MTI Report 01-01

Statewide Safety Study of Bicycles and Pedestrians on Freeways, Expressways, Toll Bridges, and Tunnels

Dr. Thomas C. Ferrara, PE

September 2001

a publication of the
Mineta Transportation Institute
College of Business
San José State University
San Jose, CA 95192 - 0219

Created by Congress in 1991

Technical Report Documentation Page

1. Report No. FHWA/CA/OR-01/20	2. Government Accession No.	3. Recipient’s Catalog No.
4. Title and Subtitle Statewide Study of Bicycles and Pedestrians on Freeways, Expressways, Toll Bridges and Tunnels.		5. Report Date September 2001
		6. Performing Organization Code
7. Authors Thomas C. Ferrara, A. Reed Gibby		8. Performing Organization Report No. 01-01
9. Performing Organization Name and Address Mineta Transportation Institute College of Business, San José State University San Jose, CA 95192-0219		10. Work Unit No.
		11. Contract or Grant No. 65W136
12. Sponsoring Agency Name and Address California Department of Transportation Sacramento, CA 95819	U.S. Department of Transportation Research and Special Programs Administration 400 7th Street, SW Washington, DC 20590-0001	13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code

15. Supplementary Notes

This research project was financially sponsored by the U.S. Department of Tranportation’s Research and Special Programs Administration and by the California Department of Transportation (Caltrans).

16. Abstract

The purpose of this study is to attempt to clarify some of the issues pertaining to bicycle on freeways. Specifically, the goal of this project is to develop policy recommendations and guidelines for bicycle and pedestrian use of freeway shoulders.

Based on the literature and investigations done as part of this study, highway bicycle collision rates per mile of bicycle travel are an order of magnitude higher than collision rates for motor vehicle traffic. Bicycle collisions are no more frequent on bridges and in tunnels than on the approaches to the bridges and tunnels. Overall vehicle collision rates are no higher on freeways open to bicycles than they are on adjacent highways open to bicycles.

Most freeway pedestrian collisions involve individuals who enter the freeway in a vehicle and leave the vehicle. A disproportionate share of these pedestrian collisions are related to installing and removing tire chains.

The project recommendations include: enhanced efforts to inform drivers and passengers of the dangers related to exiting their vehicles on a freeway, a bicycle counting program to establish bicycle ridership and collision rates, a requirement to wear a helmet and possess a drivers license to operate a bicycle on the freeway, a minimum of eight foot paved shoulders on freeways that are open to bicycles, and restrictions relating to bicycles crossing freeway ramps on the freeway side.

17. Key Words bicycle, bicycle collision, bicycle facilities, bicycle safety, bicycle travel, freeways, expressways, toll bridges, tunnels, highway safety, pedestrian safety, pedestrians, policy, transportation	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages avg is 156	22. Price $15.00

Form DOT F 1700.7 (8-72)

Library of Congress Catalog Card Number No. 2001094828

To order this publication, please contact the following:

Mineta Transportation Institute
College of Business
San José State University
San Jose, CA 95192-0219
Tel (408) 924-7560
Fax (408) 924-7565
e-mail: mti@mti.sjsu.edu
http://transweb.sjsu.edu

ACKNOWLEDGMENTS

The authors gratefully acknowledge the many individuals and organizations that contributed to the success of this study. The project was on a very tight schedule and many people cooperated promptly and efficiently. The assistance is greatly appreciated and most of it is acknowledged here. To those we inadvertently omitted from this list, we also offer our sincere thanks.

The research director at the Mineta Institute, Trixie Johnson, had confidence in the project team and supported our efforts throughout the year from early project initiation to peer review of the final report. Jerri Carmo, Director, Office of Sponsored Programs at San José State University Foundation, is also thanked for efficiently expediting our paperwork.

The staff at The University Foundation at California State University, Chico, was helpful throughout. Special thanks to Diane M. Johnson for helping with the proposal, Keith Olson, Gina Hall, and Betty Skala for project accounting and financial administration, and to Jeffery Wright, Director of the Office of Sponsored Programs, for his leadership.

Academic administrators at California State University, Chico, helped by properly scheduling release time. Dean Ken Derucher of the College of Engineering, Computer Science and Technology, and Chair Maurice Mow of the Department of Civil Engineering deserve recognition. Dagmar Hampton, Administrative Coordinator of at the Civil Engineering Department, often assisted the Chair and helped with project paperwork.

The California Department of Transportation, Office of Traffic Safety Research, provided technical project monitoring and managed the project advisory committee. Meetings also were scheduled with the Statewide Pedestrian Safety Task Force. Craig Copelan heads the office and his support was invaluable. Hung Tu Giang ably provided much of the needed assistance promptly and efficiently. His predecessor, Maggie O’Mara, got the project off to a great start. Office engineers Ahmad Khorashadi and Greg Tom provided technical assistance.

Many individuals statewide, in The California Department of Transportation, were extremely helpful with project data and in answering questions. Department management at a high level gave this project priority. Debbie Silva and the staff in the TASAS unit were continually efficient in responding very quickly to our collision data needs. The state bicycle coordinator, Richard Blunden, initially, and Ken McGuire, often provided data and insights. Other Caltrans people who provided data and answered questions are Lynn Miller, Mark Suchanek, Kristi Burney, Justin Cochran, Bob Buckley, Jim Douglas, Angi Dodd, Gary Dossey, Troy Scheiber, Tim Rochte, Sharon Severson, and Luis Melendez. Their assistance and support is likewise acknowledged and appreciated.

Many individuals from other agencies were very helpful. Deserving of recognition are Peter Tannen and Mark Erickson of the City and County of San Francisco; Darrel Perry and Ann Briggs of

Washington DOT; Kathleen McConnel of Oregon DOT; Masoud Akbarzadeh, Dan Collin, and Ananth Prasud of Santa Clara County; Jennifer Rice of Natural Resource Services, RCAA; and Bev Christ of the California Highway Patrol SWITTERS unit.

Individuals who responded to our request for information on various listserves and through other e-mail contacts are Alan Wachtel, Alan Forkosh, Joshua Putnam, Wilson Hubbel, Alex Zuckermann, Dan Gutierrez , Riley Geary, and Alan Forkosh. Their input is appreciated.

Students from California State University, Chico, who worked to collect data for this project and helped formulate study procedure through preliminary research studies are Julie Blue, Dan Cikuth, Shawn Hagstrom, Jason Wilcox, Mike Winton, Al Reed, and, James Ralston. Curt Haselton greatly assisted in the response to the peer review. He suggested many improvements in formatting the tables and figures. The work he did and his exemplary helpfulness substantially contributed to the quality of this final report. Student contributions are always an important part of the research work done in the California Public Works Studies Program in Civil Engineering at California State University, Chico. Their efforts and questioning certainly improved the quality of this research effort and final report.

Jan Botha, Professor of Civil and Environmental Engineering, and Mellownie Salvador, a graduate student, both at San José State University, completed the surveys of other agencies reported on in Chapter 2. Their considerable effort and productivity was important to this final report.

Additionally, the project team reported to the State Wide Pedestrian Safety Task force and obtained guidance from a project steering committee. Members of both groups, not cited above, that made contributions are listed here. Generally, these individuals served as the study advisory committee. They assisted in establishing a work plan, identifying specific highway segments for study, and contributed suggestions to project recommendations:

Mr. Zac Wald, Executive Director, BAYPEDS
Mr. Chris Morfas, Executive Director, California Bicycle Coalition
Mr. Dale Benson, Senior Transportation Engineer, Caltrans
Ms. Ann Murphy, Associate Transportation Engineer, Caltrans
Dr. David Ragland, Professor of Epidemiology, UC Berkeley
Paul J. Ossenbruggen, Ph.D., Institute of Transportation Studies, UC Berkeley
Mr. Maurice Shiu, Deputy Public Works Director, Transportation, Contra Costa County
Mr. Tony Anziano, Deputy Attorney, Caltrans
Mr. John Cicarelli, Associate Development Engineer, Institute of Transportation Studies,
    UC Berkeley
Ms. Patricia Mora, Office of Traffic Safety
Mr. Mark Rasmussen, California Highway Patrol
Ms. Anne Seeley, Department of Health Services

Ms. Kathy Anderson, Department of Motor Vehicles
Ms. Barb Alberson, Chief, Department of Health Service
Mr. David Cordova, Caltrans
Ms. Diane G. Winn, Associate Director, Pediatric Injury Prevention Research
Ms. Christine Ratekin, Senior Transportation Engineer, Caltrans
Mr. John R. Lonberg, Vice President, Californians for Disability Rights
Mr. Ray Duryee, Operations Manager, Redding Area Bus Authority
Ms. Vicky Cloud, Mother Against Drunk Driving
Mr. Gene Lozano, California for Blind, CSU Sacramento
Ms. Lynn Walton-Haynes, Department of Health Services
Ken Kochevar, Federal Highway Administration
Arthur Duffy, Bay Conservation and Development Commission
Ms. Nancy W. Okasaki, Metropolitan Transportation Commission
Mr. Mike Brown, Chief, California Highway Patrol
Hassan Mohtar, Caltrans District 7, Special Studies
Sandy Champion
Alice Huffaker

John Cicarelli is one individual who deserves special recognition. He willingly shared his knowledge of bicycle traffic control and facility design. The valuable contributions significantly aided our study.

The authors of this report are thankful for the opportunity to work on this project. It truly was enjoyable with all the support and assistance offered by the individuals and organizations acknowledged here.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Currently, 948 of the total 4,224 miles of freeway in California are open to bicycles. Often, bicyclists need access to freeways to reach their destinations. Current Caltrans policy states, “when a suitable alternative route does not exist, a freeway shoulder may be considered for bicycle travel.” As a multimodal agency, Caltrans should make some modest efforts to accommodate bicycle travel on freeways in prudent circumstances.

The purpose of this study is to attempt to clarify some of the issues pertaining to bicycles on freeways. Specifically, the goal of this project is to “develop policy recommendations, guidelines, and policies for bicycle and pedestrian use of freeways, expressways, tunnels, and toll bridges in California.”

SURVEY AND LITERATURE SEARCH

The initial efforts were to attempt to establish a precedent for bicycle and pedestrian use of freeways. This was accomplished by both a literature search and a survey of other Departments of Transportation (DOTs) and toll road authorities. Of 17 respondents, 15 reported having specific policies regarding bicycle use of freeways, yet only three allow bicycles access to freeway shoulders.

In regard to pedestrian use of freeways, 10 out of 13 respondents replied that they have specific policies related to pedestrian use of roadways. Fourteen respondents stated that pedestrians were not allowed to travel on freeway shoulders. The Nebraska DOT was the only respondent to state that pedestrians were allowed on “any highway other than the Interstate.”

The literature review found some statistical data relating to collision occurrence and was supported by research done in this study. Data are somewhat clouded by the fact that only a small percentage of the total bicycle-involved collisions are reported to the police (one survey reported 29 percent of all highway bicycle collisions), but trends still can be seen. Because bicycle traffic is relatively low, bicycle collisions are rare, especially on freeways. The table below shows some collision rates developed in this study and some found through the literature search.

Rates labeled “reported” are based on formal traffic collision reports. The others are based on surveys of bicyclists.

Source/Location	*Bicycle-Involved Collisions per Million Bicycle Miles*
Kaplan[a]	113
Moritz[b]	66
Expressways in Santa Clara County	19+ reported
Bridges/Tunnels Studied from Chapter 5	16 reported
Internet Survey	24
SR 101, Humbolt County, CA, District 1	5 reported

a. Jerrold A. Kaplan, *Characteristics of The Regular Adult Bicycle User.* Federal Highway Administration (1975)

b.1. William E. Moritz, *Adult Bicycle in the United States: Characteristics and Riding Experience in 1996*. Transportation Research Record No. 1636 (1998), 4.

COLLISION PATTERNS

The specific circumstances involved in each collision are also important to studying bicycle collisions. Observing large groups of collisions may make it possible to develop trends and thereby identify ways to improve safety. A study of bicycle-related collisions on freeways in Caltrans Districts 1, 2, and 3 provided the following results.

A total of 41 collisions occurred on the freeway in the nine years of study (1990-1998). Bicycle-motor vehicle collisions accounted for 61 percent of all collisions in the study. The bicyclist was found to be at fault by the reporting police officer in 73.2 percent of the collisions. The two most prevalent causes of bicycle-motor vehicle collisions were improper turns (29.3 percent) and the influence of alcohol (19.5 percent). A high percentage of collisions involved injury (85.4 percent); 7.3 percent of reported collisions were fatal. There was a fairly even distribution of collisions that occurred on freeways that allowed bicycle access (61 percent) versus freeways where bicycle access was restricted (39 percent). The table below lists some bicycle-on-freeway collision patterns.

15 Single-Bicycle Collisions
9 Hit Object
4 Hit Drain Inlet
1 Hit Pedestrian
1 Equipment Failure
14 Collisions with Motor Vehicle at Ramp Terminal
10 Off Freeway Ramp Locations
4 On Freeway Ramp Locations
12 Mainline Freeway Motor Vehicle Collisions
7 Motor Vehicles Entered Shoulder
5 Bicycles in Freeway Lane

A similar study was made regarding pedestrians on freeways in Caltrans Districts 2 and 3. A total of 327 pedestrian collisions occurred on freeways in these districts from 1990 through 1998. The majority (64.5 percent) involved pedestrians who had left a motor vehicle. Motor vehicles were most commonly found to be at fault, at 61.5 percent. Speeding was the primary collision factor associated with pedestrian collisions, at 35.8 percent. A total of 70.6 percent of collisions were reported as involving injury; 24.5 percent of collisions were reported as fatal. Snow was a major factor in pedestrian collisions, with 26.3 percent occurring in icy conditions. Of the collisions studied, 53.2 percent were the result of pedestrians being struck while assisting a disabled vehicle.

INTERNET SURVEY

During the course of this study, Caltrans conducted a survey of bicyclists over the Internet. Several questions tailored specifically to this study were added to the survey. Some collision rates were derived from the data, and information was compiled regarding the percent of injury collisions, percent involved with motor vehicles, and percent reported to law enforcement agencies. The table below presents some results from the 1,239 usable surveys. The respondents individually classified their position as to highway or nonhighway.

Collision	***Cyclists on Highway***	***Cyclists on Nonhighway***
% Injury	90	54
% Bicycle With Motor Vehicle	35	16
% Reported to Law Enforcement	29	7

BRIDGES AND TUNNELS

To address questions of the safety record of bicycles on bridges, the collision history of some structures was studied. A collision ratio was established by dividing the number of collisions reported on all structures over a nine-year period by the total length of structures. Two similar ratios were derived for the approaches to the structures. One was for 500 feet on either side of the structure, and the other was for 5 miles. The 5-mile approach was used only for bridges and tunnels under Caltrans jurisdiction. The collision ratio for all structures was 0.62 collisions per mile during the 9-year period. The 500-foot-approach collision ratio was 2.6 collisions per mile. For Caltrans bridges and tunnels only, the collision ratio was 0.84 collisions per mile. The 5-mile approaches had a collision ratio of 1.06.

Although the data includes very few collisions, it shows that bicycle collisions on bridges and tunnels are rare events. This can be due to a number of reasons, but the data compiled here do not indicate that bridges and tunnels currently open to bicycles have more frequent collisions than the adjacent highways.

STATISTICAL ANALYSIS OF COLLISIONS AND BICYCLE STATUS

In a statistical analysis of all collisions on freeways, the independent variable of Bicycle Status (bicycles permitted or prohibited) was used to attempt to predict collision rates on freeways. Bicycle Status was not found to be an adequate predictor of collision history to the 5 percent level. The lack of

Bicycle Status as a significant variable suggests that allowing bicycles on freeways does not have an adverse effect on vehicle collision rates.

RICHMOND-SAN RAFAEL BRIDGE

Under the current configuration, the Richmond-San Rafael Bridge is not suited for bicycle access, but with minor alterations, bicycles might be able to travel on the shoulder safely. The following is provided as an example of what would need to be done if the bridge were opened to bicycles.

Railing requirements for the Richmond-San Rafael Bridge may be given special consideration due to their width and their location relative to the traveled way. Only slight modifications to the railings, if any, would be needed to make the bridge ready for bicycle travel. Expansion joints would have to be covered to prevent bicycle wheel entrapment.

The Richmond-San Rafael Bridge fits the 8-foot shoulder requirement. Currently, the bridge has 12-foot shoulders over most of the span. The wide shoulders enable bicycles to travel well separated from both motor vehicles and the bridge rail. The 12-foot space does create a problem, in that motor vehicles have been observed using the shoulders for travel and passing. One permanent section has a narrow shoulder, and due to the upcoming seismic retrofit construction, there will be some semipermanent obstructions to the shoulder. Bicycle access should not be granted while there are sections of the shoulder closed to travel and until a continuous 8-foot shoulder can be maintained.

Despite these barriers, the bridge is suited to bicycles in that bicycles could access the bridge without crossing freeway ramps. Direct connections to avoid ramp crossings by bicycles would have to be added.

RECOMMENDATIONS

The recommendations developed by this study include user education, data collection, age restrictions, shoulder geometry, and procedures to allow bicyclists to cross ramps. Key recommendations are offered here in bold face type. Additional information on the recommendations can be found in Chapter 7 of this report.

Pedestrians on Freeways

How to impose pedestrian safety on freeways poses a dilemma. For the 35 percent of pedestrians involved in collisions that entered the freeway illegally, the collision-prevention solution is to stop them from entering. However, the majority of pedestrians involved left their vehicles and may not have been acting illegally. The problem is simply that a pedestrian in or near the right-of-way is in jeopardy.

The solution then is to **continue and enhance efforts to inform drivers that they should avoid exiting their vehicles on freeways.** When a pedestrian absolutely must leave a vehicle, it is imperative that the pedestrian move as far from the traveled way as possible. Many accidents have been caused when pedestrians installing chains in snowy conditions were struck by motor vehicles. Drivers need to be informed of these dangers.

Data Collection—Count Bicycles

Caltrans currently has no program to count bicycles on freeways. Bicycle travel is difficult to measure and quantify. There is no question that average daily bicycle traffic on freeways is low relative to motor vehicles. **A bicycle-counting program needs to be implemented in order to further study bicycles in a quantitative manner.** A count program would not need to be comprehensive, in that not all state highways would need bicycle counts. Locations of counts could be established where there appears to be some concentration of bicycle travel, where bicycle collisions have been identified, or where there is public demand.

Rider Requirements

Many freeway sections in California are currently open to bicycle travel, and it is assumed that bicyclists riding these roadways are of a certain level of maturity. Rather than use age, which would be hard to enforce, **the possession of a driver's license should be a requirement for using a bicycle on freeway shoulders.** Doing so would theoretically meet the following criteria: The user is at least 16 years of age and has a basic understanding of the movements of motor vehicles using freeways .

Because of the higher-than-ordinary severity rate for collisions involving bicycles on freeways, **cyclists should be required to wear helmets while riding on freeway shoulders. A vehicle code change would be necessary to implement these recommendations.**

Shoulder Width

With the current trend of adding rumble strips to freeway shoulders, the width of freeway shoulders is a concern if bicycles are to be allowed there. Because of wind forces and geometric space requirements, bicycles should not be expected to ride in or directly alongside the traveled way. Therefore, if bicyclists are to be given access to freeway shoulders, they should ride on the shoulder, to the right of the rumble strip.

The width from the edge of the traveled way to the outside of the rumble strips is up to 3 feet. A remaining width of 5 feet provides an area that is comfortable and safe for a bicycle. This gives a **total shoulder width of 8 feet, as a minimum, that should be provided on freeways open to bicycles.** It was found from the literature search that at 70 miles per hour, a large vehicle can produce enough lateral wind force to overturn a bicycle. Allowing full 8-foot shoulders diminishes the problem of wind pushing the bicyclist. **No new freeway segments should be open to bicycles unless there is an 8-foot continuous shoulder. Existing freeways open to bicycles should be improved to provide the continuous shoulder as part of the long-range state highway improvement program.**

Drain inlets, which may trap a bicycle tire, must be reconstructed or removed from highway shoulders where bicycles are allowed to ride.

Ramp Crossing

The responsibility of crossing a freeway ramp safely should rest with the bicyclist. Because bicycles are physically smaller than cars and provide less protection, bicyclists are at a major disadvantage in a collision with a motor vehicle. Reasonable expectations are the following:

- Cyclists understand they must cross high-speed motor vehicle traffic
- Motorists are expecting to merge and diverge smoothly without crossing conflicts.

All freeway ramps at which bicycles are allowed to cross on the freeway side need to be reviewed by Caltrans. While the quantitative recommendations here are based on estimates and not statistically verified by experience, they serve as a starting point for future study and refinement.

A safe crossing sight distance at least equal to the distances cited in Chapter 4 would need to be available to the bicyclist at the location where

the ramp would normally be crossed. On freeway off-ramps where approaching traffic has a 70-mph speed limit, a safe crossing sight distance of 760 feet is warranted. This assumes an 85th percentile speed of 74 mph. For freeway on-ramps with prevailing approach speeds of 45 mph, a sight distance of 460 feet would be needed.

The volumes of ramps to be crossed by a bicycle must provide adequate gaps to make a safe crossing. **Bicyclists should not be given access to cross ramps with repeated peak hour volumes at or above 500 vehicles per hour.**

High-volume ramps and locations without safe crossing sight distances need to be signed to require that bicyclists leave the freeway. Multilane ramp crossings, weave areas, and areas where a bicycle may be forced to approach an on-ramp that does not meet the ramp crossing criteria cited above need to be closed to bicycle travel. Alternate routes should be provided.

INTRODUCTION

PURPOSE

Currently, 948 of the total 4,224 miles of freeway in California are open to bicycles. Often, bicyclists need access to freeways to reach their destinations. Current California Department of Transportation (Caltrans) policy states, “When a suitable alternate route does not exist, a freeway shoulder may be considered for bicycle travel.” Bridges and tunnels, as well as many rural freeway sections, often do not have suitable alternative routes.

The lack of an alternative route should not be the only variable considered when determining whether a freeway is fit for bicycle travel. Unfortunately, no common methods or criteria currently are being employed to measure how well a given section of freeway is suited for bicycles. Caltrans policy leaves the final determination with the local district, offering several roadway factors to consider.

Initially, many people think the idea of allowing bicycles on freeways is ludicrous, and the majority of motorists are completely unaware that bicycles ever are allowed on freeways. Further analysis of the subject, however, reveals that not only do bicycles have access to some freeways, but they are actually encouraged to ride in some areas, such as the Pacific Coast Bike Route. Despite the history of bicycles on freeways, it is difficult to assess the success of allowing bicycle access.

The purpose of this study is to attempt to clarify some of the issues pertaining to bicycles on freeways. Specifically, the goal of this project is to “develop recommendations, guidelines, and policies for bicycle and pedestrian use of freeways, expressways, tunnels, and toll bridges in California.” Although pedestrians and bicycles are hardly similar, the nature of the study allowed pedestrians to be analyzed without excessive extra effort.

BACKGROUND

During the Richmond-San Rafael Bridge Public Access Feasibility Study, Caltrans agreed to sponsor a statewide study defining use and collision data for pedestrians and bicycles on freeway shoulders, including toll bridges and tunnels. On March 30, 1999, representatives of the California Highway Patrol

(CHP), bicycle advocacy groups, and Caltrans met to identify a format for the study. From this meeting, the following issues were identified for study:

- How safe is the nonmotorized use of shoulders on freeways, tunnels, bridges, and expressways? How is the degree of safety on these facilities determined, measured, and evaluated? What level of safety is acceptable for nonmotorized usage?
- Is safety the same for urban freeways and rural freeways? Should they be evaluated differently?
- What special factors for bicyclist/pedestrian safety are there through interchanges and on/off-ramps?
- How should usage data be collected and evaluated? Should the collision rate for bicyclists/pedestrians be the same as for vehicles? Is the collision rate for bicycles based on miles traveled or exposure? How are bicycle collision rates compared to vehicle collision rates?
- When/where would pedestrians be allowed to use freeway shoulders?
- Are there any bridges nationwide that allow bicycle access and are they comparable to those in the San Francisco Bay Area?
- How are the characteristics of the expected users factored into access decisions?
- How important are recovery areas for bicyclists/pedestrians using freeway shoulders?
- What data is to be collected and what will be the eventual usage?

In January of 2000, the Mineta Institute of Surface Transportation Policy Studies at San José State University contracted with The Research Foundation at California State University, Chico, to complete the study. The project began immediately, due to a tight time frame. A draft final report for peer review was delivered in September 2000.

The study budget and time frame did not permit extensive counting of bicycles and pedestrians; however, some counting of bicycles was done. Seasonal variations could not be established with a study period substantially under one year. Any existing pedestrian and bicycle count data were utilized as they were discovered. Very little count data became available.

The study encompassed freeways, expressways, toll bridges, and tunnels. The directive was to use data on expressways to help determine the best manner, if any, to accommodate bicycles and pedestrians on freeways. While freeways were to be the focus of the study, toll bridges and tunnels also were included.

A freeway is a limited-access highway with several significant characteristics:

- Vehicles traveling in opposite directions are separated by a continuous unpaved median or fixed barrier
- There are at least two lanes in each direction
- At-grade crossing conflicts are not allowed
- Vehicles enter and exit a freeway with merge, diverge, and weave movements.

After the study began, continual guidance and input was received from a steering committee. Progress of the project was presented in the form of six working papers, which served as the basis of this report. Each working paper was delivered to the steering committee with a request for comments. Replies were taken into consideration when writing the final report. Three steering committee meetings were held over the course of the study.

The first steering committee meeting was held on Thursday, February 10, 2000, in Sacramento. The main focus of this meeting was to formulate a final work plan.

The second steering committee meeting was held in San Diego on Monday, April 24, 2000, during a State Office of Traffic Safety summit. A working paper on the literature search relating to bicycle transportation was distributed and discussed at this meeting. The committee also was asked for, and offered, additional bridge and tunnel sites for study.

The final steering committee meeting was held on Friday, August 25, 2000, in Sacramento, to address project recommendations. A policy recommendations working paper was distributed to the committee; major findings and recommendations were discussed.

The draft final version of this report was submitted to the Mineta Institute for Transportation Policy Studies in September 2000. Peer reviews were conducted at the California Department of Transportation and by an anonymous reviewer. Complete peer reviews were returned to the authors in April 2001. The draft final report was adjusted, edited, and improved based on the reviews. This final report is the result.

STUDY CONTENTS

Chapters 2 through 6 of this study present independent research efforts.

