other cause		1953	n/a	1954.4	n/a
Total Accidents		2960	n/a	3126.6	n/a

* Percentage calculated based on total violations.

TABLE F.1 (CONTINUED)

		Tempe, Az. -1987		Tempe, Az. - 1988		Tempe, Az. - 1989		Tempe, Az. - 1990	
		Total	Percentage	Total	Percentage	Total	Percentage	Total	Percentage
Speed over limit/too fast for conditions		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Speed under limit - unsafe		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Fail to yield ROW to vehicle	Total	93	33.2%	65	26.5%	68	29.1%	62	23.2%
	Motorist	61	21.8%	39	15.9%	43	18.4%	45	16.9%
	Bicyclist	32	11.4%	26	10.6%	25	10.7%	17	6.4%
Disregard traffic control device	Total	42	15.0%	21	8.6%	22	9.4%	18	6.7%
	Motorist	13	4.6%	3	1.2%	5	2.1%	7	2.6%
	Bicyclist	29	10.4%	18	7.3%	17	7.3%	11	4.1%
Improper passing or turn:	Total	23	8.2%	48	19.6%	29	12.4%	37	13.9%
	Motorist	23	8.2%	34	13.9%	19	8.1%	35	13.1%
	Bicyclist	0	0.0%	14	5.7%	10	4.3%	2	0.7%
Unsafe lane change:	Motorist	n/a	n/a	n/a	n/a	n/a	n/a	2	0.7%
	Bicyclist	n/a	n/a	n/a	n/a	n/a	n/a	8	3.0%
Bicyclist riding against traffic flow		102	36.4%	97	39.6%	99	42.3%	126	47.2%
Wrong way driving		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Following too closely	Total	15	5.4%	12	4.9%	6	2.6%	10	3.7%
	Motorist	10	3.6%	8	3.3%	5	2.1%	7	2.6%
	Bicyclist	5	1.8%	4	1.6%	1	0.4%	3	1.1%
Overtake & pass insufficient clearance		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Illegal passing		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Improper parking/start from parked pos.		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Drive under Influence (D.U.I.)		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
No light on bicycle at night		5	1.8%	2	0.8%	10	4.3%	4	1.5%
Inattentive driving		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Failure to have control		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Bicyclist travelling in Ped. areas		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Cyclist too close to parked car		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Cyclist swerves unexpectedly		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Other violations		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Total Violations		280	100.0%	245	100.0%	234	100.0%	267	100.0%
Unknown or other cause		50	n/a	8	n/a	13	n/a	13	n/a
Total Accidents		330	n/a	253	n/a	247	n/a	280	n/a

* Percentage calculated based on total violations.

TABLE F.1 (CONTINUED)

		Tempe, Az. - 1991		Tempe, Az. Avg. 1987-91	
		Total	Percentage	Total	Percentage
Speed over limit/too fast for conditions		n/a	n/a	n/a	n/a
Speed under limit - unsafe		n/a	n/a	n/a	n/a
Fail to yield ROW to vehicle	Total	50	19.5%	67.6	26.3%
	Motorist	31	12.1%	43.8	17.1%
	Bicyclist	19	7.4%	23.8	9.3%
Disregard traffic control device	Total	26	10.1%	25.8	10.1%
	Motorist	5	1.9%	6.6	2.6%
	Bicyclist	21	8.2%	19.2	7.5%
Improper passing or turn:	Total	31	12.1%	33.6	13.1%
	Motorist	29	11.3%	28.0	10.9%
	Bicyclist	2	0.8%	5.6	2.2%
Unsafe lane change:	Motorist	0	0.0%	1.0	0.4%
	Bicyclist	3	1.2%	5.5	2.1%
Bicyclist riding against traffic flow		137	53.3%	112.2	43.7%
Wrong way driving		n/a	n/a	n/a	n/a
Following too closely	Total	4	1.6%	9.4	3.7%
	Motorist	3	1.2%	6.6	2.6%
	Bicyclist	1	0.4%	2.8	1.1%
Overtake & pass insufficient clearance		n/a	n/a	n/a	n/a
Illegal passing		n/a	n/a	n/a	n/a
Improper parking/start from parked pos.		n/a	n/a	n/a	n/a
Drive under influence (D.U.I.)		n/a	n/a	n/a	n/a
No light on bicycle at night		6	2.3%	5.4	2.1%
Inattentive driving		n/a	n/a	n/a	n/a
Failure to have control		n/a	n/a	n/a	n/a
Bicyclist travelling in Ped. areas		n/a	n/a	n/a	n/a
Cyclist too close to parked car		n/a	n/a	n/a	n/a
Cyclist swerves unexpectedly		n/a	n/a	n/a	n/a
Other violations		n/a	n/a	n/a	n/a
Total Violations		257	100.0%	256.6	100.0%
Unknown or other cause		2	n/a	17.2	n/a
Total Accidents		259	n/a	273.8	n/a