Chapter 2, the survey and literature search, describes studies pertaining to bicycles and pedestrians on freeways, but there is a lack of general knowledge on the subject. Numerous references are summarized, and the policies relating to bicycles on freeways of other states are reported.

Chapter 3 contains a study of Santa Clara County expressways, using the Statewide Integrated Traffic Records System (SWITRS) collision data. The objective of this study was to attempt to find trends in the collision data.

A summary of bicycle and pedestrian collisions on freeways can be found in Chapter 4. Caltrans Districts 1, 2, and 3 were selected for this study. The purpose of this work was to gain insight into the locations and movements proceeding collision of these specific types of freeway collisions. The Traffic Accident Surveillance Analysis System (TASAS) and actual traffic collision reports were the main source of collision information for this chapter.

A look at bridges and tunnels that allow bicycle access can be found in Chapter 5. Several structures from California, along with two bridges from out of state, were studied. Collision history and bridge geometry were compared and analyzed in the search for trends that might contribute to the collision experience on these structures.

Caltrans Districts 5 and 6 were the subject of a statistical analysis found in Chapter 6. An extensive database of freeway geometry, collision rates, and traffic volumes was created and analyzed. Allowing bicycle access to the freeway was an independent variable. The focus of Chapter 6 is to determine if there was any correlation between bicycle access and collision rates as reported by TASAS. Application of Caltrans' bicycle-on-freeway policy was also reviewed.

Chapter 7, the policy recommendations, is the culmination of the results from each of the aforementioned studies. This chapter presents the major findings of this report and suggests data collection that could be employed in the future to improve studies of bicycle transportation on major roadways.

SURVEY AND LITERATURE REVIEW

INTRODUCTION

The goal of the survey questionnaire and literature review was to identify existing information relating to bicycle and pedestrian use of major roadways such as freeways, toll bridges, tunnels, and expressways, and to evaluate their safety history on these roadways.

This research utilized the University library, its intra-library loan program, and the Internet to obtain and/or review information possibly pertinent to this study. A number of sources—including documents from various United States (U.S.) State Departments of Transportation (DOT), U.S. government agencies especially, and any bicycle- or pedestrian-related studies, foreign transportation agencies, and bicycle-related periodicals—were used to gain information applicable to this portion of the study.

An important facet of this review was a survey questionnaire that was forwarded to state DOTs, foreign DOTs, and selected bicycle advocacy groups. The focus was to determine whether bicycles and pedestrians were allowed on freeways in specific locations, and to obtain data and information on collisions. An overview of the survey approach and a summary of the survey results are included in this chapter. Although there was only a limited response to the survey, it aided in providing additional supporting information to the literature review. No responses were received from foreign DOTs.

In order to develop a fundamental understanding of the interaction between bicycles, pedestrians, and motor vehicles on high-speed roadways, the following issues were analyzed: bicycle rider characteristics, geometric and physical concerns, collision typologies, collision statistics, current policy, and suggestions for accommodating bikes on high-speed facilities. All pertinent information gathered as part of the literature review and survey questionnaire is presented in this chapter.

SURVEY

The survey questionnaire that was conducted as part of this study aided in providing some reference material from state DOTs, other highway agencies, and bicycle advocacy groups. The approach to conducting the survey and the survey questions and results are provided in this section.

Survey Approach

A questionnaire with three parts was developed. The first part contained questions regarding the recipient's contact information. The second and third parts were directed toward obtaining information on freeway use by bicyclists and pedestrians, respectively, and any related collision data. The questions posed to state DOTs are shown in Figures 2-1 and 2-2. Questions to bicycle advocacy groups were slightly different in form. The focus of the questionnaire was on obtaining any available information on standards and collision statistics.

An attempt was made to contact the appropriate person to complete the survey at all U.S. state DOTs, 12 bicycle advocacy groups, and four toll road authorities, as well as DOTs and advocacy groups in six English-speaking foreign countries. The contact names were obtained from different sites on the Internet. In the case of the state DOTs, the target contacts were bicycle and pedestrian program coordinators, design standards coordinators, or research directors.

If the contact at a state DOT was a bicycle or pedestrian program coordinator, a survey was sent to that person, and a request was made to pass the survey on to the appropriate person if the contact person could not complete the questionnaire. In other cases, a letter was sent to the contact requesting contact information for the appropriate person. If there was a response, a survey was sent out. In the case of the remainder of the state contacts, a letter and a survey were sent out and a request made to either complete the survey or pass it on to the appropriate person. Bicycle advocates and representatives of foreign countries were asked to pass the survey on to an appropriate person. Most of the communication was handled via e-mail. The State of Oregon, for which relevant information was obtained in another part of the study, was not included.

Survey Questions

1. *Do you know of or have any specific policies regarding bicycle use of freeways and toll bridges nationwide or elsewhere?*

   ☐ *YES* ☐ *NO*

2. *Do you know of or have any study results or summarized data, on collisions involving bicycles on freeways and toll bridges, available?*

   ☐ *YES* ☐ *NO*

3. *Do you know of or have any design standards related to bicycles on freeways and toll bridges?*

   ☐ *YES* ☐ *NO*

If the answer to any of the above questions is yes, we will appreciate it very much if you would provide us with a copy of the policy, study report or data.

In the absence of such official material, we will appreciate it if you could provide us with any available information on bicycle use of freeways and toll bridges. When providing such information we will appreciate it if you could make reference to issues such as:

- On what type of freeway is bicycle use allowed?
- What type of common characteristics of bicycle collisions on freeways?
- Were there lanes designated for bicycle riding on freeways?
- Are there warning signs alerting drivers that there may be bicyclists sharing the road?

Figure 2-1. Questions Related to Bicycle Use of Freeways

4. *Do you know of or have any policies related to pedestrian use of roadways nationwide or elsewhere?*

   ☐*YES* ☐*NO*

5. *Do you know of or have any specific policies regarding pedestrian use of freeways nationwide or elsewhere?*

   ☐*YES* ☐*NO*

6. *Do you know of or have any study results or summarized data, on collisions involving pedestrians on freeways, available?*

   ☐*YES* ☐*NO*

If the answer to any of the above questions is yes, we will appreciate it very much if you would provide us with a copy of the policy, study report or data.

In the absence of such material, we will appreciate it if you could provide us with any available information on bicycle use of freeways and toll bridges. When providing such information we will appreciate it if you could make reference to issues such as:

- On what type of freeway is pedestrian use allowed?
- What are common characteristics of pedestrian collisions on freeways or high-speed highway shoulders?
- Were there lanes designated for pedestrian walking on freeways?
- Are there warning signs alerting drivers that there may be pedestrians sharing the road?

Figure 2-2. Questions Related to Pedestrian Use of Freeways

Survey Results

Fourteen state DOTs and three toll road authorities responded:

<u>States</u>

Arizona
Colorado
Hawaii
Indiana
New York
Ohio

Connecticut
Florida
Georgia
Maine
Minnesota
Nebraska
South Carolina
Wyoming

Toll Road Authorities

Delaware River Port Authority
New Jersey Turnpike Authority
Pennsylvania Turnpike Authority

The direct responses of these organizations to the questions are provided in the following sections, together with summaries of the written comments. Arizona responded only to the bicycle survey. The responses of the advocacy groups are discussed in a later section.

Responses Related to Bicycle Use

The responses to questions regarding bicycles are presented in Tables 2-1 through 2-3. A blank in the tables indicates no response.

Table 2-1. Responses to the Question: *Do you have any specific policies regarding bicycle use of freeways and toll bridges in your jurisdiction?*

Organization	***Yes***	***No***
Arizona	X	
Colorado	X	
Connecticut	X	
Florida	X	
Georgia	X	
Hawaii	X	
Indiana	X	
Maine	X	
Minnesota	X	
Nebraska		X
New York		X
Ohio	X	
South Carolina	X	
Wyoming	X	
Delaware River Port Authority	X	
New Jersey Turnpike Authority	X	
Pennsylvania Turnpike Authority	X	

Table 2-2. Responses to the Question: *Do you have any study results or summarized data, on collisions involving bicycles on freeways and toll bridges, available?*

Organization	*Yes*	*No*
Arizona	X	
Colorado		X
Connecticut	X	
Florida		X
Georgia		X
Hawaii		
Indiana		X
Maine		X
Minnesota		
Nebraska	X	
New York		X
Ohio		
South Carolina	X	
Wyoming		X
Delaware River Port Authority		X
New Jersey Turnpike Authority		X
Pennsylvania Turnpike Authority		

Arizona

Bicycles are allowed on any freeway where bicycle prohibitions are not posted. (Typical places where bicycles are permitted are rural freeways where alternate routes that are safer and more convenient do not exist.) Bicyclists must use the freeway shoulders. Warning signs are not used.

Regarding characteristics of bicycle collisions, Arizona commented as follows:

“Less than one per year statewide on 2,000 shoulder-miles of freeway.
No child or adolescent involvement.
None occurred at ramps or merge locations.
Half occurred on freeways prohibited to bicyclists.
Half involved impaired drivers or cyclists.”

Colorado

Although Colorado officials replied that they did not have any standards for bicycle use of freeways, they noted that they used American Association of State Highway and Transportation Officials (AASHTO) standards. Bicycles

Table 2-3. Responses to the Question: *Do you have any design standards related to bicycles on freeways and toll bridges*

Organization	*Yes*	*No*
Arizona		X
Colorado		X
Connecticut		X
Florida		X
Georgia		X
Hawaii		
Indiana		X
Maine		X
Minnesota		
Nebraska		X
New York		X
Ohio		
South Carolina		X
Wyoming		X
Delaware River Port Authority		X
New Jersey Turnpike Authority		X
Pennsylvania Turnpike Authority		

are allowed on all freeways except in urban areas. Cyclists must use the shoulder. Occasionally, warning signs are used to alert drivers of bicycle use of the freeway, but there is no set standard.

Connecticut

Connecticut provided a copy of the state statute regarding restricted use of limited-access facilities, which states that bicycles are not allowed except on paths specifically provided therefore. In their response to the questionnaire, they noted that bicyclists are not allowed to use freeways. Connecticut collects data on collisions involving bicycles on freeways and toll bridges, but stated that the data are not readily accessible, nor are they specific enough to determine common characteristics of bicycle collisions on freeways.

Florida

Bicycles are not allowed on limited-access roadways or on interstate highways. However, toll bridges are not always on limited-access facilities.

Nebraska

Although Nebraska responded “no” to the question of whether there were any specific policies regarding bicycle use of freeways and toll bridges, the following comment also was made:

“Nebraska state law defines ‘freeways’ as expressways with ‘NO’ at-grade intersections. The law also states that bicycles and pedestrians are not allowed on Interstates ‘and’ freeways. There are signs reflecting this on both freeways and Interstates. Nebraska DOT doesn’t have any toll bridges on any of our freeway or Interstate highways.”

In response to the question: “On which type of freeway is bicycle use allowed?” the reply was: “All except the Interstate”.

These two responses appear to conflict.

In response to the question regarding collision studies and summaries, Nebraska stated there were collision records only, but no information regarding common characteristics of bicycle collisions on freeways. It is not clear whether there have been collisions involving bicycles on freeways.

New York

New York provided a copy of the state statute regarding restricted use of limited-access facilities, which states that bicycles are not allowed except on paths specifically provided therefore. Bicycles are, however, allowed along some parkways, where wide shoulders have been constructed to accommodate bicyclists.

South Carolina

South Carolina provided a copy of the state statute regarding restricted use of limited-access facilities, which states that bicycles are not allowed on freeways.

Their records show no collisions involving bicycles on freeways.

Wyoming

Wyoming stated that bicyclists are allowed on all freeways and that they must use the shoulder. There are no relevant warning signs posted. It was also commented that the Wyoming DOT believes that the AASHTO standards accommodate bicycles.

No Bicycles Allowed on Freeways (States)

Georgia, Hawaii, Indiana, Maine, Minnesota, and Ohio all responded that bicycles are not allowed on the freeways.

Delaware River Port Authority

Bicycles are not allowed on their bridge roadways. A walkway on the Benjamin Franklin Bridge is open to pedestrians and bicycle traffic between the hours of 6 a.m. and 7 p.m.

No Bicycles Allowed on Freeways (Toll Road Authorities)

The New Jersey Turnpike Authority and the Pennsylvania Turnpike Authority both responded that bicycles are not allowed on the freeways.

Responses Related to Pedestrians

The responses to key questions from the surveys regarding pedestrians are presented in Tables 2-4 through 2-6. A blank in the tables indicates no response.

Connecticut

Policies regarding pedestrian use of roadways can be viewed on the Connecticut State Library Web site at http://www.cslib.org/llru.htm. Connecticut provided a copy of the state statute regarding restricted use of limited-access facilities, which states that pedestrians are not allowed except during emergencies or on facilities specifically provided therefore. The response to the questionnaire noted that pedestrians are not allowed to use freeways. Connecticut collects data on collisions involving pedestrians on freeways, but stated that the data are not readily accessible, nor are they specific enough to determine common characteristics of pedestrian collisions on freeways.

Nebraska

Although Nebraska responded that they did not have any policies regarding pedestrian use of freeways, they stated that pedestrians are allowed on “Any highway other than the Interstate.”

Table 2-4. Responses to the Question: *Do you have any specific policies related to pedestrian use of roadways in your jurisdiction?*

Organization	*Yes*	*No*
Colorado	X	
Connecticut	X	
Florida		X
Georgia	X	
Hawaii		
Indiana	X	
Maine	X	
Minnesota		
Nebraska		X
New York		X
Ohio		
South Carolina	X	
Wyoming	X	
Delaware River Port Authority	X	
New Jersey Turnpike Authority	X	
Pennsylvania Turnpike Authority	X	

Table 2-5. Responses to the Question: *Do you have any specific policies regarding pedestrian use of freeways and toll bridges in your jurisdiction?*

Organization	*Yes*	*No*
Colorado	X	
Connecticut	X	
Florida		X
Georgia	X	
Hawaii	X	
Indiana	X	
Maine	X	
Minnesota		
Nebraska		X
New York		X
Ohio	X	
South Carolina	X	
Wyoming		X
Delaware River Port Authority		X
New Jersey Turnpike Authority	X	
Pennsylvania Turnpike Authority	X	

Table 2-6. Responses to the Question: *Do you have any study results of summarized data, on collisions involving pederstians on freeway and toll bridges, available?*

Organization	*Yes*	*No*
Colorado		X
Connecticut		X
Florida		X
Georgia		X
Hawaii		
Indiana	Unknown	
Maine		X
Minnesota		
Nebraska	X	
New York		X
Ohio		
South Carolina	X	
Wyoming		X
Delaware River Port Authority		X
New Jersey Turnpike Authority		X
Pennsylvania Turnpike Authority		

New York

New York provided a copy of the state statute regarding restricted use of limited-access facilities, which states that pedestrians are not allowed except where specifically provided therefore.

South Carolina

South Carolina provided a copy of the state statute regarding restricted use of limited-access facilities, which states that pedestrians are not allowed. They also provided data on pedestrian deaths on freeways, which are presented in Table 2-7.

Table 2-7. Pedestrian Deaths on South Carolina Freeways

Year	*Deaths*		*Year*	*Deaths*
1996	5		**1998**	6
1997	8		**1999**	6

No Pedestrians Allowed on Freeways (States)

Colorado, Georgia, Hawaii, Indiana, Maine, Minnesota, Ohio, and Wyoming all replied that pedestrians are not allowed on freeways.

Delaware River Port Authority

Pedestrians are not allowed on their bridge roadways. They have a walkway on the Benjamin Franklin Bridge, which is open to pedestrian and bicycle traffic use between the hours of 6 a.m. and 7 p.m.

No Pedestrians Allowed on Freeways (Toll Road Authorities)

The New Jersey Turnpike Authority and the Pennsylvania Turnpike Authority both replied that pedestrians are not allowed on freeways.

Responses from Advocacy Groups

Nine responses were received from advocacy groups. It appeared that the surveys had been circulated to persons other than the addressees. Two responses were from Illinois, and stated that bicycles are not allowed on freeways in Illinois. Another, from the state of Washington, stated that bicycles are not allowed on freeways. Six responses were received from California.

One came from someone who apparently had ridden a bicycle across the United States as part of a group. She stated that sometimes they had to use freeways when alternative routes were unavailable. She believed that the group leader called the local police to advise them in these cases. In Arizona, the State DOT sent a truck to lead them through a tunnel. She noted that rumble strips presented the biggest problem.

Another responded that in California, bicycles are allowed on freeways only when there is no alternative access. According to this person, "…the main collisions that you would expect to see are similar to those seen in high-speed expressways, i.e., cyclists are most commonly hit by motorists turning right to exit via a high-speed ramp." In response to the question regarding whether lanes were designated for bicycle riding on freeways, the person responded: "No, and this is part of the problem with rural freeways, the shoulders are typically inadequate to safely accommodate bicycles. Even where there is a shoulder, however, there is no way a bicyclist can traverse a high-speed off-ramp without exiting and re-entering the freeway. A far better alternative to freeway access is to make frontage roads or frontage bike paths available."

A respondent from San Luis Obispo stated that bicycles are allowed on a freeway bridge over a river. Because the shoulders are narrow, bicycles are allowed in the lanes. Bicycles are also allowed on the shoulders of U.S. 101 north of Paso Robles, where an alternative route is unavailable. Warning signs, alerting drivers that bicyclists may be sharing the road, will soon be installed at both locations. The person mentioned that he did not know of any collisions, but there were “some close calls due to insufficient width of lane for all vehicles.”

Another respondent mentioned that he had been involved in a study of the Richmond-San Rafael Bridge. He said that there are several bridges and freeways that are comparable or where bicycle and pedestrian access is allowed and used with some frequency. He knew of only three deaths on freeways, under very special circumstances. He noted that the AIDS ride takes place on U.S. 101 between San Francisco and Los Angeles, involving approximately 3,500 bicycles, with evidently no incidents so far. In response to the question regarding common characteristics of bicycle collisions, he stated that they usually occurred at intersections. He thought that it is “best to separate bike traffic from intersections where high volumes of on/off ramp exist. For example Highway 24 east of the hill, through Lafayette, they ask the bikes to exit and enter repeatedly. The great thing about bridges are that they have no on/off ramps for the most important over-water stretch.” He noted that warning signs sometimes were used to alert drivers that bicyclists might be sharing the road.

One reply provided information about bicycle use on freeways, obtained during a visit to Sydney, Australia. Bicycle lanes were demarcated on the shoulder and signs at the entrances instructed drivers to yield to bicyclists.

One person noted that he knew of policies and design standards, but did not provide any details.

LITERATURE REVIEW

The literature review includes background information on bicycle rider characteristics, geometric and physical concerns, collision typologies, and collision statistics. Information concerning pedestrians is incorporated, where appropriate. Current policy for bicycle and pedestrian use of multilane high-speed facilities is also included.

Bicycle Rider Characteristics

The following are some characteristics of those riders who frequently ride on and will benefit from access to high-speed facilities such as toll bridges and tunnels.

Demographics of a Typical Rider

Referring to a survey conducted of the League of American Bicyclists on riding habits and experiences during the year 1996, "The average respondent was 48 years old, married, male, professional with a college degree. More than 53 percent reported a household income in excess of $60,000 per year." It was also stated that 88 percent of respondents wore a helmet on every ride.[1]

Type of Facilities

Minor streets without bike facilities were the most commonly traveled by the bicyclists, at 45 percent of the distance traveled. Major streets without bike facilities accounted for 32 percent. Bike routes, lanes, and multiuse trails were 6 to 7 percent of the total traveled.[2]

Bike Commuters

A total of 9,160,000 cycling kilometers (km) were traveled in 1996, representing an average of 4,670 km per cyclist. Of the 53 percent who claimed to commute to work or school, 51 percent of these respondents did so most often by car. Bicycle commuting accounted for 29 percent of commutes, with an average one-way distance of 17 km and 27 minutes. Reasons cited for not commuting by bicycle were needing a car at work, dangerous roads, distance, and lack of facilities at work or school.[3]

Perceived Safety's Effect on Ridership

One of the most frequently cited fears of cyclists is their safety in traffic. "In a 1991 Harris Poll, 46 percent of individuals stated they would sometimes commute to work by bicycle if safe bicycle lanes were available, whereas 53 percent would if they had safe, separate designated paths on which to ride." Due to the difficulty of providing separate paths for bicycles, highway shoulders are the most feasible option.[4]

---

[1] Moritz, William E. *Adult Bicycle in the United States: Characteristics and Riding Experience in 1996*. Transportation Research Record No. 1636 (1998), 4.

[2] ibid., 4

[3] ibid., 4

[4] Garder, Per. "Rumble Strips or Not Along Wide Shoulders Designated for Bicycle Traffic?" *Transportation Research Record* No. 1502 (1995), 1.

Collision Frequency by Age Group

Cyclists who use high-speed facilities are generally adult college students or professionals. It is important to make a distinction between these riders and children, who have higher collision rates. Table 2-8, which comes from work by John Forester, lists some collision rates of select age groups.[5]

Table 2-8. Collision Rate per Million Bicycle Miles by Cyclist Age Group

Age Group:	Elementary	College	Adult
Rate of All Bike Collisions	720	510	113
Car-Bike-Only Collision	72	80	20

From these sources, it can be seen that the rider most likely to use high-speed, limited-access roadways is generally older, a professional or student, and concerned with his or her own safety. Their collision rate as a whole is a fraction of the total collisions for a given area. Commute length is also a major factor, which is why access to bridges and tunnels are so important to them.

Geometric and Physical Concerns

Special physical concerns that should be considered when designing for bicycle use of high-speed facilities are aerodynamic forces and pavement surface conditions.

Lateral Wind Forces

According to D. Smith, bicycles can become unstable when subjected to lateral forces greater than 3.5 pounds. A force of this magnitude can occur when large vehicles such as trucks and buses pass a bicycle at high speeds. The force generated is a function of both the vehicle speed and the distance between the vehicle and bicycle.[6] Figure 2-3 shows a graphical representation of the estimated force the bicycle is subjected to, given vehicle speed and separation distance. It can be seen from the graph that the force caused by passing vehicles is of little importance aerodynamically for speeds below 50 miles per hour (mph). However, at speeds of 70 mph or more, which is common on California highways, forces capable of overturning a bicycle can be reached at

---

[5] Forester, John. *Cycling Transportation Engineering*. Palo Alto, CA. (February 1977), 1.4-3.

[6] D. T. Smith Jr., *Safety and Location Criteria for Bicycle Facilities*. FHWA-RD-75-113 (1976), 1.4-3.

distances up to 7.5 feet or more.[7] The field data, if any, and analytical basis for Figure 2-3 [8] were not identified.

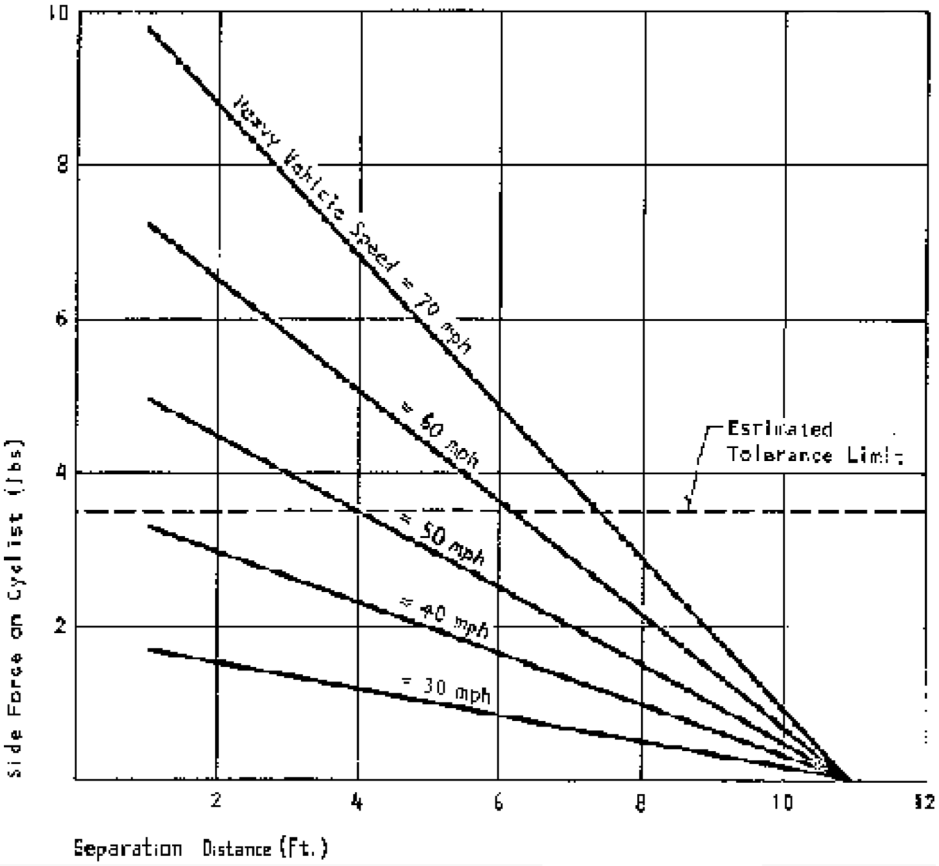


Figure 2-3. Lateral Forces Versus Separation Distances

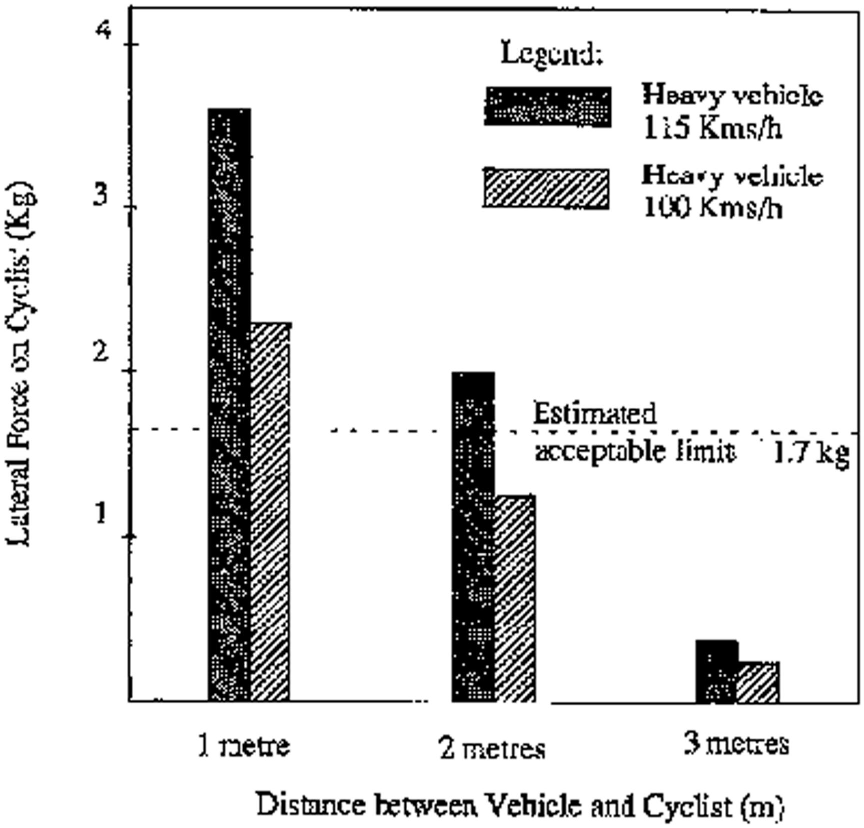
In an effort to draw some conclusions involving the benefits of paving shoulders for bicycle use, a report from A. M. Khan and A. Bacchus from Carleton University and the Ministry of Transportation in Canada, respectively, presented the following aerodynamic data. For high-speed, high-volume highways with relatively large volumes of heavy vehicles, aerodynamic factors come into play. The data in Figure 2-4, taken from the

---

[7] A. M. Khan, A. Bacchus, “Bicycle Use of Highway Shoulders,” *Transportation Research Record 1502 – Bicycles and Pedestrian Research*. (1995), 85.

[8] ibid., 85

report, estimates the lateral force on bicycles by heavy vehicles.[9] The data suggest that 2 meters (about 7 feet) of separation between bicyclist and motor vehicles are required for motor vehicle traveling at speeds of 65 mph.[10] The data reported appears to restate the information in Figure 2-3.



Source: Reference 4 (Based on an Australian Study)

Figure 2-4. Lateral Force Versus Distance Between Vehicle and Cyclist

Effect of Rumble Strips on Bicycles

In an attempt to determine whether rumble strips would pose a hazard to bicyclists, Per Garder and 20 students tested what it is like to ride over rumble strips on a bicycle. The group experimented with both milled-in and ground-in

---

[9] ibid., 15

[10] ibid., 15

strips. The group found that these strips pose little more that a nuisance to the cyclist. They stated that under no circumstances, even riding with no hands, did the rumble strips cause loss of control.[11]

Collision Typologies

Due to the tremendous difference in speed and mass of individual bicycles and motor vehicles, collisions between the two tend to be severe. This section attempts to define and identify the different crash types that can occur between the two vehicles.[12]

John Forester identifies five different maneuvers that lead to collisions between bicycles and motor vehicles on straight sections:

1. Hitting bicyclist from behind.
2. Partially overtaking and sideswiping bicyclist.
3. Motorist overtaking and stopping or slowing in front of bicyclist.
4. Hitting bicyclist from the front—the motorist from the opposite direction in the cyclist’s lane to overtake.
5. An increased hazard caused by motorists who overtake a bicyclist safely but allow too little clearance to compensate for mistakes by either party or unexpected wind gusts or road surface conditions.[13]

Collision Statistics

A respectable amount of statistical information on bicycle collisions is available in past publications. Unfortunately, due to the nature of bicycle collisions, the statistics are often varied and hard to compare. This treatment of collision statistics will start with the classification of bicycle collisions, then will look at the proportion of severe collisions, and finally complete an analysis of factors influencing bicycle collisions.

Reported Bicycle Collisions

A study in North Carolina stated that emergency rooms concluded that only 10 percent of bicycle crashes serious enough to warrant an emergency room visit

---

[11] Garder, “Rumble Strips,” 6

[12] Forester, John. *Width of the Outside Lane, Traffic Volume and Speed, and Cycling Safety.* Unpublished Report (30 March, 1974), 1

[13] ibid., 2

were reported to the police. Only 60 percent of collisions involving both a bicycle and a motor vehicle were reported.[14]

Nationwide Collisions

Approximately 850 fatalities caused by bicycle-motor vehicle collisions occur annually. This number represents nearly 90 percent of all bicycle-related fatalities. Nationwide, nearly 73 percent of these collisions occur outside urban areas. This translates to an estimated 240 fatalities that take place on rural highways, and potentially on highway shoulders.[15]

Annual Bike-Motor Vehicle Collision Information

Work by Hunter applied current National Highway Traffic Safety Administration (NHTSA) bicyclist typologies to a sample of recent crashes. His purpose was to refine and update the crash type distributions with particular attention to roadway and locational factors. There are approximately 900 fatalities involving bicycle-motor vehicle collisions each year. Estimates from 1991 state that about 70,000 bicyclists are injured each year from bicycle-motor vehicle collisions.[16]

Age was found to play a role in crash frequency and severity. Bicyclists over the age of 44 were found to be overrepresented for fatal and serious injuries. Riders between 15 and 19 years old generally had less serious injuries than other age groups.[17]

Two-thirds of bicycle-motor vehicle crashes occurred during the late afternoon and evening hours (41 percent from 2 p.m. to 6 p.m. and 25 percent from 6 p.m. to 10 p.m.). Late night and early morning collisions were generally more severe (10 p.m. to 2 a.m. and 2 a.m. to 6 a.m.); this may be related to the greater presence of alcohol and other drugs during these time periods.[18]

Alcohol use was a factor in approximately 5 percent of reported collisions.[19]

---

[14] Clark, A. and L. Tracy, *Bicycle Safety-Related Research Synthesis*. Office of Safety and Traffic Operations Reserach and Development, Federal Highway Administration (April 1995)

[15] Garder, “Rumble Strips,” 2

[16] Hunter, William W., et al, “Bicycle-Motor Vehicle Crash Types: The Early 1990’s.” *Transportation Research Record* 1502 (1995), 65.

[17] ibid., 66

[18] ibid., 67

[19] ibid., 74

Bicycle Collisions in California

In order to determine the safety record of bicycles on freeways, collision records involving bicycle-motor vehicle collisions were compiled from Caltrans records from 1988 to 1997. It was found that 2,739 bicycle-involved collisions had been reported on California freeways during this time period. Of these collisions, 2,460 collisions resulted in 2,558 injuries, 251 cases of property damage, and 28 fatalities.[20] These data include many collisions with bicycles riding on nonfreeway sections at or near surface street freeway ramp junctions. "Surprisingly only three fatalities and 15 collisions (0.4 percent) statewide, over a 10-year period, involved non-ramp and non-intersection locations of over a 4,100 mile freeway network."[21] Two of these collisions were head-on collisions, four were sideswipes, and the other nine were rear-end collisions. Only 3.1 percent (86 collisions) took place on freeway shoulders. Clearly, ramps and intersections are the critical locations when studying bicycle-motor vehicle collisions. Crashes at ramps or intersections totaled 2,556 (93.7 percent) of the total number of collisions.[22]

Arizona Collision Study

A finding by Moeur states that bicycle-motor vehicle collisions typically comprise less than 20 percent of all bicycle collisions.[23] Of these collisions, 65 to 75 percent usually occur at intersections and driveways. Generally, these collisions are likely to take place at sections where there is turning and cross traffic.[24]

Four bicycle-motor vehicle collisions occurred on Arizona limited-access highways during a recent 5-year period. All four of the collisions were in the right lane shoulder areas. Moeur states, "One of the primary safety benefits of controlled access highways is the absence of cross traffic, driveways, and intersections, which benefits both bicyclist and motorists."[25] This quote

---

[20] California Department of Transportation, *Richmond-San Rafael Bridge Public Access Feasibility Study*, 4-29, (46)

[21] ibid., 4-29

[22] ibid., 4-47 (61)

[23] Moeur, Richard C., P.E., *Bicycle-Motor Vehicle Collisions on Controlled Access Highways in Arizona 5-Year Analysis–May 1, 1993 to April 30, 1998*. Arizona DOT (16 October 1998), 1.

[24] ibid., 1

[25] ibid., 1

suggests that the data used in this analysis was restricted to freeways. The sample size is too small to develop trends.[26]

Two of the four collisions listed took place in segments prohibited to cyclists. This led the author to suggest that these prohibited areas may be used on a regular basis by cyclists. Since these prohibited areas seem to pose no more threat than the highways open to bicyclist, it would be reasonable to make adjustments to the access of controlled areas when requested.[27]

Collision Severity in North Carolina

In an effort to associate factors that influence the severity of bicycle-motor vehicle collisions, a study was performed by Klop and Khattak using North Carolina collision data. The scope of the study involved collision data of two-lane, undivided roadways during a 3-year time period (1990-1993). The data set used included 3,600 kilometers of roadway on which 1,025 collisions were reported; 80.5 percent occurred in rural areas. The severity of collisions was as follows: 1.8 percent of the victims experienced no injury, 24.4 percent reported some pain, 42.5 percent suffered nonincapacitating injury, 25.5 percent suffered incapacitating injury, and 5.9 percent were fatalities.[28]

Using statistical analysis, the study sought to derive geometric and environmental factors that influence the severity of bicycle-motor vehicle collisions. The results of the statistical model are as follows: [29]

- Both straight and curved grades increased crash severity. Other geometric variables such as crests, sags, and curves were found to be statistically insignificant.
- Although 75 percent of collisions occurred at intersections, driveways, and junctures, these areas did not show a trend towards increased severity. This is probably due to the decreased speed at these sections.
- Higher Average Annual Daily Traffic (AADT) leads to a decrease in severity of collisions. The author suggests the decreased speed and caution of the bicyclist caused of this trend.

---

[26] ibid., 1

[27] ibid., 1

[28] Klop, Jeremy R., and Asad J. Khattak, "Factors Influencing Bicycle Crash Severity on Two-Lane, Undivided Roadways in North Carolina." *Transportation Research Record* No. 1674 (1999), 78.

[29] ibid., 79

- Both fog and dark conditions showed increased severity. Reasons for this could be decreased sight distance.
- An interaction of speed and shoulder width was observed from the model. A significant decrease in severity was observed as motor vehicle speeds and shoulder width increased. This suggests that as the speed limit increases on a roadway, the shoulder width becomes more significant.[30]

National Collision Severity and Collision Rates

League of American Wheelman Survey

In 1974, Jerrold A. Kaplan conducted a national survey of members of the League of American Wheelmen (LAW).[31] The surveys included questions regarding bicycle miles traveled, number of collisions, and cause and severity of collisions. The following data were compiled from the returned surveys.

Of the 3,249 respondents, 694 (21.4 percent) answered “yes” to the question “Did you have a collision or serious fall on your bicycle last year?” The remainder responded “no.” Some of the respondents had more than one collision during this period, for a total of 854 collisions. This translates to a collision rate of 113 collisions per million bicycle miles (Col/MBM) from the reported total of 7,546,287 miles traveled by LAW members during the year. The severity of these collisions is compiled in Table 2-9. [32]

Table 2-9. Distribution of Respondents With Respect to Seriousness of Injury

Seriousness of Injury	Number Reported	Percent of Total
No Injury (Bicycle Damage Only)	148	17.0
Minor Scrapes and Bruises	479	55.1
Moderate Injury (Required Emergency Room Treatment	184	21.2
Major Injury (Required Hospitalization)	58	6.7
Total:	869	100.0

---

[30] ibid., 83, 84

[31] Kaplan, Jerrold A. *Characteristics of the Regular Adult Bicycle User.* Federal Highway Administration (1975), 5.

[32] ibid., 47

A total of 193 respondents (27.8 percent) reported at least one fall or collision that required at least an emergency room visit. When adjusted for those reporting more than one serious collision, the total jumps to 237, which translates to a serious collision rate of 31.4 serious Acc/MBM. A collision rate of this frequency translates to a collision every 31,800 miles for an average LAW member, or once every 14 years based on a long-term average. Similarly, there is a major injury collision rate of 7.6 major Col/MBM, or an collision every 132,000 miles (57 years).[33]

This study distinguished among the causes of each crash occurrence. Collisions involving moving motor vehicles were 18.2 percent (159 out of 872) of all reported collisions. For serious collisions only, collisions involving moving motor vehicles accounted for 25.9 percent (61 out of 236) of all serious collisions.[34]

An important fact to recognize from this data is that approximately 60 percent of all collisions were a result of bicyclist error.

On-street bicycle facilities, rare at the time of the study, accounted for only 1.7 percent of collisions. The greatest threats posed to bicyclists were on minor streets, with a total of 54 percent probably due to greater travel and more conflicting movements on these facilities. It is important to keep in mind that the collisions on on-street bicycle facilities will, in general, be more severe due to greater speeds.[35] A limitation of this type of survey is that it can not take into account bicycle fatalities, for those involved in fatal collisions will not have responded to the survey.

Washington Area Bicycle Association Survey

In order to provide a comparison to the LAW results, a smaller survey of the Washington Area Bicycle Association (WABA) was conducted in the District of Columbia (D.C.) in 1974. Seventy usable surveys were received. The following results were obtained from those surveys.[36]

The reported collision rate from the WABA survey was 21.4 serious Acc/MBM, the same as in the LAW study. WABA members had a much higher

---

[33] ibid., 47, 48

[34] ibid., 49

[35] ibid., 53

[36] ibid., 84

overall collision rate, with 167 Acc/MBM compard to 113 for LAW members. The reasons for the difference was left to the reader, although Kaplan did suggest the difference might be due to the fact that all WABA members lived in the metropolitan area of Washington D.C.[37]

Updated National Collision Severity and Collision Rates

In an effort to update the 1974 study *Characteristics of the Regular Adult Bicycle User*, performed by Jerrold A. Kaplan, William E. Moritz conducted a similar survey of the League of American Bicyclists (LAB) in 1997. The nationwide survey asked LAB members to report on their riding statistics and experience during the calendar year of 1996. There were 1,956 usable surveys returned; those responses were used to derive the following: 29 percent (567) of the respondents reported having been involved in some type of collision in 1996; 9 percent reported having a serious crash; the average number of crashes for those reporting a serious crash was 1.2 per year. It is important to note that only 28 percent of those serious collisions were reported to the police.[38]

This study distinguished among the causes of each crash occurrence. Collisions involving moving motor vehicles accounted for 11 percent of all reported collisions. Collisions classified as “No other object - simple fall” were the majority, at 59 percent of all collisions. For serious collisions only, collisions involving moving motor vehicles accounted for 24 percent of the total. A comparison with the Kaplan study shows that these values are consistent with historical data.[39]

Table 2-10 lists the percentage of collisions reported on various facilities.[40] For comparison, the right-hand column contains similar data from the 1974 LAW report.[41]

Table 2-11 lists the calculated collisions per million bicycle kilometers for each facility. Again, the right-hand column lists the similar data compiled from the LAW 74 report.[42] [43]

---

[37] ibid., 95

[38] Moritz, *Adult Bicycle in U*.S., 5.

[39] ibid., 6

[40] ibid., 6, Table 4

[41] Kaplan, *Characteristics of Adult Bicycle User*, 53

[42] Moritz, *Adult Bicycle in U.S.*, 6, Table 4

[43] Kaplan, *Characteristics of Adult Bicycle User*, 53

Table 2-10. Portion of Crashes by Facility Type

Facility	LAB 96 [a] Serious	Minor	All	LAW 74 [b]
Major roadway w/o bike facilities	**29%**	**17%**	**21%**	**35%**
Minor roadway w/o bike facilities	**41%**	**43%**	**42%**	**54%**
Signed bike route only	**6%**	**2%**	**3%**	**NA**
On-street bike lane	**4%**	**2%**	**2%**	**NA**
On-street bike facility	**NA**	**NA**	**NA**	**2%**
Multiuse trail	**8%**	**9%**	**9%**	**10%**
Off-road unpaved	**8%**	**23%**	**18%**	**NA**
Other	**5%**	**4%**	**5%**	**NA**
Totals	**100%**	**100%**	**100%**	**100%**
NA – not available				

a. Moritz, *Adult Bicycle in U.S.*, 6, Table 4
b. Kaplan, *Characteristics of Adult Bicycle User*, 53

Table 2-11. Crash Rates Per Million Kilometers

	LAB 96 [a] Col/Mkm	**LAW 74** [b] Col/Mkm
Major roadway w/o bike facilities	41	71
Minor roadway w/o bike facilities	59	65
Signed bike route only (BR)	32	NA
On-street bike lanes (BL)	26	NA
On-street bike facility. (BR or BL)	NA	36
Multiuse trail	8	181
Off-road/unpaved	282	NA
Other (most often sidewalk)	1026	NA
NA – not available		

a. Moritz, *Adult Bicycle in U.S.*, 6
b. Kaplan, *Characteristics of Adult Bicycle User*, 53

Roadway and Locational Factors

Table 2-12 relates roadway factors to percentage of collisions in the study. Some notable trends were that higher speed limits were overrepresented in serious and fatal collisions. As lane widths became wider, serious and fatal crashes became less frequent. Nearly half of all collisions took place at intersections and similar perpendicular crossings.[44]

Table 2-12 gives a breakdown of the number and percentage of collisions as a function of road class, speed limit, road feature, and traffic control device.[45]

The following conclusions were derived by Hunter from his study.: Intersections, driveways, and other junctions pose a sizable threat to cyclists and should be given special consideration when designing these facilities. High speeds and narrow roads have an adverse effect on collision frequency and severity.

“Much of what is reported in this study seems strongly connected to basic riding and driving patterns—in other words, related to exposure.”[46]

Frequency of Drivers Entering Shoulders

A study performed in Maine during 1993 included 205 drivers and presented the following statistics: “The average incident rate of dozing off while driving was around once every 45,000 km among randomly selected drivers.”[47] Drivers below the age of 25 reported falling asleep behind the wheel on average of once every 22,000 km. Fifteen reported a collision as a result of having fallen asleep and two more stated that they woke up off the road. Thirty-six percent stated that they fell asleep between the hours of 7 to 9 a.m., the time period when bicyclists are most likely to be on the road. These statistics reveal that drivers running off the traveled way onto the shoulder are a real concern.[48]

Current Design Policy

Design policy for bicycles varies considerably. Policy from the Federal Highway Administration (FHWA), AASHTO, and some state agencies is presented below.

---

[44] Hunter, *Bicycle-Motor Vehicle*, 68

[45] ibid., 68

[46] ibid., 74

[47] Garder, “Rumble Strips,” 3

[48] ibid., 3

Table 12: Number of Collisions per Roadway Factor [a]

	N	%		N	%
Road Class			**Speed Limit**		
Interstate	3	0.2	40 km/or less	666	27.0
U.S. route	138	8.0	48-45 km/hr	1234	50.1
State route	313	18.1	65-73 km/hr	396	16.1
County route	475	27.5	81+km/hr	168	6.8
Local street	582	33.7	Unknown	562	-
Other	217	12.6			
Unknown	1215		(1km=0.062 mile)		
Road Feature			**Traffic Control Device**		
No special feature	793	26.5	No control	1712	57.7
Bridge	8	0.3	Stop sign	739	24.9
Public driveway	344	11.5	Yield sign	9	0.3
Private driveway	229	7.6	Traffic signal	473	16.0
Alley intersection	70	2.3	Flashing signal with stop sign	3	0.1
Intersection of roadways	1402	46.8	Flashing signal w/o stop sign	5	0.2
Intersection of roadways related	108	3.6	RR gate & flasher	1	0
Non-intersection median crossing	6	0.2	Human control	4	0.1
End/Begin of divided highway	2	0.1	Other	20	0.7
Interchange ramp	8	0.3	Unknown	31	--
Interchange service road	1	0			
RR crossing	3	0.1			
Path intersects road	7	0.2			
Parking lot abut road	5	0.2			
Other	3	0.1			
Unknown	8	--			

a. Hunter, *Bicycle-Motor Vehicle*, 68

Bicycles on Freeways

Section 1003.4 of the Caltrans *Highway Design Manual* deals with factors and policies related to bicycles on freeways. It states that freeways should only be opened for bicycle use if there is no other suitable alternate route. The suitability of an alternate route can be judged using the following criteria: number of intersections, shoulder widths, traffic volumes, vehicle speeds, truck volumes, grades, and travel time.

"When a suitable alternate route does not exist, a freeway shoulder may be considered for bicycle travel."[49] Determining factors for the suitability of freeway shoulders include shoulder widths, bicycle hazards (drainage grates, expansion joints, etc.), number and location of exit and entrance ramps, and traffic volumes on these ramps. No quantitative guidelines relating to the alternate route or the freeway are offered.

"Where no reasonable alternate route exists within a freeway corridor, the Department should coordinate with local agencies to develop or improve existing routes or provide parallel bikeways within or adjacent to the freeway right of way." Because many toll bridges and tunnels are operated as freeways, the wording suggests that Caltrans "should coordinate with local agencies to" provide either alternate routes or improve freeway conditions to allow bicycle travel.[50]

Section 302.1 of the *Highway Design Manual* dealing with shoulder standards states, "For new construction, and major reconstruction projects on conventional highways, adequate width should be provided to permit shared use by motorists and bicyclists."[51]

Standards for paved shoulders listed in the *Highway Design Manual*, Chapter 300, states that 3-meter widths are preferred for two-lane freeways and expressways, and are required where there are more than two lanes. Lane widths of these facilities are specified at 3.6 meters.[52]

---

[49] California Department of Transportation, *Highway Design Manual* (July 1, 1995), 1000-22.

[50] ibid., 1000-23

[51] ibid., 300-1

[52] ibid., 300-2

Where no other reasonable alternate route is available, John Forester states that the following conditions must be met to allow bicycles on freeway shoulders: [53]

- A paved outside shoulder, preferably a minimum of 8 feet wide on both sides of the freeway, exists.
- Bicycle travel is in the normal direction on the right side of the roadway.
- The route is not expected to be used extensively by children under the age of 12.
- The route is arranged so that it does not cross exit ramps with an Average Daily Traffic (ADT) greater than some as-yet-unidentified level. For ADTs above that level, the bicycle would be expected to exit the ramp and cross the feeder road at an intersection.[54]

Arizona Access Policy

"For many locations in Arizona, controlled access highways are the only available route for travel. Therefore, bicycle travel on these highways is necessary and permitted."[55] Due to this fact, there are approximately 2,000 shoulder-miles of controlled access highway open to bicycles in Arizona.[56]

Recommendations for Lane and Shoulder Width on Highways

Table 2-13 represents what John Forester states are the limits of the acceptable standards of a highway (other than freeways) that a bicycle could safely travel.[57]

General AASHTO Standards of Intersections

Freeway ramp intersections with surface streets should be dealt with in one of the following ways: Either continue a marked bike path around the point of the on-ramp and have the bike cross at a right angle to traffic, or have the bike rider determine the merge or crossing maneuvers.[58]

---

[53] Forester, John. *Highway Standard for Bicycle Travel*. Unpublished Report. (15 June, 1974), 5.

[54] ibid., 5

[55] Moeur, *Controlled Access Highways*, 1.

[56] ibid., 1

[57] Forester, *Highway Standard for Bicycle Travel*, 2.

Table 2-13. Acceptable Standards for Cycling Suitable Highways

Traffic Volume ADT	***Peak Hr***	***Road Standard Lanes (ft)***	***Shoulder (ft)***	***Outside Lane (ft)***
1,000	<100	2x14	No	14
1,000-3,000	100-300	2x16	No	16
3,000-9,000	300-900	2x12	8	20
<12,000	<1,200	4x12	4	16
>12,000	>1,200	2x12	8	20

Equations to Identify Suitable Corridors

An equation was developed by FHWA to identify corridors or streets that have the highest potential for bicycle travel as a measure of the Bicyclist Compatibility Index (BCI). Geometric and operational variables were identified in the field or on video. These variables were presented to a group of bicyclists, and a regression model was created by the rider response to these variables. The following is a sample of the variables used in this analysis.[59]

- Number of lanes
- Curb lane width
- Shoulder characteristics
- Motor vehicle speed and volume
- Presence of parking, median, sidewalks, and roadside development.

This BCI is then converted to a Level-of-Service (LOS) measure on a scale of A though F, where A represents “extremely high” compatibility and F represents “extremely low” compatibility.[60] Four equations were given representing different rider characteristics. These could be used to evaluate any roadway, including freeways, although they are not included in the analysis.

Accommodation of Bikes on High-Speed Facilities

Although bicycles are physically small compared to motor vehicles, they still require a reasonable portion of the roadway in order to travel safely. The

---

[58] American Association of State Highway and Transportation Officials (AASHTO), *Guide for the Development of Bicycle Facilities*. (1999), 62

[59] Harkey, David L., et al., *Development of the Bicycle Compatability Index: A Level-of-Service Concept*. FHWA-RD-98-072 (December 1998), 28.

[60] ibid., 34

following abstracts define some criteria to be followed when designing a high-speed facility for bicycle travel.

Factors to Consider When Designing for Bicycles

Major factors that should be considered when making decisions concerning bicycle access to freeways access should include:[61]

- Number of freeway ramps;
- Traffic volume on ramps;
- Interchange geometrics;
- Existence of merge lanes, with special attention paid to areas where shoulder width is decreased to accommodate merge lane, leaving no width available for bicycle travel;
- Traffic volumes on freeways;
- Traffic mix on freeways, paying special attention to large trucks, which create a cross-wind factor for bicyclists;
- Width of freeway shoulders;
- Existence of narrow bridges; and
- Problem areas on shoulders, including slotted drains, bridge expansion joints, and rumble strips, and the potential for correcting these problems.

These criteria suggest that the bicyclist is directed to ride on freeway shoulders; the geometry of the roadside as bikeways is addressed next.

Bridge and Tunnels

Where cyclists ride adjacent to bridge railings, the railing shall be at least 48 inches high. Lower railings contact the cyclist below his or her center of gravity, causing the rider to topple over the railing rather than being prevented from going over. Long tunnels that carry heavy cyclist traffic should be illuminated sufficiently for motorists to see the cyclist ahead of them at a distance appropriate for the design speed of the tunnel.[62]

---

[61] Wilkinson, W. C. , A. Clarke, B. Epperson, R. Knoblauch, *Effects of Bicycle Accommodations of Bicycle/Motor Vehicle Safety and Traffic Operations*. Center for Applied Research, Incorporated (July 1994), 53

[62] Forester, *Cycling Transportation Engineering*, 3.7-1.

Highway Shoulders

Considerable attention was paid to design of shoulders in many of the reviewed documents.

Bikes on Shoulders

All 50 states either define or treat bicycles as vehicles, and states require vehicles to be on the right half of the roadway. The shoulder is certainly included in the definition of a roadway.