* Percentage calculated based on total violations.

TABLE F.1 (CONTINUED)

		Madison, Wis. - 1992		Winnipeg, Manitoba, Canada - 1976-89			Total
		Total	Percentage	Total	Avg. per Year	Percentage	Data Points
Speed over limit/too fast for conditions		3	1.6%	n/a	n/a	n/a	6
Speed under limit - unsafe		n/a	n/a	n/a	n/a	n/a	5
Fail to yield ROW to vehicle	Total	87	47.3%	794	56.7	34.6%	25
	Motorist	61	33.2%	447	31.9	19.5%	20
	Bicyclist	26	14.1%	347	24.8	15.1%	20
Disregard traffic control device	Total	7	3.8%	286	20.4	12.5%	25
	Motorist	n/a	n/a	31	2.2	1.4%	19
	Bicyclist	7	3.8%	255	18.2	11.1%	20
Improper passing or turn:	Total	n/a	n/a	230	16.4	10.0%	24
	Motorist	n/a	n/a	113	8.1	4.9%	19
	Bicyclist	n/a	n/a	117	8.4	5.1%	19
Unsafe lane change:	Motorist	n/a	n/a	29	2.1	1.3%	16
	Bicyclist	n/a	n/a	n/a	n/a	n/a	2
Bicyclist riding against traffic flow		n/a	n/a	174	12.4	7.6%	19
Wrong way driving		n/a	n/a	n/a	n/a	n/a	5
Following too closely	Total	n/a	n/a	n/a	n/a	n/a	10
	Motorist	n/a	n/a	n/a	n/a	n/a	5
	Bicyclist	n/a	n/a	n/a	n/a	n/a	5
Overtake & pass insufficient clearance		n/a	n/a	104	7.4	4.5%	19
Illegal passing		n/a	n/a	n/a	n/a	n/a	5
Improper parking/start from parked pos.		n/a	n/a	5	0.4	0.2%	19
Drive under influence (D.U.I.)		n/a	n/a	n/a	n/a	n/a	5
No light on bicycle at night		n/a	n/a	230	16.4	10.0%	19
Inattentive driving		32	17.4%	n/a	n/a	n/a	1
Failure to have control		n/a	n/a	90	6.4	3.9%	14
Bicyclist travelling in Ped. areas		55	29.9%	328	23.4	14.3%	15
Cyclist too close to parked car		n/a	n/a	107	7.6	4.7%	14
Cyclist swerves unexpectedly		n/a	n/a	102	7.3	4.4%	14
Other violations		n/a	n/a	n/a	n/a	n/a	5
Total Violations		184	100.0%	2479	177.1	108.1%	12
Unknown or other cause		36	n/a	n/a	n/a	n/a	n/a
Total Accidents		220	n/a	2293	163.8	100.0%	n/a

* Percentage calculated based on total violations.