Bicycles tend to ride to the left edge of the shoulder, since this area is swept free of debris by air currents generated by passing vehicles. This places the bicyclist closer to the passing motor vehicle and may increase the chance of conflict. The only way noted to alleviate the tendency of cyclist to use the left portion of the shoulder is through frequent machine sweeping.[63]

Shoulder Usage by Pedestrians

Shoulders are an important portion of the overall roadway design. The AASHTO *Green Book* states that shoulders are desirable on all highways and urban arterials, because shoulders accommodate the following:

- Occasional pedestrian travel;
- Bicycle travel;
- Disabled vehicles;
- Plowed snow; and
- Speed changes for turning vehicles.

Attitudes pertaining to the use of shoulders as pedestrian facilities differ. One view is that shoulders are adequate for pedestrian use; another is that they are a last resort for accommodation. Louisiana's *Statewide Bicycle and Pedestrian Master Plan* states that "for the pedestrian, a paved shoulder can offer a safe route away from the path of motorists along an otherwise hazardous road." [64]

The *Design and Safety of Pedestrian Facilities* developed by the Institute of Transportation Engineers (ITE) discusses that "in extreme cases, a roadway

---

[63] Wilkinson, et. al., *Effects of Bicycle Accommodations*, 43-44.

[64] Louisiana Department of Transportation, *Statewide Bicycle and Pedestrian Master Plan*. (May 1998), 4-1.

shoulder can also provide a safer pedestrian accommodation than walking in the travel lanes themselves." In the design of shoulders, pedestrians should always be a consideration. Even where pedestrian use is discouraged, shoulders are the routes in which pedestrians leave and return to disabled vehicles. Throughout the literature, it is clear that shoulders are no substitute for sidewalks or walkways.[65]

Whether people are using the shoulder as a means of transportation to or from a destination or as a place to travel when a sidewalk is not present, the practice should be discouraged. Approximately 15 percent of pedestrian collisions in rural and suburban areas occur when a pedestrian is struck while walking along a roadway.[66]

A shoulder facility is not appropriate for the elderly, the disabled, or children. The Americans with Disabilities Act Accessibility Guidelines (ADAAG) does not apply to the pedestrian use of shoulders. Although it is not legally necessary to design shoulders for the use of disabled pedestrians, it is recommended that this consideration be made where possible.[67]

Shoulder Width

Benefits of paving highway shoulders includes road-user safety of reduced "run-off-road" collisions, safe accommodation of bicycle travel, pedestrian safety, structural support of travel lane, reduced shoulder maintenance cost, better drainage, usefulness for rehabilitation work of travel lanes, enhanced snowplow operation, improved aesthetics, movement of agriculture equipment, and a safe sense of open highway.[68]

Possible criteria influencing the width of shoulders include travel lane width, AADT, percentage of heavy vehicles, vehicle speed, and bicycle volume.[69]

The horizontal and vertical alignments of shoulders are controlled by automobile design criteria. A 1.5-meter paved shoulder with 0.5 meter of buffer area is assumed to be the minimum adequate for low-speed highways.

---

[65] Zeeger, Charles V., ITE Chair, *Design and Safety of Pedestrian Facilities* (March 1998), 30.

[66] ibid., 9

[67] Missouri Department of Transportation, *Pedestrian Facility Guidelines* (August 1999)

[68] Khan, *Bicycle Use of Highway Shoulders*, 8

[69] ibid., 10

This leaves 1 meter of paved surface for a bicycle to travel. This configuration was found to be adequate by the Pennsylvania Turnpike Commission.[70]

The use of a full shoulder of 1.5 meters or greater reduces the risk of motor vehicle-bicycle collisions on highways, as opposed to shared-use facilities.[71] The bikeway benefits are a function of bicycle traffic and the value of prevented collisions. The maintenance and motor vehicle safety benefits increase linearly with shoulder pavement width.[72]

For low-speed facilities, the 1.5-meter shoulder in conjunction with the rumble strip buffer provides a sufficient path for bikes to use. For high-speed, high-volume facilities, wider shoulders are needed to prevent bicycles from overturning due to the aerodynamic forces of heavy vehicles.[73]

AASHTO states that for a freeway shoulder to safely accommodate a bicycle, the width should be at least 1.5 meters (4.92 feet), without rumble strips.[74]

It has been shown that 1.2-meter paved shoulders on rural two-lane highways reduce run-off-road, head-on, and sideswipe collisions by 29 percent, and 2.4-meter shoulders caused a 49 percent reduction. These data suggest that there are other benefits to wide paved shoulders other than bike paths.[75] A typical minimum shoulder width to support pedestrian activity is 1.2 meters. This dimension is set to accommodate light pedestrian volumes on roadways without high vehicle speeds. When pedestrian traffic or traffic volumes are greater, larger sections should be considered.

Louisiana's Statewide Bicycle and Pedestrian Plan

Standards presented in Louisiana's S*tatewide Bicycle and Pedestrian Plan* state that where pedestrian use is expected to be light on rural roads, a 4-foot paved shoulder is sufficient. Paved shoulders of less than 1.2 meters may be used where the AADT is less than 1,200 and pedestrian use is only occasional. The decision to use widths less than 1.2 meters should be based on motorized

---

[70] ibid., 11-12

[71] ibid., 17

[72] ibid., 17

[73] ibid., 12

[74] American Association of State Highway and Transportation Officials, *Guide for the Development of Bicycle Facilities*, 20

[75] Garder, "Rumble Strips," 2.

and nonmotorized traffic flows, highway geometrics, and collision data. Widths greater than 1.2 meters should be considered when any of the following apply:

- Vehicle speeds are greater than 48 kph (30 mph)
- AADT is greater than 2,000 vehicles
- Trucks, buses, and recreational vehicles contribute more than 5 percent of the traffic
- Bicycle use is expected occasionally.
- Pedestrian trip generators exist within 3 miles.
- Pedestrians are expected to travel in groups.

An 8- to 10-foot shoulder is suitable for high-speed suburban arterial state highways.[76]

New Jersey Department of Transportation Planning and Design Guidelines

The *Pedestrian Compatible Planning and Design Guidelines* developed for the New Jersey Department of Transportation outlines similar standards—the exception is that to consider a larger shoulder width, the vehicle speeds should be over 65 kph (40 mph).[77]

Oregon Bicycle and Pedestrian Plan

Standards for the widths of a usable shoulder for rural areas, rural collectors, and rural local roads are shown in Table 2-14.[78] These standards coincide with the guidelines listed in AASHTO "Geometric Design of Highways and Streets" (1990).[79]

Shoulder Markings

Shoulders used as pedestrian facilities must be visible to drivers. AASHTO suggested that shoulders should differ in color and texture from the travel lanes

---

[76] Louisiana Department of Transportation, *Master Plan*, 4-2

[77] New Jersey Department of Transportation, *Pedestrian Compatible: Planning and Design Guidelines* (April 1996), chp. 2, pg. 6-7

[78] Oregon Department of Transportation, *Oregon Bicycle and Pedestrian Plan* (June 1995), 67

[79] American Association of State Highway and Transportation Officials, 1994. Excerpts from "Policy on Geometric Design of Highways and Streets."

Table 2-14. Guidelines for Shoulder Width

	ADT under 250	ADT 250-400	ADT 400-DHV*100	DHV 100-200	DHV 200-400	DHV over 400
Rural Arterials	1.2 m (4 ft)	1.2 m (4 ft)	1.8 m (6 ft)	2.4 m (8 ft)	2.4 m (8 ft)	2.4 m (8 ft)
Rural Collectors	0.6 m (2 ft)	0.6 m (2 ft)	1.2 m (4 ft)	2.4 m (8 ft)	2.4 m (8 ft)	2.4 m (8 ft)
Rural Local Routes	0.6 m (2 ft)	0.6 m (2 ft)	1.2 m (4 ft)	1.8 m (6 ft)	1.8 m (6 ft)	2.4 m (8 ft)

**DHV (Design Hourly Volume) is the expected traffic volume in the peak design hour (usually at commuter times)–usually about 10 percent of ADT in urban areas, higher on rural highways with high recreational use (beach access, ski resorts, etc.).*

to make them more recognizable at night and in foul weather by sight and roughness, and to discourage vehicular use as an additional lane. For concrete surfaces, bituminous, crushed stone, gravel, and turf shoulders are appropriate options. For asphalt pavements, turf and various aggregates can be considered.

Following the guidelines of the *Manual on Uniform Traffic Control Devices*, a 10- to 15-centimeter (4- to 6-inch) white line for the pavement edge stripe will decrease the necessity for contrasting colors and textures.[80]

The *Pedestrian Facilities Guidebook* developed for the Washington State DOT suggests the possible use of nonstandard markings for delineation, such as an extra-wide fog line, a dashed stripe, or an angled stripe.[81]

Raised pavement markers usually are not suitable for this use because of the possible adverse affects for bicycle riders.

Shared Pedestrian and Bicycle Use of Shoulders

While several sources state that the shoulder should be wide enough for both pedestrians and bicycles, at least one says that this is not typically a suitable shared use. Both Vermont’s and New Jersey’s policies state that the shoulder should be of sufficient width for pedestrian and bicycle use. AASHTO

---

[80] “Policy on Geometric Design of Highways and Streets.” Excerpts from AASHTO 1994, 83.

[81] Washington State Department of Transportation, *Pedestrian Facilities Guidebook.* (September 1997), 103

Geometric Design of Highways and Streets (1990) says that shoulders can accommodate both bicycles and the occasional pedestrian. [82, 83]

Unlike the above policies, Washington State's policy suggests that shoulder use as a combined bicycle and pedestrian facility is not recommended unless designed as multiuse trail in accordance with local, state, and federal standards.

On- and Off-Ramps

Because of high speed differentials and length of exposure to turning and merging traffic, right-side merge sections on freeways intimidate bicyclists. Incidents are often fatal because of the high speeds involved. Although there is still disagreement on how to accommodate bicyclists at these locations, the best suggestion appears to be that bicyclists choose a point where the ramp crossing can be made at a right angle to the traffic and at a point where sight distances are good.[84]

Shared Facility

For instances where bicyclists share the lane with motor vehicles, John Forester established criteria for two-lane highways, as shown in Table 2-15.[85] It is likely that here lane width refers to lane plus paved shoulder width.

Table 2-15. Lane Width for Two-Lane Shared-Use Highways ADT

Lane Width (ft)	***Maximum ADT***
12-14	4,000
16	6,000-7,000
20	12,000

It was determined that for a multilane highway, outside lane widths are subject to the following criteria:

> "Outside lane width of 12 feet is marginal if there is sufficient traffic to fill one lane. Outside lane width of 16 feet is good at all traffic volumes at low or moderate speeds, 25 to 40 mph approximately. Outside lane width of 20 feet is good at all volumes and speeds."[86]

---

[82] New Jersey Department of Transportation, *Design Guidelines*.

[83] State of Vermont Agency of Transportation, *Bicycle and Pedestrian Plan* (November 1999), 17.

[84] Clark and Tracy, *Bicycle Safety-Related*, 50

[85] Forester, *Width of Outside Lane*, 5.

When lanes are 16 feet or more in width, motorists may tend to use the lane as two lanes. With wide outside lanes, it is thus important to separate the paved shoulder from the traveled lanes with a shoulder stripe.

SUMMARY OF FINDINGS

Identification of some of the needs associated with safe passage of bicycles and pedestrians on high-speed facilities is covered in prior literature. The bicycle user has been identified as a professional or student whose route is influenced by trip length and perceived route safety. Highway geometry that accommodates bicycles consists of wide paved shoulders, modest grades, and infrequent interchange ramps.

The survey got responses from 17 DOTs or equivalent, and only the transportation departments of Arizona, Colorado, and Wyoming indicated that bicyclists are allowed to use their freeways. In those states, bicyclists are restricted to the shoulder, and only Wyoming reported that pedestrians are allowed to use freeway shoulders. Bicyclists are not allowed to use urban freeways in Colorado. In New York, bicyclists are allowed to use the shoulders on some parkways. Arizona reported some low collision occurrence, but since they provided only collision totals, which cannot be compared with bicycle collisions on alternative routes, the data are inconclusive.

The advocacy groups were generally in favor of bicycle use of freeways, although some concern was expressed about possible problems at interchanges. Rumble strips on freeways may also present problems.

The literature review found that statistical data on where collisions occur are reasonably available and probably accurate. Data are somewhat clouded by the fact that only a small percentage of total collisions are reported to the police, but trends can still be seen from the data. Because bicycle traffic is relatively low, bicycle collisions are rare, especially on freeways.

Statistically, collisions are treated as rare events. Among all collisions on limited-access highways, reported bicycle collisions are in the significant minority as are the bicycle traffic volumes. Studies comparing limited-access

---

[86] ibid., 5

highways where bicycles are allowed to locations where bicycles are not allowed were not identified.

A serious problem in measuring relative bicycle safety is that no accepted measure of effectiveness exists. Ordinarily, collision rates are determined by counting motor vehicles and reported collisions. Analysis of highway safety commonly uses the measure of collisions per million vehicle miles of travel, but bicycles have no such measurement. This literature search shows that the few attempts to establish a bicycle collision rate relied on surveys done of bicycle riders self-reporting their collision history and miles traveled. Rates per million bicycle miles of travel are computed by dividing the number of self-reported accidents by the self-reported miles of travel. An important facet of this research report is that it brings to light the void of bicycle traffic counts, which are necessary to analyze how effective different roadway treatments are in increasing bicycle safety. Without counts, recommendations for the safe accommodation of bicycles are difficult to establish. Unlike treatments for general motor vehicle safety, there is little or no "before and after" data available to study.

The data and recommendations derived from the literature search present the common methods and ideas in use today. Many of the recommendations could be used in some situations, but in order to improve the process of bicycle facility design and accurately measure the effectiveness of the actions taken to increase bike access to roads and decrease collisions, a more comprehensive method needs to be established.

The most common treatment for bicycles appears to be simply letting bicycles ride on the shoulders. Specific standards for motor vehicle traffic volume and width have been suggested based on the opinions of bicyclists. Highway authorities did not adopt these standards, nor have they been tested in controlled or partially controlled studies of collision frequency. The literature does not contain an identified design process to deal with the potential problem of bicycles on freeways, expressways, and toll bridges.

BICYCLE COLLISION DATA FOR SELECTED EXPRESSWAYS IN SANTA CLARA COUNTY

INTRODUCTION

Santa Clara County is an urban environment with a roadway system consisting of highways, freeways, expressways, collectors, and local roads and streets. For the purpose of this study, the expressways were of interest because they had freeway-like characteristics and allowed bicycle access. Bicycle counts were completed, collision diagrams were drawn, and collision data were analyzed.

Expressways are unique in that they have both characteristics of arterial streets and freeway-like features. Arterial describes the section of the expressway having minor and major cross streets, stop signs or signals, and crosswalks. Freeway characteristics of the expressway include frequent access to the expressway by ramps, higher speed limits, and metered car pool and bus lanes. Medians are present on these freeway-like segments, with interchanges to the major crossroads.

Relevant California's Statewide Integrated Traffic Records System (SWITRS) data pertaining to bicycle-related collisions on the chosen expressways were extracted and entered into a Microsoft Excel spreadsheet. The spreadsheet data were then sorted, and percentages for each category were determined.

While the spreadsheet data were compiled entirely from the SWITRS data, reading the actual collision reports could clarify any ambiguities or discrepancies found in the SWITRS data. This could lead to modest differences in the total percentages tabulated in this report.

EXPRESSWAY SECTIONS

The expressway segments were selected based on advice from bicycle and highway professionals familiar with the area. The Montague, San Tomas, Lawrence, and Central Expressways were selected for their freeway-like characteristics. The Page Mill Expressway was selected because of its popularity with bicyclists. Bicycle-related collision data, from 1990 to 1998, were retrieved from SWITRS. By reviewing and interpreting each collision in SWITRS, one could then generate collision diagrams to help detect patterns and trends of the collisions occurring on these expressways.

A total of 111 collisions occurring on the selected Santa Clara County expressways were studied. Central, Lawrence, and Page Mill Expressways had the most collision occurrences. Table 3-1 is a summary, by percentage of collisions and length of section studied, for the years 1990 to 1998 on the given expressways.

Table 3-1. Santa Clara County Selected Expressway Data

Expressway	*# of Collisions*	*% of Collisions*	*Length (miles)*	*From*	*To*
Central	36	32.4%	10.0	Alma St.	De La Cruz Blvd.
Lawrence	27	24.3%	8.8	Caribbean Dr.	Quito Rd.
Montague	4	3.6%	5.7	I-680	SR 101
San Tomas	18	16.2%	7.1	SR 101	Campbell Ave.
Page Mill	26	23.4%	3.1	Alma St.	Arastra-dero Rd.

Bicycle Counts

During a three-day period, four bicycle counts were conducted at selected expressway locations in Santa Clara County. Each count was conducted from inside a vehicle at a location adjacent to the expressway intersection or interchange. All lanes and expressway components, such as ramps, were visible.

Since the best time to conduct a count is when traffic is at its peak, all of the two- to three-hour interval counts were done at the peak hours of the day: 7:30 a.m. to 9:30 a.m., 11 a.m. to 2 p.m., and 4:30 p.m. to 6:30 p.m. Before each count, detailed maps of the location were drawn, including ramps, shoulder width, and the number of lanes on the expressway.

San Tomas and Central Expressways

The junction of San Tomas and Central Expressways is grade separated. Central Expressway runs east and west over San Tomas Expressway, which runs north and south. San Tomas has four lanes in each direction, while Central Expressway has three lanes in each direction for most of its length.

There is ramp access between expressways at this interchange. The interchange is complete except that, when traveling west on Central Expressway, there is no exit allowing Central traffic to go south on San Tomas. Similarly, there is no entrance to allow San Tomas traffic going south to enter Central going west.

Two counts were conducted at the interchange of San Tomas and Central in the early morning and late afternoon. These counts were conducted on Thursday, June 8, 2000; the weather was cloudy with light sprinkling occurring sporadically. The count is summarized in Table 3-2.

Table 3-2. Summary of Bicycle Counts Conducted at San Tomas and Central Expressways

		Direction of Travel Toward:				
Location	***Times***	***North***	***South***	***East***	***West***	***Total***
San Tomas	7:30-9:30 a.m.	5	1			6
Central	7:30-9:30 a.m.			6	2	8
					Total:	***14***
San Tomas	4:30-6:30 p.m.	0	6			6
Central	4:30-6:30 p.m.			9	6	15
					Total:	***21***

During the early morning count, 7:30 to 9:30 a.m., there were a total of 14 bicyclists—six traveling on San Tomas and eight on Central. Of the 14 bicyclists counted, one was not wearing a helmet. From appearance, it seemed that most of the bicyclists were serious advocates of biking and the remaining few were businessmen or students. One of the 14 bicyclists entered the expressway from a ramp.

The late afternoon count, 4:30 to 6:30 p.m., demonstrated that most of the bicyclists in the early morning were returning, going in the opposing direction. This count resulted in a total of 21 bicyclists—six traveling on San Tomas and 15 on Central. The six bicyclists on San Tomas were traveling in the opposing direction from the morning count, while six of the eight bicyclists counted on

Central in the early morning were returning in the opposing direction in the late afternoon. Almost all bicyclists were wearing helmets; one entered the expressway from a ramp.

Lawrence and Central Expressways

The junction of Lawrence and Central Expressways is also grade separated; Lawrence runs north and south beneath Central, which runs east and west. Lawrence has four lanes in each direction; Central has three lanes in each direction for most of the length studied. There is full ramp access to both expressways at this interchange.

One count was conducted on Thursday, June 8, 2000, at the Lawrence and Central Expressway intersection for a three-hour period in the midafternoon, 11 a.m. to 2 p.m. The count is summarized in Table 3-3. The weather was mostly cloudy with intermittent sprinkles. A total of five bicyclists were counted during this time—two traveling south on Lawrence Expressway and three traveling west on Central Expressway. Of the five bicyclists, one was both not wearing a helmet and traveling on the wrong side of the road.

Table 3-3. Summary of Bicycle Count Conducted at Lawrence and Central Expressways

		Direction of Travel Toward:				
Location	***Time***	***North***	***South***	***East***	***West***	***Total***
Lawrence	11 a.m.-2 p.m.	0	2			2
Central	11 a.m.-2 p.m.			0	3	3
					Total:	***5***

Page Mill Expressway at El Camino Real (Highway 82)

Page Mill Expressway runs east and west. It is roughly 3 miles long, which is shorter than the other expressways studied in Santa Clara County.

One count was completed at the intersection of Page Mill Expressway and an arterial street, El Camino Real (Highway 82) located in Palo Alto. This count was conducted on Friday, June 9, 2000, from 7:30 to 9:30 a.m.; the weather was sunny with a slight breeze. The count included left- and right-turning movements in all directions. Thus, a total of 12 movements were recorded in this count, summarized in Table 3-4.

Table 3-4. Summary of the Bicycle Count Conducted at Page Mill Expressway and Highway 82 (El Camino Real)

		Direction of Travel Toward:				
Location	***Time***	***North***	***South***	***East***	***West***	***Total***
Page Mill	7:30-9:30 am			0	4	4
SR 82	7:30-9:30 am	7	10			17
					Total:	***21****
**This number represents the bicyclists proceeding straight. A total of 22 bicyclists were counted; one was making a left turn onto westbound Page Mill Expressway.*						

During the two-hour count, 22 bicyclists were counted traveling through this intersection, of which four were actually on the Page Mill Expressway. One bicyclist made a left turn; the other 21 bicyclists were proceeding straight. Most of the bicyclists were not wearing helmets and appeared to be students or young adults.

Stanford University is very near this intersection; however, two days before the count, Stanford completed spring term final examinations.[87]

ANALYSIS OF SWITRS DATA

The following data were extracted from the SWITRS selective bicycle-related collision data and entered into a spreadsheet: type of parties involved, fault, primary collision factor, severity, road surface, road condition, cross street, and distance. Some categories, such as location, type of hit, bicycle on expressway, description of expressway, and collision pattern, had to be interpreted given maps of the Santa Clara County area and the SWITRS data.

During the nine-year period, 1990 to 1998, 111 collisions involving bicycles were reported on the selected expressway sections in Santa Clara County—an average of about 12 collisions per year.

---

[87] Stanford University. http:// www-portfolio.Stanford.edu/105432. Accessed July 23, 2000.

Description of Data

The following is a brief discussion and description of the factors involved in the 111 bicycle-related collisions on the selected Santa Clara County expressways.

Party Type

Of the 111 reported bicycle collisions, 89 were bicycle-motor vehicle collisions. Single-bicycle collisions accounted for 15 percent (17) of the reported collisions. Four collisions involved two bicycles, and one collision involved three bicycles.

Fault

In 53 collisions (48 percent) the bicyclist was reported to be at fault, while 38 percent of the collisions were caused by a motor vehicle operator. In four cases the fault was unknown, and 12 reports did not state who was at fault.

Primary Collision Factor

Although the data show that there is no single significant primary collision factor or cause explaining the majority of the collisions, a few factors are relatively frequent. Listed below are the primary collision factors by decreasing percentage. Numbers in parentheses give the total number of collisions and indicatd how many were the fault of the Bicyclist (B), the Motor Vehicle (MV), or an Unknown Fault or Not Stated (UN).

- 18.9% (21 total, 8 B, 11 MV, 2 UN) were the result of a party failing to yield. Nine of the 21 were caused by the party failing to yield at a signal (9 total, 5 B, 2 MV, 2 UN).
- 17.2% (19 total, 10 B, 9 MV) were the result of parties making improper turns.
- 15.3% (17 total, 11 B, 6 MV) were caused by a party speeding.
- 12.6% (14 total, 3 B, 11 UN) of the collisions had an unknown cause.
- 9.0% (10 total, 10 B) were caused by the bicyclist traveling on the wrong side of the road.
- 8.1% (9 total, 7 B, 1 MV, 1 UN) were the result of improper driving.
- 7.2% (8 total ,7 MV, 1 UN) were due to a party making a lane change.

- 5.4% (6 total, 1 B, 4 MV, 1 UN) were caused by something other than the driver.
- 4.5 % (5 total, 2 B, 3 MV) were due to influence of alcohol.
- 1.8 % (2 total, 2 B) were caused by a party following too close.

Location

Forty-seven percent (52) of the collisions occurring on the expressways in Santa Clara County happened in the intersection of the expressway and a cross street. This includes both freeway-like and arterial-like segments of the expressways. Ten collisions occurred at the ramp entry on the expressway, and three collisions occurred at the ramp exit of the expressway. A mainline expressway, away from ramp junctions or intersections, was the location for 38.7 percent (43) of the reported collisions. Two collisions were at an unknown location, and the location of one was not stated.

Type of Hit

Right-angle collisions accounted for 55.9 percent of the total, while single-bicycle collisions represented 16.2 percent of the 111 collisions. In six cases the motor vehicle had overtaken the bicyclist, and 15 collisions resulted from left turns. Nine collisions were categorized as "other." Many of these involved bicycles colliding with other bicycles as a result of following too closely or speeding. The type of hit for one collision was unknown.

Arterial or Freeway Characteristic

Most of the collisions, 73 of 111, occurred on a portion of the expressway having freeway-like characteristics where access is controlled by ramps. This also includes ramp junctions having freeway-like characteristics. Thirty-seven collisions occurred where an expressway intersected with an arterial street. These sections were deemed arterial-like expressway segments. The expressway characteristics of one collision could not be identified. Of the 35 miles of expressway studied, 21 miles were deemed to resemble freeways.

Severity

Ninety-nine of the collisions occurring on the expressways resulted in injury. There were four fatalities in the 9 years studied. In eight cases, the severity was not stated.

Collision Patterns

Collisions occurred most frequently in the intersection of the expressway. Many involved a bicycle being struck by a motor vehicle making a left or right turn, or single-bicycle collisions resulting from improper driving.

Listed below are the observed collision patterns in decreasing order of frequency. Related to each collision pattern is the type of hit—RA is a right-angle collision, OT is an overtake, LT is a left-turn collision, S is a single-bicycle collision, and UN is an unknown type of hit.

- 15.3% (17 total, 17 RA)—Bike in intersection away from ramp terminals, hit by motor vehicle at right angle.
- 13.5% (15 total, 15 S)—Single bike proceeding straight, collision due to improper driving.
- 10.9% (12 total, 12 RA)—Bike hit by motor vehicle merging or entering traffic on expressway.
- 9.9% (11 total, 10 RA, 1 S)—Bike or motor vehicle proceeding straight, hit by motor vehicle or bike attempting to change lanes.
- 8.1% (9 total, 6 OT, 3 other)—Bike or motor vehicle proceeding straight, overtook bike going straight.
- 8.1 % (9 total, 9 LT)—Bike or motor vehicle proceeding straight, hit by bike or motor vehicle making left turn at ramp terminal intersection.
- 7.2% (8 total, 8 RA)—Bike proceeding straight through ramp terminal intersection hit by motor vehicle at right angle.
- 6.3 % (7 total, 7 RA)—Bike or motor vehicle proceeding straight, hit by bike or motor vehicle exiting or entering mainline at ramp.
- 5.4% (6 total, 1 RA, 5 other)—Bike was speeding and hit stopped motor vehicle or bike, parked car, or slowing bike.
- 3.6% (4 total, 4 RA)—Bike made unsafe turn or meandered in expressway lane and hit motor vehicle or bike.
- 3.6% (4 total, 4 RA)—Bike going wrong way away from intersection and ramp terminals, struck by motor vehicle at right angle.
- 1.8% (2 total, 2 RA)—Bike on wrong side, struck by turning motor vehicle at a right angle at ramp terminal intersection.

- 1.8% (2 total, 2 S)—Single bike, collision caused by something other than the bike.
- 1.8% (2 total, 2 RA)—Bike proceeding straight, away from intersection and ramp terminals, hit by a motor vehicle making a right turn.
- 0.9% (1 total, 1 RA)—Bike proceeding straight, away from intersection and ramp terminals, hit by motor vehicle making a left turn.
- 0.9% (1 total, 1 S)—Single bike, hits object.
- 0.9% (1 total, 1 UN)—Unknown.

Road Surface

Santa Clara County averages 62 rainy days per year; the remainder of the year is dry.[88] The majority of the collisions (88 percent) occurred on dry road surfaces; 11 percent (12 of 111) occurred on wet road surfaces. One reported collision occurred on a slippery road.

Road Condition

Of the 111 collisions, 102 took place where “no unusual conditions” existed. Three collisions occurred on a portion of the roadway having holes and ruts. Five collisions were categorized as having “other” road condition factors. One collision occurred on a roadway under construction or in a repair zone.

Summary of Bicycle Collisions

Table 3-5 summarizes the bicycle-related collisions occurring on the selected expressways in Santa Clara County from 1990 to 1998.

Table 3-5. Summary of the 111 Bicycle Collisions on Selected Expressways in Santa Clara County, 1990-1998

Type of Party			
80.2%	(89) Bicycle-Motor Vehicle	15.3%	(17) Bicycle
3.6%	(4) Bicycle-Bicycle	0.9%	(1) Bicycle-Bicycle-Bicycle

---

[88] City of San Jose, Santa Clara County. http://homes.wsj.com/d/profile-sanjosecalif.html. Accessed July 13, 2000.

Table 3-5. Summary of the 111 Bicycle Collisions on Selected Expressways in Santa Clara County, 1990-1998 (Cont.)

Fault

47.8%	(53) Bicycle	37.8%	(42) Motor Vehicle
10.8%	(12) Not Stated	3.6%	(4) Unknown

Primary Collision Factor

17.1%	(19) Improper Turn	15.4%	(17) Speeding
12.6%	(14) Unknown	10.8%	(12) Failure to Yield
9.0%	(10) Wrong Side	8.1%	(9) Failure to Yield at Signal
8.1%	(9) Improper Driving	7.2%	(8) Lane Change
5.4%	(6) Other Violations	4.5%	(5) Influence of Alcohol
1.8%	(2) Following Too Close		

Location

46.9%	(52) In Intersection	38.7%	(43) Expressway
9.0%	(10) Ramp Entry at Expwy	2.7%	(3) Ramp Exit at Expwy
1.8%	(2) Unknown	0.9%	(1) Not Stated

Type of Hit

55.9%	(62) Right Angle Collision	16.2%	(18) Single Vehicle Collision
13.5%	(15) Left Turn Collision	8.1%	(9) Other
5.4%	(6) MV Overtakes Bike	0.9%	(1) Unknown

Severity

89.2%	(99) Injury	7.2%	(8) Not Stated
3.6%	(4) Fatal		

Expressway Characteristics

65.8%	(73) Freeway-like	33.3%	(37) Arterial-like
0.9%	(1) Unknown		

Road Surface

88.3%	(98) Dry	10.8%	(12) Wet
0.9%	(1) Slippery		

Road Condition

91.9%	(102) No Unusual Conditions	4.5%	(5) Other
2.7%	(3) Holes, Ruts	0.9%	(1) Construction, Repair Zone

Expressway

32.5%	(36) Central	24.3%	(27) Lawrence
23.4%	(26) Page Mill	16.2%	(18) San Tomas
3.6%	(4) Montague		

Summary of Expressway Bicycle Collisions

Table 3-6 summarizes the bicycle collisions occurring on the segments of the expressway having freeway-like characteristics.

Table 3-6. Summary of the 73 Freeway-Like Bicycle Collisions on Selected Santa Clara County Expressways, 1990-1998

Type of Party			
76.7%	(56) Bike-Motor Vehicle	16.4%	(12) Bicycle
5.5%	(4) Bicycle-Bicycle	1.4%	(1) Bicycle-Bicycle-Bicycle
Fault			
53.4%	(39) Bicycle	37.0%	(27) Motor Vehicle
9.6%	(7) Unknown		
Primary Collision Factor			
19.2%	(14) Speeding	15.1%	(11) Improper Turn
13.7%	(10) Failure to Yield	11.0%	(8) Improper Driving
9.6%	(7) Wrong Side	6.8%	(5) Other than the Driver
6.8%	(5) Unknown	5.5%	(4) Influence of Alcohol
5.5%	(4) Lane Change	4.1%	(3) Failure to Yield at Signal
2.7%	(2) Following Too Close		
Type of Hit			
50.7%	(37) Right Angle	17.8%	(13) Single Bike
12.3%	(9) Left Turn	12.3%	(9) Other
5.5%	(4) Overtake	1.4%	(1) Unknown
Severity			
87.7%	(64) Injury	6.8%	(5) Unknown
5.5%	(4) Fatal		
Location			
42.5%	(31) Expressway	39.7%	(29) Intersection
12.3%	(9) Ramp Entry Expwy	4.1%	(3) Ramp Exit Expwy
1.4%	(1) Unknown		
Road Surface			
84.9%	(62) Dry	13.7%	(10) Wet
1.4%	(1) Slippery		
Expressway Characteristics			
100%	(73) Freeway-like	0%	(0) Arterial-like

Table 3-6. Summary of the 73 Freeway-Like Bicycle Collisions on Selected Santa Clara County Expressways, 1990-1998 (Cont.)

Expressway

39.7%	(29) Central	27.4%	(20) Lawrence
19.2%	(14) San Tomas	9.6%	(7) Page Mill
4.1%	(3) Montague		

Road Condition

90.4%	(66) No Unusual Conditions	6.9%	(5) Other
2.7%	(2) Holes, Ruts		

Collision Patterns

- 13.7% (10 total, 10 S)—Single bike proceeding straight, improper driving.
- 2.3% (9 total, 9 RA)—Bike hit by motor vehicle merging or entering traffic on expressway.
- 12.3% (9 total, 9 LT)—Bike or motor vehicle proceeding straight, hit by bike or motor vehicle making left turn at ramp terminal intersection.
- 11.0% (8 total, 8 RA)—Bike proceeding straight through ramp terminal intersection, hit by motor vehicle at right angle.
- 11.0% (8 total, 7 RA, 1 other)—Bike or motor vehicle proceeding straight, hit by motor vehicle or bike attempting to change lanes.
- 9.6% (7 total, 7 RA)—Bike or motor vehicle proceeding straight, hit by bike or motor vehicle exiting or entering mainline at ramp.
- 9.6% (7 total, 4 OT, 3 other)—Bike or motor vehicle proceeding straight, overtook bike going straight.
- 6.8% (5 total, 5 other)—Bike speeding, hit stopped motor vehicle or bike, parked car, or slowing bike.
- 5.5% (4 total, 4 RA)—Bike made unsafe turn or meandered in expressway lane and hit motor vehicle or bike.
- 2.7% (2 total, 2 RA)—Bike on wrong side, struck by turning motor vehicle at right angle at ramp terminal intersection.
- 2.7% (2 total, 2 S)—Single bike, collision caused by something other than the bike.
- 1.4% (1 total, 1 S)—Single bike, hit object.
- 1.4% (1 total, 1 UN)—Unknown.

ESTIMATED AVERAGE DAILY BICYCLE TRAFFIC (ADT) OF THE SELECTED EXPRESSWAYS IN SANTA CLARA COUNTY

Estimated ADT volumes can be calculated for a specific location or time of day, given reliable traffic counts. Two of the four bicycle counts conducted at the Central and San Tomas Expressways provided enough data; thus, this information was used to determine an estimated ADT. The counts completed at Central/Lawrence Expressways and Page Mill Expressway at El Camino Real provided insufficient data and, therefore, are not used to calculate an estimated ADT for these expressway segments.

Methods of Calculating ADTs

Methods used to calculate ADTs for the segments of the San Tomas and Central Expressways are discussed below. These methods assumed that the counts made are representative of all segments of both expressways each and every day over the years 1990 to 1998. This is a very generalized assumption based on seven hours of counting in June 2000.

The total number of bicyclists counted in the peak hour of the day was then multiplied by a factor of 10 to give a rough estimate of the ADT of bicyclists on the expressway segments. Table 3-7 shows the results of this method for each expressway. It is evident that the average daily bicycle traffic for both expressways is roughly 50. Midday counts done on the Central Expressway at Lawrence were inconclusive and not used.

Table 3-7. Count Data Used to Calculate Estimated ADTs

	Peak Hour		***Method***
Expressways	A.M.	P.M.	Peak Hr x 10
Central			
East of San Tomas	2	6	60
West of San Tomas	5	5	50
San Tomas			
North of Central	1	5	50
South of Central	5	0	50

Estimated Collision Rates

From the estimated ADTs in the previous section, collision rates can be calculated, given the total number of reported collisions on the selected expressway in the nine-year period and the length of the expressway studied. Collision rates generally are calculated in terms of collisions per million bicycle miles (mbm).

Central and San Tomas Expressways

In the nine years studied, Central and San Tomas Expressways had a total of 54 reported collisions (36 Central, 18 San Tomas). Central is approximately 10 miles in length, while San Tomas is 7.1 miles in length.

With an estimated ADT of 50, the collision rate can be calculated as follows:

$$\frac{54 \text{ collisions} \times 10^6}{50 \text{ bikes/day} \times 17.1 \text{ miles} \times 9 \text{ years} \times 365 \text{ days/year}}$$

After all units are canceled and the quotient is reduced, the result is 19 collisions per million bicycle miles.

Lawrence Expressway

The number of reported collisions per mile on the Lawrence Expressway is about the same as on the San Tomas and Central sections studied. Bicycle travel volumes appear to be lower on the Lawrence Expressway, given the low number of bicycles counted during the peak hours (five bicyclists were counted in 3 hours). Therefore, the collision rate of the Lawrence Expressway is greater than the 19 reported collisions per million bike miles estimated for the two expressways.

Page Mill Expressway at El Camino Real

It is likely that the collision rate is higher than 19 per million bicycle miles on the Page Mill Expressway because of the low number of bicycles counted there. Of the 22 bicycles counted at this intersection, four were on Page Mill and 18 were on El Camino Real (Highway 82). Representative bicycle counts are not available for this expressway, so calculating ADT is not practical.

Collision Diagrams

Collision diagrams were drawn from the SWITRS data for the selected expressways in Santa Clara County. The purpose of these collision diagrams was to illustrate, in a more visual form, the patterns of collisions occurring in the past nine years on the selected expressways. The diagrams are not reproduced here because they do not provide additional insight to the collision data.

The only clear pattern to these collisions is that many of the collisions occurred in intersections at right angles. This finding is enforced by the SWITRS data and percentages shown on the previous pages (56 percent were right angle collisions, 47 percent occurred in an intersection). Thirteen of the 111 collisions (11.8 percent) occurred on the ramp terminals at the expressway. The remaining 43 collisions (38.7 percent) occurred on the mainline of the expressway.

FREEWAY BICYCLE AND PEDESTRIAN COLLISION ANALYSIS FOR DISTRICTS 1, 2, AND 3

INTRODUCTION

It is the intent of this study to provide an understanding of the patterns of bicycle and pedestrian collisions on California freeways. To accomplish this, it was necessary to retrieve collision data from the Traffic Accident Surveillance and Analysis System (TASAS) managed by Caltrans.

CALTRANS CURRENT POLICY

Section 1003.4 of the California *Highway Design Manual* discusses Caltrans' policy regarding bicycles and their use of the freeway. "Where no reasonable alternate route exists within a freeway corridor, the Department should coordinate with local agencies to develop or improve existing routes or provide parallel bikeways within or adjacent to the freeway right of way."[89] Each district's director makes the final determination as to whether bicycles are to be allowed on a section of freeway. Factors to be considered when determining if the freeway shoulder is suitable for bicycles are:

- Shoulder widths;
- Hazards on shoulder;
- Ramp traffic volumes; and
- Number and locations of ramps.[90]

Avid bicyclists generally want the opportunity to choose to use freeways. Of particular interest is the Richmond-San Rafael Bridge, which is not currently available for bicycle use. A study of the bridge, published in December of 1998, identified an interest in a broader look at the issue of bicycles on freeways and toll bridges.[91] This working paper is one contribution to that "broader look."

---

[89] California Department of Transportation, *Highway Design Manual*, 1000-23.

[90] ibid., 1000-22

[91] California Department of Transportation, *Richmond-San Rafael*, 1-1.

DATA COLLECTION

Initially, bicycle and pedestrian collision data for Districts 1, 2, and 3 were obtained from TASAS for analysis. The three districts were selected because traffic collision reports were readily available. The districts contain both urban and rural areas, as well as mountainous and level terrain. A spreadsheet was then generated in Microsoft Excel to store the relevant TASAS collision data in a simple format that could be expanded on and edited for future use.

Since TASAS data does not specifically describe certain characteristics of each collision, such as fault or how the collision occurred, it was necessary to review each Traffic Collision Report (TCR) extensively. By extracting this pertinent information from the TCRs, patterns and percentages could then be determined for all freeway bicycle and pedestrian collisions in these two districts. TCRs also provide significant information, including whether any participant involved in a traffic collision was actually on the freeway, the exact location relative to the freeway, and the primary collision factor.

TCRs can be used to derive collision diagrams and conduct statistical analysis for bicycle-motor vehicle and pedestrian-related collisions occurring on California freeways. It is essential to analyze a sufficiently large sample. If the data sample size was too small, the results of this report may lead to inaccurate conclusions and, subsequently, ineffective policy and recommendations. Consequently, several districts' data is vital to this analysis.

TASAS Data

TASAS is a computerized record system where data for each collision occurring on state highways are stored and can be retrieved. These collisions are categorized in TASAS by location, general collision data, and party data. The following is a list of the critical data extracted from TASAS for this analyses:

- Year;
- Type of parties involved (bicycle, pedestrian, motor vehicle);
- Party at fault;
- Primary Collision Factor (PCF);
- Location of the collision;
- Type of collision (for bicycle collisions);

- Position in road (for pedestrian collisions);
- Severity of injury;
- Road surface;
- Road conditions; and
- Number of lanes.

Interpreting Traffic Collision Reports

The researchers for this report developed a system to expand upon the TASAS data by reading each TCR involving a bicyclist or a pedestrian. By reading each report, one can detect how the collision occurred (bicycle equipment failure, bicycle hit by motor vehicle while in crosswalk, pedestrian in freeway lane struck by motor vehicle, etc.) and whether the bicyclist or pedestrian was on the freeway. The collision number was used to insure that the TASAS data and the TCR were properly linked.

When reading the TCR for bicycle-motor-vehicle-related collisions, it was imperative to verify that the parties involved, fault, primary collision factor, location, and type of hit agree with the TASAS data. Two additional categories were created specifically for this analysis: collision pattern and “bicyclist (or pedestrian) on freeway.” The collision patterns help determine how the collision occurred, and “bicyclist (or pedestrian) on freeway” clarifies whether the bicyclist (or pedestrian) was actually on the freeway or just on a ramp-related local street or cross street when the collision occurred.

TCRs for pedestrian-related collisions are read in a similar fashion, with two exceptions. First, all data is analyzed in the same manner, except “type of hit” is replaced with the pedestrian’s “position in road,” which describes the location where the pedestrian was hit. Second, a new set of collision patterns was developed solely for the purposes of reading the pedestrian-related collision reports.

Bicycle-Related Collision Data

The following data were extracted from TASAS, with the exception of “bicycle on freeway” and “collision pattern,” which were derived by reading the reports.

Bicycle on Freeway

The "bicycle on freeway" column was developed to calculate how many collisions actually occured on the freeway. The freeway is considered to be the mainline of the freeway, freeway ramps, and freewayside ramp terminals. Any collision occurring on one of the these three freeway components would be marked "Y" for Yes, the bicyclist was on the freeway.

Collision Pattern

The collision pattern describes how the collision occurred. This information was obtained by reviewing the diagrams in the TCR and the officer's comments in the conclusion of the report.

The collisions were coded using a number system, one through ten. If the bicyclist was traveling the wrong way, a "w" was placed next to the corresponding number. After the collision pattern was identified, the appropriate corresponding number was recorded in the "collision pattern" column on the table.

Method for Developing Bicycle Collision Data

Since TCRs are generally filed under the route, county, and milepost where the collision took place, it was important to have the actual TASAS Selective Record Retrieval data sheets that correlated the milepost to the collision number as a reference.

Verifying TASAS Data

After each TCR had been retrieved, data were tabulated. The following procedure was used to verify that the TCR agreed with the necessary TASAS data:

1. **Type of Parties Involved** was checked by reviewing the left-hand side of the first page in the TCR.
2. **Fault** is typically located on the second page of the TCR, next to the violation code. Fault is as reported by the officer who did the initial investigation.
3. **PCF** is the "cause" of the collision determined by the reporting officer. This was determined by reviewing the Cause paragraph located in the Summary and Conclusions section near the end of the TCR.

4. **Location** of the collision was determined from the scene diagram or by reviewing the summary.
5. **Type of Hit** was verified by reviewing the scene diagram and summary of the TCR.

Data Derived from TCR

Once the TASAS data were verified, it could be determined whether the bicyclist was on the freeway by reviewing the Scene Diagram or Summary. **The freeway is considered the freeway mainline, ramp, and freeway-side ramp terminals**.

The “collision pattern” was derived by analyzing both the Scene Diagram and the Summary of the TCR; the Summary was beneficial because it expanded on the details of the collision.

Pedestrian-Related Collision Data

There was a slight variation in the categorization of pedestrian-related collision data compared to the bicycle-related collision data. The Access to Freeway column was no longer relevant and was deleted. Pedestrian-related collisions occurring on state highways include dismounted pedestrians seeking assistance. A person who enters the freeway in a vehicle and then exits the vehicle while still on the freeway, probably because the vehicle became disabled or because the person exited it to assist drivers of other vehicles, is considered a dismounted pedestrian.

Method for Developing Pedestrian Collision Data Tables

It is still important to have the TASAS Selective Record Retrieval data sheets that correlate the milepost to the collision number as a reference. The following procedure describes how the pedestrian data were collected from the TCR, given the TASAS data.

Verifying TASAS Data

1. **Type of Parties Involved**, or participants in the traffic collision, are checked by reviewing the left-hand side of the first page in the TCR.
2. **Fault** is typically located on the second page of the TCR next to the violation code.

3. **PCF** is the “cause” of the collision determined by the reporting officer. This was determined by reviewing the Cause paragraph in the Summary and Conclusions section near the end of the TCR.
4. **Location** of the collision was determined by reviewing the Scene Diagram.
5. **Position in Road** of the collision was found by reviewing the Scene Diagram. If no Scene Diagram is present, the position in road should be discussed in the Summary and Conclusions.

Data Derived from Traffic Collision Reports

Once the TASAS data had been verified, it could be determined whether the pedestrian was on the freeway by reviewing the Scene Diagram or Summary. **The freeway is considered the freeway mainline, ramp, and freeway-side ramp terminals**. This data is then entered into the appropriate column with a simple “Yes” or “No” (Y or N).

The “collision pattern” was derived by analyzing both the Scene Diagram and the Summary of the TCR. While the scene diagram shows a realistic layout of the collision, it does not specify or expand on the details.

DATA ANALYSIS

Bicycle-Related Collisions in District 1

District 1 is significant in California in that all of its freeway miles are open to bicyclists. In the nine-year period, 1990 to 1998, 32 bicycles were involved in collisions coded to a freeway route segment. Through reading collision reports, it was determined that 24 of the 32 bicycle-involved collisions actually occurred on the freeway. The other eight collisions occurred on a local street near a freeway ramp terminal. One fatality and one property-damage-only collision were reported in this time period; the remaining collisions were injury related. The information available is summarized in Table 4-1.

Table 4-1. Summary of Freeway-Related Bicycle Collisions in District 1

Type			
75.0%	(24) Bike-Motor Vehicle	15.6%	(5) Bike
6.3%	(2) Other	3.1%	(1) Bike-Pedestrian

Table 4-1. Summary of Freeway-Related Bicycle Collisions in District 1 (Cont.)

Fault			
59.4%	(19) Bike	28.1%	(9) Motor Vehicle
9.4%	(3) Unknown	3.1%	(1) Bike and Motor Vehicle
Primary Collision Factor			
37.5%	(12) Improper Turn	21.9%	(7) Other Violations
9.4%	(3) Speeding	6.3%	(2) Failure to Yield
6.3%	(2) Improper Driving	6.3%	(2) Other than the Driver
6.3%	(2) Unknown	3.1%	(1) Lane Change
3.1%	(1) Influence of Alcohol		
Location			
59.4%	(19) Freeway	18.8%	(6) Ramp-Related, Local Street
6.3%	(2) Ramp Exit, Freeway	6.3%	(2) Ramp
6.3%	(2) Ramp Exit, Surface Street	3.1%	(1) Ramp Entry, Freeway
Severity			
93.8%	(30) Injury	3.1%	(1) Fatal
3.1%	(1) Property Damage Only (PDO)		
Type of Hit			
46.9%	(15) Motor Vehicle Overtakes Bike		
21.9%	(7) Right-Angle Collision	15.6%	(5) Single Vehicle
9.4%	(3) Other	6.3%	(2) Head-On Collision
Bicycle Access Allowed			
100%	(32) Yes	0.0%	(0) No
Bicycle on Freeway			
75.0%	(24) Yes	25.0%	(8) No
Road Surface			
87.5%	(28) Dry	12.5%	(4) Wet
Road Condition			
93.8%	(30) No Unusual Condition	3.1%	(1) Loose Material
3.1%	(1) Construction		
Number of Lanes (per direction of travel)			
87.5%	(28) 2 Lanes	12.5%	(4) 3 Lanes

Table 4-1. Summary of Freeway-Related Bicycle Collisions in District 1 (Cont.)

Freeway Miles[a]			
100%	(133.8 mi) Bikes Allowed	0%	(0 mi) Bikes not Allowed

a. California Department of Transportation, 1998 Accident Data on California State Highways (Road Miles, Travel, Accidents, Accident Rates),13.

Party Type

"Party Type" describes each participant in a traffic collision—a passenger car, pickup, bicycle, pedestrian, etc. Of the 32 collisions

- 24 were bicycle-motor-vehicle-related;
- 5 involved a single bicycle;
- 2 involved a bicycle making contact with a type of vehicle not stated; and
- 1 involved a single bicycle colliding with a pedestrian.

Fault

Nineteen (59 percent) of the collisions were determined to be the bicyclists' fault; in nine (28 percent), fault was attributed to the motor vehicle. In three collisions the fault was unknown; one was the fault of both the bicycle and the motor vehicle.

Primary Collision Factor

The PCF is what the reporting officer determined to be the main cause of the collision. The most common PCF was a bicyclist making an improper turn; in only one case did the motor vehicle make an improper turn. The fault is attributed to the Bicycle (B), Motor Vehicle (MV), or Unknown Party at Fault (UN), as designated in parentheses below. The PCFs are listed as follows:

- 37.5% (12 total, 10 B, 2 MV) were the result of a party making an improper turn.
- 21.8% (7 total, 5 B, 2 MV) were categorized as having "other violations."
- 9.3 % (3 total, 1 B, 1 MV, 1 B and MV) were the result of a party speeding.
- 6.3% (2 total, 2 MV) were caused by a motor vehicle failing to yield.
- 6.3% (2 total, 2 B) were the result of the bicyclist driving improperly.

- 6.3% (2 total, 1 B, 1 UN) involved a cause other than the driver.
- 6.3% (2 total, 2 UN) had an unknown cause.
- 3.1% (1 total, 1 MV) involved a motor vehicle operator being under the influence.
- 3.1% (1 total, 1 MV) was the result of a motor vehicle making a lane change, failing to see the bicyclist.

Location

Location describes the type of roadway where the collision occurred. Twenty-four of the collisions occurred on freeway segments—nineteen on the freeway mainline, two at the freeway-end ramp exit, two on the ramp mainline, and one at the freeway-end ramp entry.

Seven of the 32 collisions occurred on a ramp-related local street. One collision took place at the surface street end of the ramp exit.

Type of Hit

Type of Hit describes the nature of the collision at point of impact. In 15 collisions, the motor vehicle had overtaken the bike, while seven collisions occurred at right angles. Single-bike incidents accounted for five of the collisions. Two collisions were head-on; no collisions involved left turns. In three cases, the type of hit was categorized as other because it had unique circumstances.

Severity

Severity is the degree of bodily harm resulting from the collision. All the collisions were injury-related with the exception of two—one was a fatality and one was property damage only.

Bicycle Access

Bicycle access refers to a segment of a freeway that allows bicycle riding. All freeways in District 1 allow bicycles access.

Bicycle on Freeway

The freeway includes freeway ramps and freewayside ramp terminals. The freeway mainline generally consists of two or more lanes in each direction, separated by a median. The ramp entry and exit directly adjacent to the freeway is considered part of the freeway, along with the mainline section between ramps. The ramp entry and exit directly adjacent to the surface street are not considered part of the freeway.

Twenty-four of the 32 collisions occurred while the bike was on the freeway, freeway ramp, or freewayside ramp terminals; eight collisions occurred at locations other than on the freeway.

Collision Patterns

The collision pattern describes *how* the collision occurred. The following list describes the collisions occurring in District 1 from 1990 to 1998. The type of hit is correlated to each pattern; an overtake is denoted by OT, right angle by RA, head-on by HO, and a single-bike collision by S.

- 25.0% (8 total, 6 OT, 2 other)—Bike hit by motor vehicle when crossing the off-ramp at the freeway end.
- 18.8% (6 total, 5 OT, 1 HO)—Motor vehicle entered shoulder or bike lane and overtook bike.
- 12.5% (4 total, 2 OT, 2 RA)—Bike hit by motor vehicle when crossing on ramp at freeway.
- 9.4% (3 total, 3 S)—Single bike, hits object.
- 6.3% (2 total, 2 RA)—Bike in crosswalk going wrong way, hit by motor vehicle.
- 6.3% (2 total, 2 RA)—Bike in intersection away from crosswalk, hit by motor vehicle.
- 6.3% (2 total, 1 OT, 1 RA)—Bike meanders in freeway lane.
- 3.1% (1 total, 1 S)—Single bike, equipment failure.
- 3.1% (1 total, 1 S)—Single bike, hits drain.
- 3.1% (1 total, 1 OT)—Bike hit by motor vehicle when crossing on-ramp at surface street.
- 3.1% (1 total, 1 HO)—Bike going wrong way crossing on ramp at surface street, hit by motor vehicle.
- 3.1% (1 total, 1 OT)—Bike hits pedestrian on freeway.

Road Surface

Twenty-eight of the 32 collisions occurred on dry road surfaces; four occurred on a wet surface.

Road Condition

Thirty of the collisions occurred when no unusual conditions were present. One collision transpired on a road surface with loose material, and one occurred in a construction/repair zone.

Number of Lanes

Twenty-eight collisions occurred on or near a freeway route with two lanes per direction; four occurred on a freeway with three lanes per direction.

Distance of Freeway Miles

District 1 has a total of 133.8 freeway miles; all are open to bicycles.

Collision Rate

A collision rate was estimated for a section of Highway 101 in Humboldt County from Arcata to Trinidad. This rate covered 21.5 miles of freeway in the nine-year period 1990 to 1998, during which 17 collisions occurred. Bicycle counts were conducted at the Mad River Bridge (see Chapter 5, “A Study Of Bicycles On Selected Bridges And Tunnels”) and at two locations on the expressway segment to the south. An estimated volume of 50 bicycles per day was used to determine the collision rate of five collisions per million bicycle miles. This is a conservatively low rate. It is likely that bike volumes are much lower on the northern portion of this freeway segment.

Bicycle-Related Collisions in District 2

After analyzing District 2 collision data for the years 1990 through 1998, it is evident that few bicycle-related collisions occurred on the freeway. A total of 10 bicycle collisions were coded in TASAS to freeway state highways. In fact, most of the collisions transpired on ramp-related local streets where a party failed to yield, resulting in a right-angle collision.

The following is a brief discussion and description of factors involved in the 10 bicycle-related collisions in District 2.

Summary of Bicycle Related Collisions in District 2

Table 4-2 summarizes, by percentage and number, the ten freeway-related bicycle collisions reported in TASAS for District 2 in the nine-year period.

Party Type

Of the 10 collisions reported, nine were bicycle-motor vehicle and one involved a single bicycle.

Fault

In six of the 10 collisions, the bicycle was at fault; for the remaining four collisions, the motor vehicle was at fault.

Primary Collision Factor (PCF)

The PCFs are listed below in order of most occurrences. Fault is also indicated in parentheses, where B = bicycle and MV = motor vehicle.

- 40% (4 total, 1 B, 3 MV) were the result of a party failing to yield.
- 20% (2 total, 2 B) were categorized as “other violations” in both TASAS and the TCR.
- 20% (2 total, 1 B, 1 MV) were due to the influence of alcohol.
- 10% (1 total, 1 B) were caused by a bicycle making an improper turn and striking a motor vehicle.
- 10% (1 total, 1 B) were due to the bicyclist’s driving improperly.

Location

Seven of the 10 collisions took place near a freeway ramp terminal and the surface street. One collision occurred at the ramp entry on the surface street, which is not considered part of the freeway.

Table 4-2. Summary of Freeway Related Bicycle Collisions in District 2

Type			
90%	(9) Bike-Motor Vehicle	10%	(1) Bike
Fault			
60%	(6) Bike	40%	(4) Motor Vehicle
Primary Collision Factor			
40%	(4) Failure to Yield	20%	(2) Influence of Alcohol
20%	(2) Other Violations	10%	(1) Improper Turn
10%	(1) Improper Driving		
Location			
70%	(7) Ramp-Related, Local Street	20%	(2) Freeway
10%	(1) Ramp Entry, Surface Street		
Type of Hit			
70%	(7) Right Angle Collision	20%	(2) Other
10%	(1) MV Overtakes Bike		
Severity			
70%	(7) Injury	20%	(2) PDO
10%	(1) Fatal		
Bicycle Access Allowed on Freeway			
90%	(9) No	10%	(1) Yes
Bicycle on Freeway			
80%	(8) No	20%	(2) Yes
Road Condition			
100%	(10) No Unusual Conditions		
Number of Lanes (per direction)			
100%	(10) 2-Lane Freeway		
Freeway Miles (184 miles total)			
54.4%	(98.5 mi) Bicycles Not Allowed	47.2%	(85.5 mi) Bicycles Allowed
Road Surface			
90%	(9) Dry	10%	(1) Wet

Two of the ten collisions occurred on the mainline of the freeway, away from a ramp terminal. In one collision, the bicyclist was at fault due to improper driving; the collision involved PDO. No injuries or fatalities resulted from this collision. The second collision was caused by the motor vehicle driver being under the influence of alcohol. The motor vehicle overtook the bicyclist, resulting in a fatality to the bicyclist.

Type of Hit

Seven of the 10 collisions occurred at right angles. One collision was caused by a motor vehicle overtaking a bicyclist. The remaining two collisions were categorized under “other”—meaning their orientation of impact was not a right angle, head on, a single vehicle, or a motor vehicle overtaking a bike.

Severity

In nine years, District 2 had one fatality—a bicyclist on the freeway was overtaken by a motor vehicle entering the shoulder. Most of the collisions, however, resulted in injuries. There were two PDO collisions, both the fault of the bicyclist.

Bicycle Access

Ninety percent of the collisions occurred where no bicycle access was allowed. One collision occured where bicycle access was permitted.

Bicycle on Freeway

Two of the ten collisions occurred on the freeway; the remaining eight were on ramp-related local streets, with one at the ramp entry surface street.

Collision Patterns

The collision pattern describes *how* the collision occurred. The following list describes how each of the bicycle-related collisions in District 3 occurred.

- 30% (3 total, 3 RA)—Bike going wrong way in intersection, away from crosswalk, hit by motor vehicle.
- 20% (2 total, 1 OT, 1 other)—Motor vehicle enters shoulder or bike lane and overtakes bike.
- 10% (1 total, 1 RA)—Bike on crosswalk, hit by motor vehicle.

- 10% (1 total, 1 RA)—Bike going wrong way on crosswalk, hit by motor vehicle.
- 10% (1 total, 1 other)—Single bike, hits object.
- 10% (1 total, 1 RA)—Bike in intersection, away from crosswalk, hit by motor vehicle.
- 10% (1 total, 1 RA)—Bike hit by motor vehicle when crossing surface street.

Road Surface

Road Surface pertains to the condition of the road surface during the time of the collision. Nine of the ten collisions occurred on a dry road surface; one took place when the surface was wet.

Road Condition

Road Condition describes the quality of the roadway at the time of the collision. All ten collisions occurred when no unusual conditions existed.

Number of Lanes

This describes the number of lanes on the freeway at the time of the collision. All ten collisions occurred on freeways with two lanes in each direction.

Freeway Miles Bikes Allowed

There are 184 total freeway miles in District 2, of which 46.5 percent (85.5 miles) allow bicycle access. The remaining 53.5 percent (98.5 miles) prohibit bicycle use.

Bicycle-Related Collisions in District 3

District 3 collision data were also analyzed for the nine-year period 1990-1998. During this time, there were 171 bicycle-related collisions, of which three were fatal. There were 152 bicycle-motor-vehicle-related collisions and 19 involving a single bicycle. In 77 percent of the collisions, the bicycle was at fault; unknown fault accounted for 1 percent.

In most collisions, the bicyclist was at fault and “other violations” were present. More than half of the collisions occurred at right angles on ramp-related local streets and resulted in injury. Common types of collisions were a bicycle going the wrong way in a crosswalk and being hit by a motor vehicle, and a bicycle in the intersection away from the crosswalk hit by a motor vehicle.

These patterns and trends will be discussed in more detail in the following section. A summary of the data can be found in Table 4-3.

Table 4-3. Summary of Freeway-Related Bicycle Collisions in District 3

Type			
88.3%	(151) Bike-Motor Vehicle	11.7%	(20) Bike
Fault			
76.6%	(131) Bike	22.2%	(38) Motor Vehicle
1.2%	(2) Unknown		
Primary Collision Factor			
41.5%	(71) Other Violations	17.5%	(30) Failure to Yield
11.1%	(19) Improper Turn	7.6%	(13) Influence of Alcohol
7.6%	(13) Wrong Way	4.7%	(8) Speeding
4.1%	(7) Improper Driving	4.1%	(7) Unknown
1.8%	(3) Other than the Driver		
Type of Hit			
64.3%	(110) Right-Angle Collision	15.2%	(26) MV Overtakes Bike
12.3%	(21) Single Vehicle	4.7%	(8) Head-On Collision
2.3%	(4) Other	1.2%	(2) Left-Turn Collision
Severity			
89.5%	(153) Injury	8.7%	(15) PDO
1.8%	(3) Fatal		
Road Surface			
95.3%	(163) Dry	4.1%	(7) Wet
0.6%	(1) Not Stated		
Road Condition			
97.6%	(167) No Unusual Conditions	1.2%	(2) Construction
0.6%	(1) Holes, Ruts	0.6%	(1) Loose Material
Location			
55.6%	(95) Ramp-Related, Local Street	23.4%	(40) Ramp Exit, Surface Street
10.5%	(18) Ramp Entry, Surface Street	5.8%	(10) Freeway
3.5%	(6) Ramp	1.2%	(2) Ramp Entry, Freeway

Table 4-3. Summary of Freeway-Related Bicycle Collisions in District 3 (Cont.)

Number of Lanes (in each direction)			
37.4%	(64) 2-Lane Freeway	26.9%	(46) 3-Lane Freeway
23.4%	(40) 4-Lane Freeway	7.6%	(13) 5-Lane Freeway
4.7%	(8) 6-Lane Freeway		
Bicycle on Freeway			
91.2%	(156) No	8.8%	(15) Yes
Bicycle Access Allowed			
99.4%	(170) No	0.6%	(1) Yes
Freeway Miles (423.8 miles total)			
81.4%	(345) Bicycles Not Allowed	18.6%	(78.8) Bicycles Allowed

Party Type

Almost 90 percent of the bicycle-related collisions involved two parties—a bicycle and motor vehicle. Nineteen of the 171 collisions involved a single bicycle.

Fault

In 76.6 percent of the collisions, the bicyclist was deemed at fault; the remaining 22 percent were the fault of the motor vehicle. In two collisions, the fault was unknown.

Primary Collision Factor

More than 40 percent of the collisions were a result of "other violations"; more detail was not specified in TASAS. Forty-two of the 171 collisions were due to a party failing to yield. All of the PCFs are listed below.

- 42.1% (72 total, 56 B, 16 MV)—Other violations.
- 24.6% (42 total, 30 B, 12 MV)—Failing to yield.
- 11.1% (19 total, 17 B, 2 MV)—Improper turns.
- 7.0% (12 total, 11 B, 1 MV)—Influence of alcohol.
- 4.7% (8 total, 7 B, 1 MV)—Speeding.
- 4.7% (8 total, 8 B)—Improper driving.

- 4.1% (7 total, 1 B, 4 MV, 2 UN)—Unknown cause.
- 1.8% (3 total, 3 B)—Other than the driver.

Location

Roughly 90 percent (158 of 171) of the bicycle collisions in District 3 occurred on freeway-related roadways, not the freeway mainline. Approximately 56 percent (95) of the collisions transpired on ramp-related local streets. Eighteen percent of the collisions occurred at the ramp exit surface street, while 10 percent occurred at the ramp entry of the surface street. The on-freeway locations, where the remaining 10 percent of the collisions occurred, are described as follows.

- 5.6% (10) occurred on the freeway mainline away from ramp terminals.
- 3.5% (6) occurred on the ramp of the freeway.
- 1.2% (2) occurred on the ramp entry adjacent to the freeway.
- 0% (0) occurred on the ramp exit adjacent to the freeway.

Three of the ramp collisions involved a bicycle traveling on a surface street that encroached on the ramp. These three collisions were not treated as on-freeway collisions.

Type of Hit

Right-angle collisions were common in District 3, accounting for 64 percent of the collisions. In 15.2 percent of the collisions, a motor vehicle had overtaken a bicycle. Single-vehicle collisions, involving the bicyclist alone, accounted for 12.3 percent of the collisions. Only eight head-on collisions took place during the nine-year period of TASAS reports studied. The remaining collisions accounted for less than 4 percent—two left-turn collisions and four “other” collisions.

Severity

Three bicycle-related fatalities occurred on or near a freeway in District 3 from 1990 to 1998. The majority (89.5 percent) of the collisions resulted in injury. Fifteen of the 171 collisions were PDO.

Bicycle Access

One collision occurred on a freeway where bicycle access was allowed; the remaining 170 collisions occurred where bicyclists are not allowed on the freeway or with a bicycle riding on a nonfreeway roadway near a ramp terminal.

Bicycle on Freeway

Most of the bicycle-related collisions in District 3 did not occur on the freeway—91.2 percent occurred at locations other than the freeway and only 8.8 percent actually occurred on the freeway.

Collision Pattern

The most common pattern for these bicycle-related collisions involved a bicyclist traveling through an intersection; most of those bicyclists were traveling the wrong way through the intersection, in or out of the crosswalk. The following list provides a description of how the collisions occurred, along with the numbers and percentages of each collision pattern.

- 28.1% (48 total, 46 RA, 1 OT, 1 HO)—Bike going wrong way in crosswalk, hit by motor vehicle.
- 22.8% (39 total, 30 RA, 5 OT, 2 HO, 1 other)—Bike in intersection, away from crosswalk, hit by motor vehicle.
- 9.4% (16 total, 15 RA, 1 OT)—Bike in crosswalk, hit by motor vehicle
- 8.8% (15, 15 S)—Single bike, hits object.
- 7.0% (12 total, 9 RA, 3 OT)—Bike crossing surface street, hit by motor vehicle.
- 6.4% (11 total, 1 RA, 8 OT, 1 HO, 1 other)—Motor vehicle enters shoulder or bike lane and overtakes bike.
- 2.9% (5 total, 4 RA, 1 HO)—Bike crossing surface street going wrong way, hit by motor vehicle.
- 2.3% (4 total, 1 RA, 3 LT)—Bike or motor vehicle hit by bike or motor vehicle making left turn.
- 1.7% (3 total, 3 S)—Single bike, collision with drain inlet.
- 1.7% (3 total, 2 RA, 1 other)—Bike hit at right angle by motor vehicle merging off of off-ramp at surface street.
- 1.7% (3 total, 2 OT, 1 HO)—Bicycle meanders in freeway lane and is struck by motor vehicle.
- 1.2% (2 total, 2 S)—Single bike, equipment failure.

- 1.2% (2 total, 2 RA)—Bike going wrong way in intersection away from crosswalk, hit by motor vehicle.
- 1.2% (2 total, 1 RA, 1 OT)—Bike hit by motor vehicle when crossing off-ramp at freeway.
- 1.2% (2 total, 2 OT)—Bike hit by motor vehicle when crossing on-ramp at freeway.
- 1.2% (2 total, 2 OT)—Bicycle meanders in surface street lane and is struck by motor vehicle.
- 0.6% (1 total, 1 OT)—Other collision pattern.
- 0.6% (1 total, 1 RA)—Data not available.

Road Surface

Of the 171 collisions, 163 occurred on a dry road surface; seven occurred on a wet road surface. One collision had an unstated road surface in both TASAS and the TCR.

Road Condition

All but four reported collisions occurred when no unusual conditions were present in the roadway. Two collisions occurred during road construction or in a repair zone. One collision was the result of holes and ruts being present in the roadway; another was due to loose material in the roadway.

Number of Lanes

Most of the collisions occurred on or near freeways having two, three, or four lanes in each direction. Thirteen collisions occurred on five-lane freeways, and eight on six-lane freeways.

Freeway Miles Bikes Allowed

In District 3, 19 percent of the total 423.3 freeway miles allow bicycles access. The remaining 345 freeway miles do not allow bicycle access.

DISTRICTS 1, 2, AND 3—BICYCLES ON FREEWAY

A total of 41 collisions occurred on the freeway in the nine years of study. Of the 41 collisions, the bicyclist was at fault in 30. Two motor vehicle operators were at fault, causing a collision due to the influence of alcohol. Table 4-4 summarizes these collisions. It demonstrates the frequencies of the PCF and collision patterns for all three districts' on-freeway collisions. Fault is identified with the PCF, and type of hit is provided for the collision patterns.

Table 4-4. Summary of On-Freeway Bicycle Collisions in Districts 1, 2, and 3

Type			
61.0%	(25) Bike-MV	34.2%	(14) Bike
2.4 %	(1) Other	2.4%	(1) Bike-Pedestrian
Fault			
73.2%	(30) Bike	19.5%	(8) Motor Vehicle
4.9%	(2) Unknown	2.4	(1) Bike and MV
Primary Collision Factor			
29.3%	(12) Improper Turn	19.5%	(8) Influence of Alcohol
14.6%	(6) Other Violations	12.2%	(5) Speeding
9.8%	(4) Improper Driving	4.9%	(2) Other than the Driver
4.9%	(2) Unknown	2.4%	(1) Lane Change
2.4%	(1) Failure to Yield		
Type of Hit			
48.8%	(20) MV Overtakes Bike	31.7%	(13) Single Vehicle
7.3%	(3) Head-On Collision	7.3%	(3) Other
4.9%	(2) Right-Angle Collision		
Severity			
85.4%	(35) Injury	7.3%	(3) PDO
7.3%	(3) Fatal		
Location			
73.2%	(30) Freeway	14.6%	(6) Ramp
7.3%	(3) Ramp Exit, Freeway	4.9%	(2) Ramp Entry, Freeway
Bicycle Access Allowed on Freeway			
61.0%	(25) Yes	39.0%	(16) No
Number of Lanes (per direction)			
78.1%	(32) 2-Lane Freeway	17.1%	(7) 3-Lane Freeway
2.4%	(1) 4-Lane Freeway	2.4%	(1) 5-Lane Freeway
Freeway Miles (742 mi total)			
59.8%	(444) Bicycles Not Allowed	40.2%	(298) Bicycles Allowed

Table 4-4. Summary of On-Freeway Bicycle Collisions in Districts 1, 2, and 3 (Cont.)

Road Surface			
95.1%	(39) Dry	4.9%	(2) Wet
Road Condition			
97.6%	(40) No Unusual Condition	2.4%	(1) Construction

Primary Collision Factor

- 29.3% (12 total, 10 B, 2 MV)—Improper turns.
- 17.1% (7 total, 5 B, 2 MV)—Influence of alcohol.
- 14.6% (6 total, 4 B, 2 MV)—Other violations.
- 12.2% (5 total, 5 B)—Improper driving.
- 12.2% (5 total, 3 B, 1 MV, 1 B and MV)—Speeding.
- 4.9% (2 total, 2 B)—Other than the driver.
- 4.9% (2 total, 2 UN)—Unknown cause.
- 2.4% (1 total, 1 B)—Failure to yield.
- 2.4% (1 total, 1 MV)—Lane change.

Primary Collision Pattern

- 24.4% (10 total, 7 OT, 1 HO, 2 other)—Bike hit by motor vehicle when crossing off-ramp at freeway.
- 22.0% (9 total, 9 S)—Single bike, hits object.
- 17.1% (7 total, 6 OT, 1 HO)—Motor vehicle enters shoulder and overtakes bike.
- 12.2% (5 total, 1 RA, 3 OT, 1 HO)—Bicycle in freeway lane is struck by MV.
- 9.8% (4 total, 3 S, 1 other)—Single bike, collision due to drain on roadway shoulder.
- 9.8% (4 total, 1 RA, 3 OT)—Bike hit by motor vehicle when crossing on-ramp at freeway.
- 2.4% (1 total, 1 S)—Single bike, collision due to equipment failure.

- 2.4% (1 total, 1 OT)—Bike collides with pedestrian on freeway.

OBSERVATIONS RELATING TO ON-FREEWAY BICYCLE COLLISIONS

Collisions that involved bicycles actually on the freeway are diverse and fall into three categories: single-bicycle collisions, motor vehicle-bicycle on a continuous straight pipe freeway section, and motor vehicle-bike near a freewayside ramp terminal. All three categories are approximately evenly represented, and collisions on freeways where bicycles are not allowed are a substantial portion of the total. The officer preparing the traffic collision report most often attributes fault to the bicyclist.

Bicycles Crossing Ramps

The freeway is a place where users, especially motor vehicle operators, do not expect to encounter crossing conflicts. Therefore, bicycles crossing ramps, a vehicle-vehicle crossing conflict, will be given some attention here.

Crossing a ramp on the freeway requires a bicyclist's extra care and attention. The cyclist must be patient and even willing to abort a crossing when high volume and high-speed motor vehicles make the crossing dangerous.

Care is especially necessary when the ramp is used by motor vehicles leaving the freeway. Motor vehicles approaching the ramp gore area are traveling at high speeds, and a bicyclist attempting to cross the ramp may not be able to tell which motor vehicles intend to use the ramp to leave the freeway. Ideally, the bicyclist will be able to observe approaching vehicles by looking back while riding and then cross the ramp through an adequate gap in motor vehicle traffic, without stopping the bicycle. In some instances, the bicyclist will have to stop and wait for an adequate gap to cross the stream of ramp traffic.

An analysis of the stopped bicycle crossing a freeway ramp, thought to be the critical case, is offered here. A distance of 40 feet is assumed to be required for a bicycle to make a ramp crossing, although conditions will vary from ramp to ramp. The 40 feet, measured in the direction of bicycle travel, conservatively must include the lane width to be crossed at a skew. Other factors that determine the length of the ramp-crossing maneuver include the clear space between the bicyclist and the approaching motor vehicle and the length of the bicycle.

Observations of bicycles starting from a stop at urban intersections in Chico, California, show that it takes an average of 5 seconds to travel 40 feet. Still, 5 seconds to make a 40-foot dash is reasonably conservative. A visual perception and reaction time of 2 seconds is added to the time necessary to cross ramp traffic, meaning that a 7-second gap in the ramp traffic stream is necessary to make a crossing from a stop.

Safe Crossing Sight Distance

Once stopped, the bicyclist must be able to see if a 7-second or greater gap exists in approaching traffic. Thus a distance back along the freeway in the case of the off-ramp, or down the ramp in the case of the on-ramp, must be visible. That distance must be greater than or equal to the speed of the oncoming motor vehicles times 7 seconds. Safe freeway ramp crossing sight distances are shown in Table 4-5. The distance should be based upon the 85th percentile speed of approaching vehicles. Speeds in excess of the common 70-mph rural freeway speed limit may be applicable.

Table 4-5. Safe Ramp Crossing Sight Distance

Motor Vehicle Approaching Speed (mph)	Safe Crossing Sight Distance (feet)
80	820
70	720
60	620
50	510
40	410
30	310

Ramp Volumes

Even with adequate sight distance, some ramps may not have sufficient adequate gaps of 7 seconds or greater for bicycles to proceed. Bicycles must not be left on the shoulder waiting for an adequate gap for an extended period. The probability of an adequate gap of greater than 7 seconds is a function of the ramp traffic volume and the proportion of platooned vehicles in the traffic stream.[92] A ramp volume of 575 vehicles per hour (vph) corresponds to a 25 percent probability of any one gap exceeding 7 seconds. Ramp volumes of

---

[92] May, Adolf D., *Traffic Flow Fundamentals*, 1990, 35

320 vph offer a 50 percent probability of any one gap in the traffic stream exceeding 7 seconds.

Average daily ramp volumes were taken from the Caltrans publications “Ramp Volumes on the California State Highways" for the specific ramps where on-freeway bicycle-motor vehicle collisions occurred.[93] The most recent ramp volume prior to each collision was tabulated. Ramps where on-freeway collisions occurred had average daily traffic between 110 and 9,200. The median "ramp with bicycle collision" volume was 3,900 vehicles per day. The median corresponds to an approximate peak hour volume of 470 vph. Collisions at high-volume ramps appeared to be no more frequent than collisions at low-volume ramps. Low bicycle exposure and the analysis of only 14 freewayside bicycle-motor vehicle ramp area collisions limit the value of this observation.

INTERNET BICYCLIST SURVEY

Caltrans conducted a survey of bicyclists over the Internet in February 2000. The survey included questions relating to the effect of rumble strips on bicycles.[94] Several questions tailored specifically to this study were added to the survey. Out of 1,602 replies received, 1,239 were complete and, therefore, used in this study. In order to prepare the resulting database for analysis, the following steps were taken. All values reported as NA (not applicable) were changed to zero. All outliers were removed, since most of them were obviously erroneous. The majority of problems were present in the reported ridership. Values larger than 90 trips per months were discarded, as well as miles per average trip larger than 100. Repeated information, most likely caused by users pressing “Submit” more than once, was also removed.

Of the 1,239 surveys, 24 reported riding on highways only, 605 stated that they only rode on nonhighway paths, and 610 reported riding on both. A total of 68 bicycle collisions on highways were reported by the survey over a three-year period (1997-1999), whereas 370 collisions were reported on nonhighways. Using the number of collisions reported and the total million bicycle miles traveled by the bicyclists over the three-year period, two bicycle collision rates were derived. Highways, with a total of 634 respondents and 68 collisions for

---

[93] California Department of Transportation, “Ramp Volumes on the California State Freeway System,” July 1996.

[94] Khorashadi, Ahmad. <Ahmad_Khorashadi@dot.ca.gov> "RE: Bicycle Accidents," 8 July 2000, personal e-mail (9 July 2000).

three years, had a bicycle collision rate of 24 collisions per million bicycle miles (Col/mbm). Nonhighways, with 1,215 total respondents and 370 total reported collisions, had a collision rate of 69 Col/mbm. Respondents individually classified their position as to the highway or nonhighway location. These collision rates are reasonably close to those reported in the Kaplan[95] and Moritz[96] studies, which reported 113 and 66 respectively for major roadways without bicycle facilities.

Also included in the survey were questions as to how many of the total collisions reported on the survey were injury collisions, involved motor vehicles, and were reported to a law enforcement agency. The results of these questions can be seen in Table 4-6.

Table 4-6. Results from Internet Survey

Collisions	***Cyclist on Highway***	***Cyclist on Nonhighway***
% Injury	90%	54%
% Bicycle With Motor Vehicle	35%	16%
% Reported to Law Enforcement	29%	7%

PEDESTRIAN-RELATED COLLISIONS IN DISTRICT 2

In District 2, there were 41 pedestrian freeway-involved collisions in a nine-year period, 1990-1998. Thirty-six of the collisions occurred on the freeway, resulting in 10 fatalities. While fewer than 10 of these collisions actually occurred in the average year, it is still vital to analyze and detect the patterns of these collisions.

The TASAS data and Traffic Collision Reports for the relevant pedestrian-related collisions show that the majority of the collisions in District 2 involved dismounted pedestrians, with both the pedestrian and motor vehicle equally likely to be at fault. While most of these collisions are labeled “other violations,” a few primary collision factors are repeated. Motor vehicles

---

[95] Kaplan, *Characteristics of Adult Bicycle User*, 45.

[96] Moritz, *Adult Bicycle in U.S.*, 6, Table 4.

speeding and intoxication are prime causes for most of these collisions. These collisions occurred most often when the pedestrian was in the roadway and/or assisting a disabled vehicle.

Pedestrians are not legally allowed to use freeways for travel purposes. They do legally occupy space on the freeway when required to leave a motor vehicle. The following describes the 41 pedestrian-involved collisions in more detail.

Party Type

Twenty-five of the 41 collisions involved dismounted pedestrians—meaning they entered the freeway in a vehicle, then exited the vehicle while still on the freeway, probably because the vehicle was disabled or the pedestrian was assisting drivers of other vehicles. Sixteen collisions involved pedestrians who did not enter the freeway with a vehicle, but were otherwise on the freeway.

Fault

In District 2, fault was shared equally between pedestrians and motor vehicles in the 41 collisions: In 20 collisions the pedestrian was at fault, and the motor vehicle was at fault in 20. In one collision, the fault was “unknown.”

Primary Collision Factor

The most frequent PCFs were the influence of alcohol (six collisions), speeding (10 collisions), and other violations (16 collisions). Fourteen of the 16 collisions in which “other violations” was a cause occurred on the freeway. They generally resulted from the pedestrian being in the freeway lane or on the side of the road assisting a disabled vehicle. The remaining PCFs, listed below, had fewer occurrences:

- Four collisions were due to a party failing to yield—three were caused by the motor vehicle and one by the pedestrian.
- One collision was the result of improper driving by the motor vehicle’s operator.
- Four collisions involved a cause other than the driver—three of the four were the fault of the pedestrian and one was unknown.

Location

Seventy-eight percent of the collisions (32 of the 41) occurred on the freeway mainline. Four collisions occurred on the ramps, which are also considered part of the freeway. Ramp-related local streets were the locale for four of the collisions, while one collision occurred at the ramp entry to the freeway adjacent to the surface street.

Position in Road

Twenty-six of the 41 collisions involved pedestrians struck while on the side of the road; thirteen involved pedestrians in the actual roadway. Two collisions occurred when the pedestrian was at a cross street.

Severity

Ten of the 41 pedestrian collisions (24.4 percent) occurring on District 2 freeways resulted in fatalities. Thirty of the remaining 31 collisions were injury collisions, with one PDO.

Pedestrian on Freeway

Five collisions occurred with a pedestrian on a local street near a freeway ramp terminal. The remaining 36 (87.8 percent) occurred on the freeway. Of these, 32 collisions occurred on the freeway and four occurred on the ramp of the freeway.

Collision Pattern

The majority of the collisions involved a pedestrian being struck by a motor vehicle while in the freeway lane. Pedestrians struck while assisting a disabled vehicle accounted for roughly 30 percent of the collisions. Five collisions were caused by a pedestrian throwing an object at a motor vehicle; these were reported in TASAS as pedestrian collisions even though the pedestrian was not struck. Below is a list of the collision patterns for freeway pedestrian-related collisions in District 2. The total number of collisions and their percentages are listed for each collision pattern.

- 39.0% (16)—Pedestrian in freeway lane, hit by motor vehicle.
- 29.3% (12)—Pedestrian hit while assisting disabled vehicle.
- 12.2% (5)—Pedestrian hits motor vehicle with thrown object.
- 7.3% (3)—Pedestrian enters surface street, hit by motor vehicle.

- 4.9% (2)—Pedestrian away from ramp terminal junctions on mainline ramp, hit by motor vehicle.
- 4.9% (2)—Pedestrian hit by motor vehicle entering the shoulder
- 2.4% (1)—Pedestrian in crosswalk, hit by motor vehicle.

Road Surface

In 68.3 percent of the collisions, the road surface was dry. The road surface was wet during six collisions, and snowy and icy conditions existed in six collisions. In one collision, the road surface condition was not stated in either TASAS or the TCR.

Road Condition

For 38 collisions there were “no unusual conditions”; one collision involved other roadway factors. Two collisions occurred in a construction or repair zone.

Number of Lanes

Thirty-five of the collisions happened on a two-lane freeway; the remaining eight occurred on freeways with three lanes in a single direction.

Summary of Pedestrian-Related Collisions in District 2

Table 4-7 summarizes, by percent and number, the 41 pedestrian-related collisions for District 2 in the nine years of study, as discussed in the previous section.

Table 4-7. Summary of Pedestrian Collisions on or Near Freeways in District 2

	Type		
61.0%	(25) Dismounted Pedestrian	39.0%	(16) Pedestrian
	Fault		
48.8%	(20) Motor Vehicle	48.8%	(20) Pedestrian
2.4%	(1) Unknown		

Table 4-7. Summary of Pedestrian Collisions on or Near Freeways in District 2

Primary Collision Factor			
39.0%	(16) Other Violations	24.4%	(10) Speeding
14.6%	(6) Influence of Alcohol	9.8%	(4) Failure to Yield
9.8%	(4) Other than the Driver	2.4%	(1) Improper Driving
Severity			
73.2%	(30) Injury	24.4%	(10) Fatal
2.4%	(1) PDO		
Road Surface			
68.3%	(28) Dry	14.6%	(6) Snow, Icy
14.6%	(6) Wet	2.4%	(1) Not Stated
Location			
78.0%	(32) Freeway	9.8%	(4) Ramp-Related, Local Street
9.8%	(4) Ramp	2.4%	(1) Ramp Entry, Surface Street
Number of Lanes (per direction)			
80.5%	(33) Two-Lane Freeway	19.5%	(8) Three-Lane Freeway
Position in Road			
63.4%	(26) Side of Road	31.7%	(13) Roadway
4.9%	(2) Cross Street		
Pedestrian on Freeway			
87.8%	(36) Yes	12.2%	(5) No
Road Condition			
92.7%	(38) No Unusual Condition	4.8%	(2) Construction
2.4%	(1) Other		

PEDESTRIAN-RELATED COLLISIONS IN DISTRICT 3

District 3 has more than twice the length of freeway miles as District 2. It is also much more urbanized than District 2. Thus, it is not surprising that more pedestrian-related collisions occurred each year in District 3 than in District 2. During a nine-year period, 1990 to 1998, there were 379 pedestrian collisions reported on District 3 freeways or near surface street freeway ramp terminals.

Of the 379 total collisions, 77 percent occurred on the freeway. These collisions were mostly the result of dismounted pedestrians assisting disabled vehicles on the freeway; more than 60 percent of the collisions were caused by the motor vehicle speeding or failing to see the dismounted pedestrian. Nineteen percent of the pedestrian-related collisions that occurred resulted in fatalities, while 75 percent were injury crashes.

The following paragraphs discuss the elements and percentages of the most commonly occurring collisions.

Party Type

Fifty-three percent of the reported collisions involved a dismounted pedestrian, while 47 percent involved other pedestrians.

Fault

The motor vehicle was at fault in 63 percent of the collisions; the remaining collisions were caused by the pedestrian, with the exception of 3 percent, in which the fault was unknown.

Primary Collision Factor

Thirty-one percent of the collisions were caused by motor vehicles speeding and 26 percent were related to other violations. The causes of the pedestrian-related collisions are distributed as follows.

- 30.6% (116) Speeding;
- 26.1% (99) Other violations;
- 17.9% (68) Failure to yield;
- 7.1% (27) Improper turns;
- 6.6% (25) Influence of alcohol;
- 6.6% (25) Other than the driver;
- 2.6% (10) Improper driving;
- 1.3% (5) Unknown; and
- 0.5% (2) Driver fell asleep.

Location

Nearly 70 percent of the collisions occurred on the freeway mainline, and 6 percent occurred on the freeway ramp terminals. Ten percent of the collisions occurred on a ramp-related local street. Twelve percent of the collisions occurred near a ramp entry or exit—2 percent occurred at ramps adjacent to the freeway.

Position in Road

Forty-eight percent of the collisions transpired while the pedestrian was in the roadway, and 38 percent occurred while the pedestrian was on the side of the road. Fourteen percent of the collisions took place at a cross street away from the freeway.

Severity

The majority of the collisions involved injuries, but 19 percent resulted in fatalities. Two percent were PDO.

Pedestrian on Freeway

Seventy-seven percent of the pedestrian-involved collisions transpired on the freeway; 23 percent occurred on nearby roadways other than the freeway.

Collision Pattern

Forty-five percent of the collisions occurred while a pedestrian was assisting a disabled vehicle; nearly all of these pedestrians were dismounted. Twenty-seven percent of the collisions were the result of a pedestrian being hit by a motor vehicle while walking in the freeway lane. Pedestrians hit by a motor vehicle while in a crosswalk accounted for 13 percent of the total collisions. The remaining collisions are infrequent, and are distributed as follows. In parentheses, the total number of collisions are listed, as well as who was at fault, with P = pedestrian, MV = motor vehicle, and UN = unknown fault or not stated.

- 5.5% (21 total, 18 MV, 3 P) took place when a motor vehicle entered the shoulder and struck the pedestrian.
- 4.8% (18 total, 11 P, 5 MV, 2 UN) involved pedestrians struck by a motor vehicle when entering a surface street.
- 2.6% (10 total, 5 MV, 5 P) occurred when a pedestrian was struck by a motor vehicle at a right angle away from the ramp junction.

- 1.3% (5 total, 4 MV, 1 UN) were the result of a pedestrian being struck by a motor vehicle while in a ramp surface street crosswalk.
- 0.8% (3 total, 3 P) were the result of a pedestrian throwing an object and striking a motor vehicle.

Road Surface

In 64 percent of the collisions, the road surface was dry. Twenty-two percent of the collisions occurred on snowy and icy surfaces, and 12 percent occurred when the road surface was wet. Many of these were on Interstate 80 in the eastern portion of the district. In 1 percent of the collisions, the condition of the road surface was not stated.

Road Condition

In 89 percent of the collisions, there were no unusual roadway conditions. Two percent of the collisions occurred on a roadway with reduced road width. Three percent of the collisions occurred in a construction or repair zone, and 1 percent were due to an obstruction in the roadway. Less than 4 percent of the collisions occurred on roadways with holes, ruts, loose material, or other conditions.

Number of Lanes

Nearly 50 percent of the pedestrian-related collisions transpired on or near a freeway with two lanes in each direction, while 42 percent occurred on or a near freeways having three or four lanes in each direction. Eight percent of the collisions occurred on or near a five-lane freeway, while 4 percent occurred on or near a freeway with six lanes per direction.

Summary of Pedestrian-Related Collisions in District 3

Table 4-8 summarizes the 379 freeway pedestrian collisions in District 3 from 1990 to 1998. In 291 collisions, the pedestrian was on the freeway mainline or freewayside ramp terminals when the collision occurred. In three cases, the pedestrian was not on the freeway when the collision occurred but caused the collision by throwing an object at the motor vehicle.

Table 4-8. Summary of Pedestrian Collisions on or Near Freeways in District 3

Type			
52.8%	(200) Dismounted Pedestrian	47.2%	(179) Pedestrian
Fault			
63.1%	(239) Motor Vehicle	34.0%	(129) Pedestrian
2.9%	(11) Unknown		
Primary Collision Factor			
30.6%	(116) Speeding	26.1%	(99) Other Violations
17.9%	(68) Failure to Yield	7.1%	(27) Improper Turn
6.6%	(25) Influence of Alcohol	6.6%	(25) Other than the Driver
2.7%	(10) Improper Driving	1.3%	(5) Unknown
0.5%	(2) Driver Fell Asleep	0.3%	(1) Following Too Close
0.3%	(1) Not Stated		
Position in Road			
48.0%	(182) Roadway	37.7%	(143) Side of Road
14.3%	(54) Cross Street		
Pedestrian on Freeway			
76.8%	(291) Yes	23.2%	(88) No
Severity			
75.5%	(286) Injury	19.0%	(72) Fatal
5.5%	(21) PDO		
Location			
68.8%	(261) Freeway	10.5%	(40) Ramp-Related Local Street
6.3%	(24) Ramp	6.1%	(23) Ramp Exit, Surface Street
5.8%	(22) Ramp Entry, Surface Street	1.1%	(4) Ramp Entry, Freeway
1.1%	(4) Ramp Exit, Freeway	0.3%	(1) Cross Street Intersection
Road Surface			
64.4%	(244) Dry	21.9%	(83) Snow, Icy
12.4%	(47) Wet	1.3%	(5) Not Stated
Road Condition			
88.7%	(336) No Unusual Condition	4.0%	(15) Other
3.2%	(12) Construction Zone	2.3%	(9) Reduced Road Width
1.0%	(4) Obstruction in Road	0.5%	(2) Loose Material
0.3%	(1) Holes, Ruts		

Table 4-8. Summary of Pedestrian Collisions on or Near Freeways in District 3 (Cont.)

Number of Lanes (per direction)			
46.9%	(178) 2-Lane Freeway	20.6%	(78) 3-Lane Freeway
20.6%	(78) 4-Lane Freeway	7.9%	(30) 5-Lane Freeway
4.0%	(15) 6-Lane Freeway		

SUMMARY OF FREEWAY PEDESTRIAN COLLISIONS IN DISTRICTS 2 AND 3

The freeway includes freeway ramps and freewayside ramp terminals. The freeway mainline generally consists of two or more lanes in each direction, separated by a median. The ramp entry and exit directly adjacent to the freeway is considered part of the freeway, along with the mainline section between ramps. The ramp entry and exit directly adjacent to the surface street is not considered part of the freeway.

In the nine years of collision data studied, 327 pedestrian collisions occurred on the freeways in Districts 2 and 3—36 in District 2 and 291 in District 3. Table 4-9 summarizes these data.

Table 4-9. Summary of on-Freeway Pedestrian Collisions in Districts 2 and 3

Type of Party			
64.5%	(211) Dismounted Pedestrian	35.5%	(116) Pedestrian
Fault			
61.5%	(201) Motor Vehicle	36.1%	(118) Pedestrian
2.4%	(8) Unknown		
Primary Collision Factor			
35.8%	(117) Speeding	28.8%	(94) Other Violations
9.5%	(31) Failure to Yield	8.9%	(29) Influence of Alcohol
6.7%	(22) Other than the Driver	6.1%	(20) Improper Turn
2.4%	(8) Improper Driving	0.9%	(3) Unknown Cause
0.6%	(2) Driver Fell Asleep	0.3%	(1) Following Too Closely
Position in Road			
52.0%	(170) Roadway	47.7%	(156) Side of Roadway
0.3%	(1) Cross Street		

Table 4-9. Summary of on-Freeway Pedestrian Collisions in Districts 2 and 3 (Cont.)

Severity

70.6%	(231) Injury	24.5%	(80) Fatal
4.9%	(16) PDO		

Location

88.7%	(290) Freeway Mainline	8.6%	(28) Ramp
1.2%	(4) Ramp Entry at Freeway	1.2%	(4) Ramp Exit at Freeway
0.3%	(1) Intersection Cross Street		

Road Surface

60.6%	(198) Dry	26.3%	(86) Snow, Icy
11.9%	(39) Wet	1.2%	(4) Not Known

Road Condition

87.1%	(285) No Unusual Condition	4.6%	(15) Other
3.7%	(12) Reduced Road Width	2.8%	(9) Construction
1.2%	(4) Not Stated	0.3%	(1) Holes, Ruts
0.3%	(1) Loose Material		

Number of Lanes

53.8%	(176) 2-Lane Freeway	19.0%	(62) 3-Lane Freeway
16.5%	(54) 4-Lane Freeway	7.6%	(25) 5-Lane Freeway
3.1%	(10) 6-Lane Freeway		

Collision Patterns

53.2%	(174) Pedestrian hit while assisting a disabled vehicle
36.4	(119) Pedestrian in freeway lane hit by motor vehicle
5.2%	(17) Pedestrian hit by motor vehicle entering shoulder
3.1%	(10) Pedestrian on ramp, away from junction, hit by motor vehicle at right angle
1.5%	(5) Pedestrian hits motor vehicle with thrown object
0.3%	(1) Pedestrian falls while trying to avoid a collision
0.3%	(1) Pedestrian hit by motor vehicle while in ramp crosswalk

A STUDY OF BICYCLES ON SELECTED BRIDGES AND TUNNELS

GOAL

This study will look at several toll bridges, similar structures, and tunnels that currently allow bicycles either to ride in the outside shoulder or to share the right lane with motor vehicles. One bridge that does not currently allow bicycle access, the Richmond-San Rafael Bridge, was also studied as a comparison to the bridges with access. Consideration of the Richmond-San Rafael bridge was specifically requested by members of the advisory committee that participated in this study. The goal of this study is to see if any generalizations can be made about safety, design, or operation relating to these facilities.

METHODOLOGY AND APPROACH

The steps taken in this study were to identify the bridges and tunnels, then collect TASAS collision tables, traffic volume, and geometric data for each structure, and finally to analyze this information. Because this study is restricted to tunnels and bridges with toll bridge-type cross sections and ADT, it was important to be selective when choosing the structures to study. The specific properties of a toll bridge-type structure were lengthy, narrow lanes and heavy commuter traffic. Unfortunately, in California and elsewhere, such facilities are rare.

Our steering committee initially provided us with several bridges and tunnels to study. Later, facilities-n-planning@topica.com, a national “listserv” for bicycle professionals, was contacted with a request to identify other sites to study. (A “listserv” is an e-mail community with a specific theme, in this case bicycle planning and safety issues.)

Initial efforts to obtain information on these structures only involved requesting collision records. We hoped this would give us an initial estimate of the number of bicycle collisions on these structures. TASAS reports were requested for the Antioch Bridge, the Richmond-San Rafael Bridge, and the Mad River Bridge The results were somewhat surprising in that of the three bridges, only one had a single reported bicycle collision in nine years. This initial survey reaffirmed our assumption that not only are there few toll-type bridges that allow bicycle access, but there is relatively low use by bicycles on those bridges. This emphasizes the fact that there is little historical bicycle count data, because there are not enough bikes out there to readily facilitate counting.

This lack of collisions posed a new problem. With no collisions and no source for quantitatively measuring bicycle travel on each facility, there seems to be no way to measure a bicycle collision rate, which is the common method of measuring the safety of a highway section. It was decided that more information was required in order to draw any conclusions. The additional data obtained are described below.

The cross-sectional geometry for all bridges and tunnels under Caltrans jurisdiction was identified with the 1997 California State Highway Log.[97] These values were obtained for the other structures from a combination of Internet searches and contacting the respective governing bodies.

Average Daily Traffic (ADT) for autos and trucks were obtained from the 1997 *Traffic Volumes on California State Highways*[98] and 1997 *Annual Average Daily Truck Traffic on the California State Highway System*.[99] Values for structures outside of the jurisdiction of Caltrans were obtained from Internet searches and each structure's local jurisdiction.

The remainder of the collision information was either requested through TASAS or was given to us by the local bicycle coordinator or other professionals.

STRUCTURES STUDIED

The structures studied are described briefly below. Specific information is highlighted and unique features are identified. Information is provided uniformly for Caltrans bridges in Table 5-1, other bridges in Table 5-2, and tunnels in Table 5-3.

---

[97] California Department of Transportation, *1997 California State Highway Log*.

[98] California Department of Transportation, *1997 Traffic Volumes on California State Highways* (June 1998).

[99] California Department of Transportation, *1997 Annual Average Daily Truck Traffic on the California State Highway System* (April 2000).

Table 5-1. Caltrans Bridges

Structure	***Mad River Bridge***	***Santa Maria Bridge***	***Richardson Bridge***	***Antioch Bridge***	***Richmond-San Rafael Bridge***
Length (miles)	0.137	0.316	0.542	1.787	4.04
# Lanes	2	2	4	1	2
Right Lane Width (feet)	12	12	12	12	12
Outside Shoulder Width (feet)	L2 R0*	0	10	5	12
Speed Limit (mph)	65	65	55	55	55
ADT	28500	60000	133000	10000	60000
Bike ADT	55	-	-	-	-
Truck ADT	2964	4500	3802	1100	3588
5+Axel Truck ADT	1112	2345	464	713	1338
Bike Collisions on Structure	1	0	0	0	0
Bike Collisions on Approaches (500 ft)	2	0	1	0	0
Bike Collisions on Approaches (5 miles)	10	0	14	0	-
Structure Acc/mile	7.3	0	0	0	-
Approach (500 ft) Acc/mile	10.6	0	5.3	0	-
5-Mile Approaches Acc/mile	1	0	1.4	0	-

** For instances when the values were not constant on both sides of the roadway, the values are given as Left and Right in direction of increasing milepost. Both indicated shoulder widths are to the right of the driver.*

Table 5-2. Other Bridges

Structure	***Astoria Bridge***	***Hood Canal Bridge***
Length (miles)	4.1	1.49
# Lanes	1	1
Right Lane Width (feet)	14	12
Outside Shoulder Width (feet)	2	4
Speed Limit (mph)	55	40
ADT	6206	13000
Bike ADT	-	-
Truck ADT	537	1430
5+Axel Truck ADT	250	780

Table 5-3. Tunnels

Structure	***Gaviota Tunnel***	***Sepulveda Boulevard Tunnel***	***Collier Tunnel***	***Broadway Tunnel***	***Stockton Tunnel***
Length (miles)	0.08	0.362	0.357	0.17	0.31
# Lanes	2	3	1	L1 R2*	2
Right Lane Width (feet)	12	11	12	11	11
Outside Shoulder Width (feet)	L8 R6*	8	1	0	0
Speed Limit (mph)	55	40	55	25	40
ADT	27000	57000	2900	5310	16370
Bike ADT	-	-	-	-	125
Truck ADT	3186	1596	487	-	-
5+Axel Truck ADT	1870	40	176	-	-
Bike Collisions on Structure	1	1	0	0	3
Bike Collisions on Approaches (500 ft)	0	1	0	2	0
Approach (500 ft) Acc/mile	0	5.3	0	10.6	0
Structure Col/mile	12.5	2.76	0	0	9.68

** For instances when the values were not constant on both sides of the roadway, the values are given as Left and Right in direction of increasing milepost. Both indicated shoulder widths are to the right of the driver.*

Mad River Bridge—Located north of Arcata, California, in Humbolt County, U.S. 101 crosses the Mad River on this bridge. There are two independent bridges approximately one-eighth of a mile long; the northbound bridge is a cantilever truss bridge, the southbound is a concrete bridge. Both spans are two lanes with no median shoulder. The southbound bridge has a 2-foot right side shoulder, while the northbound bridge has no right shoulder. The northbound bridge employs a warning system for motorists that the bicyclist activates. The warning device consists of a button located on the shoulder of the approach to the bridge, which the bicyclist pushes to activate a flashing sign above the bridge that states "Bicyclist on Bridge When Flashing." The bicyclist deactivates the sign on the other side of the bridge. The ADT for this bridge is reported at 28,500 vehicles per day.

Santa Maria River Bridge—Approximately four-tenths of a mile long, U.S. 101 in San Luis Obispo County crosses the Santa Maria River on this bridge. There are two lanes in each direction of travel, with no shoulders or median. The bridge has a substantial traffic volume of 60,000 vehicles per day.

Richardson Bay Bridge—Located just north of the Golden Gate, U.S. 101 crosses the Richardson Bay on this bridge. The half-mile-long structure is a concrete bridge with ramps close to both ends. There are five lanes in the northbound direction and four lanes southbound. A barrier in the median with no shoulders separates directional travel. Both north- and southbound spans have 10-foot right-side shoulders. There is an extremely high ADT here, with a reported volume of 133,000 vehicles per day.

Antioch Bridge—The Antioch Bridge connects Contra Costa County to Sacramento County over the San Joaquin River. It is the least traveled of the San Francisco Bay toll bridges. It currently has one lane in each direction of travel, with a concrete barrier separating the lanes. The bridge has a steep grade and a high percentage of trucks and recreational vehicles. Five-foot outside shoulders in each direction are provided, where bicycles are currently allowed to travel.

Richmond-San Rafael Bridge—Connecting Contra Costa to Marin County, the Richmond-San Rafael Bridge spans approximately 4.5 miles across the San Francisco Bay. This bridge carries a reported 60,000 vehicles per day between Richmond and San Rafael on a total of four lanes, two in each direction. The bridge is split level, with moderate grades. Each lane is 12 feet in width, with a 12-foot shoulder on the right side. There are two 1-foot-high, 2-foot-wide utility trays, one to the left of the left lane and the other on the outside of the right shoulder. Railings on the bridge measure 48 inches from the deck, and are 1 foot, 3 inches wide on the main span of the bridge, for a total distance of 3 feet, 3 inches from the edge of the railing to the traveled roadway. The bridge was the subject of an extensive study completed in 1998.[100] Organized bicycle groups are actively advocating that the bridge be opened to bicycle traffic. Thus, the Richmond-San Raphael Bridge is included in this study, even though bicycles are currently prohibited from riding on this toll bridge.

Astoria Bridge—Located on the Oregon-Washington border, the Astoria Bridge spans 4.1 miles across the mouth of the Columbia River as it flows into the Pacific Ocean. This cantilevered truss bridge has one 14-foot lane in each direction of travel that is shared by both motor vehicles and bicycles. The bridge has a section in the middle with grades near 6 percent, but is near level over most of its length. As reported in the Appendix of the *Richmond-San Rafael Public Access Feasibility Study*, the Astoria Bridge has a motor vehicle ADT of 5,900, and a bicycle ADT of 40 to 50 bikes per day in summer, and 30 in the winter.[101]

Hood Canal Bridge—The Hood Canal Bridge is an approximately 1.5-mile-long concrete pontoon floating bridge located across the Puget Sound from Seattle, Washington. It has a center draw opening of 600 feet that provides passage for boats and submarines to access the Olympic Peninsula of Northwest Washington. The bridge comprises two 12-foot lanes with 3- to 4-foot shoulders on each side, but because the bridge has a retractable span, the geometry toward midspan is somewhat unique. Toward the center span, the lanes are separated; this allows the roadway to slide up in between for boat access. Average daily traffic for the Hood Canal Bridge is approximately 14,000 vehicles per day. The bridge has sunk from a heavy storm with winds near 120 mph; therefore, during inclement weather, the middle span is retracted, closing the bridge to vehicle traffic.

Gaviota Tunnel—The Gaviota Tunnel is located in Santa Barbara County on US 101. The tunnel is nearly 0.08 mile in length, with two lanes in each direction. There are shoulders on the right lanes, one 8 feet wide, and the other 6 feet. Average Daily Traffic through the tunnel is 27,000 vehicles per day. There is a moderate grade with northbound traffic heading in the uphill direction.

---

[100] California Department of Transportation, *Richmond-San Rafael*, 1-1.

[101] ibid., Appendix G-1.

Sepulveda Boulevard Tunnel—The Sepulveda Boulevard Tunnel is the section of Highway 1 that runs approximately 0.36 mile underneath Los Angeles International Airport. The tunnel has three lanes of travel in each direction with an 8-foot shoulder on both sides. It has an ADT of approximately 57,000 vehicles per day.

Collier Tunnel—The Collier Tunnel is located in Del Norte County in Northern California, close to the Oregon border on Highway 199. The relatively low daily traffic, reported at 2,900 vehicles per day, uses the one available lane in each direction. There is a 1-foot right shoulder on each side. The tunnel has a slight grade through its 0.36-mile length, with southbound traffic going uphill. The Collier Tunnel has a warning device similar to that on the Mad River Bridge. The cyclist activates the warning system with a button on the approach to the tunnel. This button turns on a flashing sign that states "Bicyclist in Tunnel When Flashing."

Stockton Tunnel—Serving the downtown San Francisco area, the Stockton Tunnel is nearly 0.2 of a mile long. It has no shoulders, but has a 4-foot bike lane in the northbound (uphill) direction. There are two motor vehicle lanes in the southbound direction and one northbound. The tunnel has a 25 mph speed limit, and a reported ADT of 5,310 vehicles per day.

Broadway Tunnel—Just northwest of the Stockton Tunnel is the Broadway Tunnel. This tunnel is nearly 0.3 of a mile and has a posted speed limit of 40 mph. Its reported ADT is 16,370 vehicles per day. There are two lanes of travel in each direction and no shoulder on either side. The Broadway Tunnel has a reported bicycle ADT of 125 bikes per day.

RESULTS FROM BRIDGE AND TUNNEL STUDY

Structures With Collisions Rates

Mad River Bridge

Since the Mad River Bridge had one reported collision in nine years, bicycle counts were performed on two separate occasions in order to estimate the bicycle ridership on this bridge. The counts were performed in March 2000, one on Tuesday the 21st and the other on Friday the 24th. Both counts were made between 11 a.m. and 2 p.m.

Using the two counts and information given to us from the Caltrans District 1 bicycle coordinator, a bicycle ADT of 55 bikes per day was established. Using this data, the bridge length, and the fact that there was one reported collision on the bridge in nine years, a collision rate of 40 reported bicycle collisions per million bicycle miles was derived.

Broadway Tunnel

The City and County of San Francisco provided us with the necessary data for calculating a bicycle collision rate for the Broadway Tunnel. With a bicycle ADT of 125 bikes per day, and three reported collisions in nine years, the Broadway Tunnel has a bicycle collision rate of 24 reported bicycle collisions per million bicycle miles.

Although both of these reported collision rates seem high (24 BA/mbm for Broadway Tunnel and 40 BA/mbm for Mad River Bridge) compared to motor vehicle collision rates, they may not be so high when compared to bicycle collision rates for different facilities. For example, the 1974 Kaplan study cited a collision rate of 113 collisions per million bicycle miles on major roadways without bicycle facilites.[102] Moritz, in a similar study, found a bicycle collision rate on major roadways without bicycle facilities of 66 collisions per million bicycle miles.[103] Both 24 and 40 collisions per million bicycle miles are lower by comparison. The rates reported on the Mad River Bridge and Broadway Tunnel were derived from collisions reported to law enforcement organizations. The rates reported by Kaplan and Moritz are likely to include collisions that were not so reported, because they were based on surveys of bicyclists.

Structures With Reported Collisions

The Sepulveda and Gaviota Tunnels both have had bicycle collisions reported on their main spans in the nine-year period of study. Due to their geographic location and the lack of bicycle counts done locally, we were not able to derive bicycle collision rates for these tunnels.

Structures Without Reported Collisions

The following structures studied had no reported bicycle collisions during the nine-year period 1990 through 1998; therefore, they have no collision rates.

---

[102] Kaplan, *Characteristics of Adult Bicycle User*, 45.

[103] Moritz, *Adult Bicycle in U.S.*, 6, Table 4.

- Richardson Bay Bridge;
- Antioch Bridge;
- Santa Maria Bridge;
- Astoria Bridge;
- Hood Canal Bridge;
- Broadway Tunnel; and
- Collier Tunnel.

This list of structures was checked for any distinguishing characteristics that might set them apart from the structures that had reported collisions. However, this list is varied to the point that there is no apparent correlation. There are no factors common to these bridges that would set them apart from structures with collisions.

Comparison of Structures and Approaches

Two efforts were made to compare the bridges and tunnels with their respective approaches. First, the number of collisions involving bicycles on both the structure and the approaches was compiled for the years 1990 through 1998. The approaches are defined as the 500 feet preceding the structures on either side. A second set of data was requested for the highways on both sides of the studied structures. For this set, collision data for the 5 miles on either side of the bridges and tunnels were requested for only the structures under Caltrans jurisdiction. Caltrans structures were used because information on these structures is the most readily available through TASAS and is in the correct, consistent format needed for this study. Only collisions reported as "hwy" (highway) collisions were used for this analysis. The Richmond-San Rafael Bridge was omitted from this comparison, as it does not allow bicycles.

For the first data set, six collisions total were reported for all the structures, and six on the approaches for the nine-year period. The lack of variance between the number of collisions on the structures and the approaches suggests that bridges and tunnels have collisions no more frequently than the roadways leading up to them. This is especially evident when the total length of the structures is compared to the approaches. There were 9.7 miles of structures studied; this gives a collision ratio of 0.62 reported collisions per mile of structure, compared to the 2.3 miles of approach studied, with a collision ratio of 2.6 reported collisions per mile of approach. The probable higher risk and more frequent conflicts at ramps may account for this difference.

For the data set specific to Caltrans structures, the following results were derived. The total length of the seven bridges and tunnels was 3.6 miles. Three collisions were reported on these spans, giving a collision ratio of 0.84 reported collisions per mile of roadway. As a comparison, seven total structures with 5 miles on either side covers 70 total miles. A total of 74 collisions involving bicycles were reported in TASAS on these spans over the nine-year period. The result is a collision ratio of 1.06 reported collisions per mile for the approaches.

Both sets of data show that the structures have a collision frequency no higher than the approaches leading up to them. With a collision ratio lower than the approaches in both sets of data, the structures actually seem less susceptible to collisions involving bicycles than their approaches are. The underlying assumption in this conclusion is that bicycle volumes on bridges and tunnels are similar to the volumes on the highways leading to them.

The data are very limited, especially by the lack of available bicycle counts. Collisions reported on bridges that involve bicycles are rare. Bridges were selected for study based on recommendations of the project advisory committee. An effort was made to identify bridges where bicycle traffic was present. Comparing the approach roadway to the bridge or tunnel itself yields some insight. Reported collisions per roadway mile on the approaches to bridges were actually lower than on the structure itself, in most instances. The bicycle traffic volume on the bridge and approaches are likely very similar.

Some fear that bicycles are more likely to be involved in collisions when on bridges. They are expected to ride nearer the motor vehicle lane to avoid colliding with the bridge rail. Wind on long bridges may also cause stability problems for the cyclist. Fortunately, there have not been enough reported collisions on bridges to validate these concerns.

Trends in the Data

A surprising trend found was that the general relationship between length and number of collisions was the opposite of what was expected. The number of collisions actually seems to be more frequent as length decreases (see Table 5-4 below), that is, shorter span structures have a greater number of bicycle collisions than longer ones. However, it appears that the longer bridges also have wider shoulders.

Table 5-4. Structures Sorted by Length

Structure	*Length (miles)*	*# Lanes*	** Left outside shoulder width (ft)*	** Right outside shoulder width (ft)*	*# of collisions on structure*
Gaviota Tunnel	0.08	2	8	6	1
Mad River Bridge	0.137	2	2	0	1
Broadway Tunnel	0.17	2/1	0	0	0
Stockton Tunnel	0.31	2	0	0	3
Santa Maria River Bridge	0.316	2	0	0	0
Collier Tunnel	0.357	1	1	1	0
Sepulveda Boulevard Tunnel	0.362	3	8	8	1
Richardson Bay Bridge	0.542	4	10	10	0
Hood Canal Bridge	1.49	1	4	4	0
Antioch Bridge	1.787	1	5	5	0
Astoria Bridge	4.1	1	2	2	0

** Both shoulders are on the right side of the traffic lanes. Here left and right refer to the direction of increasing milepost.*

As seen in Table 5-5, when the spreadsheet was sorted with ascending shoulder widths, it was not evident that shoulder width has any effect on the collision history of these bridges. When the spreadsheet was sorted for ADT, number of lanes, right-lane width, and truck volumes, no clearly visible trend existed between these variables and the number of collisions. The Richmond-San Rafael Bridge was not included in these comparisons because bicycle access is not currently allowed there.

This data set shows that bicycle collisions on bridges and tunnels are rare events. To have only six reported collisions on 15 structures over a nine-year period suggests that either these roadways do not pose an extreme danger to bicyclists or very few bicycles ride on them.

Table 5-5. Structures Sorted by Shoulder Width

Structure	Length (miles)	# Lanes	* Left outside shoulder width (ft)	* Right outside shoulder width (ft)	# of collisions on structure
Broadway Tunnel	0.17	2/1	0	0	0
Stockton Tunnel	0.31	2	0	0	3
Santa Maria River Bridge	0.316	2	0	0	0
Collier Tunnel	0.357	1	1	1	0
Astoria Bridge	4.1	1	2	2	0
Mad River Bridge	0.137	2	2	0	1
Hood Canal Bridge	1.49	1	4	4	0
Antioch Bridge	1.787	1	5	5	0
Gaviota Tunnel	0.08	2	8	6	1
Sepulveda Boulevard Tunnel	0.362	3	8	8	1
Richardson Bay Bridge	0.542	4	10	10	0
**Both shoulders are on the right side of the traffic lanes. Here left and right refer to the direction of increasing milepost.*					

Bicycle Compatibility Index, BCI

To further evaluate the bridges and tunnels studied, the bicycle compatibility index (BCI) was calculated for each. The BCI was developed for urban and suburban streets.[104] The equations were created by showing videotape to bicyclists and asking them to rate the quality of the street and its suitability for bicycle travel. Four equations were created: one equation representative of all cyclists, and separate equations to represent experienced commuter cyclists, experienced recreational cyclists, and casual recreational riders. The equations were not intended to be used for the evaluation of freeways, expressways, toll bridges, and tunnels. Therefore, the results presented here should be viewed and used with caution.

In order to apply the BCI concept to freeways, toll bridges, and tunnels, it is necessary to take some major steps beyond the intended use by the developers of the BCI method. The two most significant steps are as follows: (1) It must be considered that freeways, toll bridges, and tunnels are generally rural highways, while the method was developed for urban and suburban streets. (2) The range of independent variables used here is outside the range used to

---

[104] Harkey, *Bicycle Compatibility Index*, 5.

develop the BCI equations. Two of the most critical examples are cited here. (1) The maximum value for a paved shoulder or bicycle lane used to develop the BCI equations is 7.4 feet. Shoulders on freeways, toll bridges, and tunnels are often as wide as 10 feet and occasionally, as on the Richmond-San Rafael Bridge, are 12 feet wide. (2) The BCI equations also used the 85th percentile speed of the motor vehicle traffic. The maximum value appearing in the database used to develop the equations was 53 mph. Speed limits on freeways, tunnels, and toll bridges can be as high as 70 mph.

For this research, the equations developed based on responses from experienced commuter bicyclists will be used to evaluate the bridges and tunnels studied. The above-cited limitations are understood by the researchers and must be understood clearly by readers of this report. The equation that follows this paragraph was the one utilized for this analysis. It has been converted to English units.

BCI (Experienced Commuter) =3.65 - 1.56BL - 0.159CLW + 0.0015CLV + 0.0004OLV + 0.034SPD + 0.433PKG

BCI = The Bicycle Compatibility Index (low values designate satisfactory roadways for bicycle riding)

BL = Presence of a bike lane or paved shoulder (Yes = 1, No = 0)

CLW = Curb lane width in feet

CLV = Hourly curb lane volume

OLV = Other lane(s) hourly volume in the same direction

SPD = The 85th percentile speed of traffic in miles per hour

PKG = Presence of a parking lane with at least 30% of the spaces occupied (Yes = 1, No = 0)

The BCI is increased when there are large trucks in the curb lane. An increment of 0.50 is added when there are 120 or more trucks in a peak hour. The increment decreases to zero when there are fewer than 10 large trucks in the hour.

The assumptions used to calculate BCI follow. These assumptions generally follow the recommendations of the authors and developers of the model equations. The 85th percentile speed was estimated by adding 6 mph to the posted speed limit. The peak hour volumes were used and, in general, were taken from the 1998 traffic volumes on California State Highways.[105] The assumption was made that 5.5 percent of the average daily traffic would be flowing in the peak direction and the traffic would be distributed equally across all through lanes. Truck volume was established with the 1998 truck volume manuals.[106] Eighty percent of the truck traffic was assigned to the curb lane when more than one through lane in each direction existed. It was assumed that 5.5 percent of the average daily truck traffic was traveling at the peak hour and in the peak direction. There was no parking on the facilities studied. The variable PKG was always set to zero.

The developers of the BCI equations provided a methodology to convert a BCI to level of service. That methodology applied to all bicyclists in urban areas. No level-of-service calculation or reporting is done here. Level-of-service standards were not developed for the experienced commuter bicycle rider on rural high-speed highways.

The computed BCI is reported here for all bridges and tunnels where data were sufficient to do so. The facilities are listed in Table 5-6 from best (lowest BCI) to worst as perceived by the experienced commuter bicyclist. BCI values are presented as a range of values for two tunnels in the City and County of San Francisco. The range was necessary because truck traffic volume was not available for the tunnels.

The BCI is a convenient way to evaluate a route as to its suitability for bicycles. The BCI requires neither a count of bicycle collisions, which are rare events, nor counts of bicycle traffic, which are often nonexistent. Unfortunately, there is no correlation between BCI and collision frequency or rate. Regular bicycle counts are required to establish a correlation. With the correlation, a threshold could be established for various levels of treatment. For example, bridges open to bicycles and with a BCI above a certain level could be candidates for the flashing beacons that are present on the Mad River Bridge and Collier Tunnel.

---

[105] California Department of Transportation, *1998 Traffic Volumes on California State Highways* (June 1999).

[106] California Department of Transportation, *1997 Truck Traffic*.

Table 5-6. BCI Values for Bridges and Tunnels

Structure	***BCI***
Hood Canal Bridge	3.22
Antioch Bridge	3.48
Gaviota Tunnel	3.69
Collier Tunnel	4.17
Astoria Bridge	4.21
Sepulveda Tunnel	4.71
Richmond-San Rafael Bridge	5.89
Mad River Bridge	6.15
Richardson Bay Bridge	7.69
Santa Maria River Bridge	7.79
Broadway Tunnel	3.31-3.81
Stockton Tunnel	4.32-4.82

CONCLUSION OF COLLISION DATA ON BRIDGE AND TUNNELS

Although these data include few collisions, they show one important fact: Bicycle collisions on tunnels and bridges are rare events. Based upon the small amount of data compiled here, bridges and tunnels currently open to bicycles do not have higher collision frequencies compared to the approaching highways.

MULTIVARIATE REGRESSION ANALYSIS OF FREEWAYS OPEN TO BICYCLES AND ALL FREEWAY COLLISIONS

GOAL

The goal of this paper was to analyze various freeway characteristics in order to see which ones affect the overall collision rate on freeways in Caltrans Districts 5 and 6. The primary focus of this study was the independent variable of bike status, or whether bicycles are allowed on a given section of freeway. It was hoped that by performing a multivariate regression analysis on the data, it would be possible to determine how significant the bicycle access variable is to the collision history.

METHODOLOGY AND APPROACH

In addition to looking at bicycle access as an independent variable to collision history, the database we developed was used to analyze what roadway characteristics are common to freeways open to bicycles in Districts 5 and 6. This was accomplished by comparing the Pearson correlation coefficients for bicycle access and all the independent and dependent variables. The desired outcome of this procedure was to gain insight into the bicycle access policy for Caltrans Districts 5 and 6. The database was also used to perform an analysis using an equation that quantitatively measures bicyclists' comfort level on a particular section of roadway know as a BCI.[107]

The preliminary efforts in preparing the database for statistical analysis involved identifying the sections of freeway to be studied. California Highway Logs from the year 1997 for Districts 5 and 6 were used for this task.[108] The column "AC: Access Control" was scanned for sections designated "F" for full control, or freeway segment. Using the independent variables identified and listed below, these sections from the highway logs then were grouped into geometrically similar larger segments.

---

[107] Harkey, *Bicycle Compatibility Index*, 5.

[108] California Department of Transportation, *1997 California State Highway Log for Districts 5 and 6*.

COLLISION DATABASE AND VARIABLES

A Traffic Accident Surveillance and Analysis System (TASAS) Table B report was requested from Caltrans for the segments identified through the highway logs. This provided the collision data for analysis.

The remaining data for analysis were taken from "Truck Traffic on California Highways" for each respective year, and a spreadsheet provided to us by Caltrans identifying all freeway sections in California open to bicycles.[109] Unfortunately, no source listed the amount of bicycle ridership on these freeways; as a substitute, bicycle access allowed was used as the independent bicycle variable. This does not account, however, for riders on restricted access portions, nor does it give a quantitative value for the number of bicycles on these portions.

The route number, county, and beginning and end postmiles were obtained from the 1997 *California State Highway Log, Caltrans Districts 5 & 6* for each of the above mentioned geometrically similar segments.[110] For each of these segments, the following independent variables were determined from the highway log. The uppercase letters in the descriptions refer to designations in the Highway Log.

- X1–**Area—**Area codes were identified from the column RU. For the purposes of statistical compilation, the codes used in the highway log were altered as follows:

Name	***Population***	***Highway Log Code***	***Database Code***
Rural	< 5,000	A,B,C,D,E,F,G	0
Urban	5,000 to 50,000	J,K,L,M,N,O,P	1
Urbanized	>50,000	S,T,U,V,W,X,Y,Z	2

- X2–**No. Lanes—**The number of lanes in each direction was identified from column NO LN. When the number of lanes in each direction were not the same, the lower number was chosen.

---

[109] California Department of Transportation, *1990-1997 Annual Average Daily Truck Traffic on the California State Highway System*.

[110] California Department of Transportation, *Districts 5 and 6*.

- X3–**Shoulder Width—**Outside shoulder widths were extracted from column TR. This value represents the treated shoulder width in feet. When the shoulder widths were different in each direction of travel, the lower value was used.
- X4–**Section Length—**This value is the difference between the beginning and end postmiles from the highway log.

Bike status was extracted from a spreadsheet provided to us by the Caltrans statewide bicycle coordinator.

- X5–**Bike Status—**Freeway segments open to bicycles were given a value of “1”; “0” indicates sections closed to bicycles.

The following additional independent variables were all derived from the TASAS Table B report that was received from Caltrans.

- X6–**Year—**The year to which the given information pertains. The years 1990 through 1998 were used for this analysis, as they were the only years available from TASAS at the start of the study. Values in the database and in equations are given as the last two digits of the year. For example, 1998 would be entered as “98.”
- X7–**Total MVM—**Total million vehicle miles traveled on each segment for a given year. Values given in millions of vehicle miles traveled.
- X8–**ADT—**Average daily traffic on each segment for a given year as reported by TASAS. Values given in vehicles per day.

Annual Average Daily Truck Traffic on the California State Highway System for each of the above-identified years was used to produce the following values.[111] Volumes expressed in this log are for specific mileposts; therefore, volumes for sections were taken as the median of all reported volumes on the section.

- X9–**5+ Axle ADT—**The daily volume of large trucks, those with five axles or larger. This value is expressed in trucks per day.
- X10–**Total Truck ADT—**The daily total truck volume. This value is expressed in trucks per day.

---

[111] California Department of Transportation, *1990-1997 Truck Traffic*.

- X11–**5+ Axle ADT/X8—**The daily large-truck volume divided by total vehicle ADT. This value is expressed as a ratio of large trucks to total vehicles.
- X12–**Total Truck ADT/X8—**The daily total truck volume divided by the total vehicle ADT. This value is expressed as a ratio of large trucks to total vehicles.

The TASAS Table B report was used to extract dependent variables.

- Y1–**Number of Collisions**—An integer value of the total number of collisions occurring within the segment of freeway on the given year.
- Y2–**Actual F & I Rate**—A value derived by the number of fatal and injury collisions occurring within the segment of freeway divided by the Total MVM for a given year.
- Y3–**Actual Collision Rate**—A value derived by the total number of collisions occurring within the given segment of freeway, divided by the Total MVM for a given year.

The resulting database was checked for errors and prepared for statistical analysis. A total of 2,752 entries were made for each dependent and independent variable. There were a total of 305 highway segments, most of which had nine years of valid data for analysis. The mean, standard deviation, maximum and minimum values from the database are shown in Table 6-1.

Similar statistics are provided in Table 6-2 for the freeway segments on which bicycles are allowed. Table 6-3 gives the statistics for freeway segments in Districts 5 and 6 where bicycle access is not allowed.

Table 6-1: Statistical Values of Variables—All Freeway Segments

	N	*Mean*	*SD*	*Max*	*Min*
Year	2752	94	2.582	98	90
Area	2752	1	0.900	2	0
# Lanes	2752	2	0.405	4	1
Shoulder Width	2752	7.2	3.039	10	0
Bike Status	2752	0.26	0.438	1	0
Section Length	2752	2.414	6.271	71.726	0.004
Total mvm	2752	29.943	61.898	632.500	0.130
ADT	2752	41551	22947	133800	2800
5+ Axle Trucks	2752	2713	2522	13175	17
Total Trucks	2752	4598	3095	20520	124
Number of ACC	2752	18.259	42.562	409	0
F + I ACC Rate	2752	0.257	0.496	6.720	0
Collision Rate	2752	0.671	0.901	13.390	0
5 + Trucks / ADT	2752	0.078	0.073	0.621	0.001
Total Trucks / ADT	2752	0.129	0.089	0.782	0.009

Table 6-2: Statistical Value of Variables—Bicycle-Allowed Segments

	N	*Mean*	*SD*	*Max*	*Min*
Year	711	94	2.584	98	90
Area	711	1	0.825	2	0
# Lanes	711	2	0.432	4	2
Shoulder Width	711	6.9	3.270	10	0
Bike Status	711	1	0.000	1	1
Section Length	711	3.324	11.130	71.726	0.005
Total mvm	711	32.031	91.119	632.5	0.14
ADT	711	35599	17996	80000	7200
5+ Axle Trucks	711	2297	2153	13033	42
5+ Axle Trucks	711	3965	2799	16418	124
Number Collisions	711	16.820	43.506	313	0
Actual F & I	711	0.241	0.477	6.26	0
Actual Collision Rate	711	0.608	0.800	10.44	0
5+ Trucks / ADT	711	0.073	0.076	0.621	0.003
Total Trucks / ADT	711	0.123	0.096	0.782	0.009

Table 6-3: Statistical Values of Variables—Bicycle-Prohibited Segments

	N	*Mean*	*SD*	*Max*	*Min*
Year	2041	94	2.582	98	90
Area	2041	1	0.901	2	0
# Lanes	2041	2	0.396	4	1
Shoulder Width	2041	7.3	2.951	10	0
Bike Status	2041	0	0	0	0
Section Length	2041	2.097	3.087	15.098	0.004
Total mvm	2041	29.215	47.688	330.64	0.13
ADT	2041	43625	24099	133800	2800
5+ Axle Trucks	2041	2857	2625	13175	17
Total Trucks	2041	4818	3163	20520	145
Number Collisions	2041	18.761	42.227	409	0
Actual F & I	2041	0.263	0.503	6.72	0
Actual Collision Rate	2041	0.693	0.932	13.39	0
5+ Trucks / ADT	2041	0.080	0.072	0.364	0.001
Total Trucks / ADT	2041	0.131	0.086	0.531	0.013

PROCEDURE

Fatality Plus Injury Rate

Two linear backward regression analysis procedures were performed with Fatal and Injury collision rate as the dependent variable. The first used X1 through X10 as the independent variables. The second used all but X9 and X10, 5+ Axle Trucks and Total Truck volume, and replaced those with X11 and X12, the truck ratios.

Both analyses returned the same result, with Year, Area, and Shoulder Width being the only remaining variables in a linear model at the 10 percent significance level. These results were checked for intercolinearity, and it was found that none of the independent variables had higher Pearson correlation values with each other than with the dependent variable.

Actual Collision Rate

A similar analysis was performed for the actual collision rate variable. An initial run was performed using the same independent variables as the Fatal plus Injury analysis. In this case, both 5+ Trucks and Total Trucks were statistically significant to the 10 percent level. These two measurements of truck volumes had a Pearsons correlation value of 0.956. With such a high Pearsons value, it was evident that by using both these values, our model would be subject to intercolinearity. The independent variable 5+ Trucks was removed because it was less significant to the model than Total Trucks. The significance was measured by the coefficient **t** value of each independent variable. The significant variables from the analysis with 5+ Trucks removed were Area, Shoulder Width, and ADT. These values were checked for intercolinearity, and it was found that the model was valid.

Another model was created using the truck ratios as was done in the Fatal plus Injury analysis. The resulting model, like the first, listed both truck ratios as significant to the model. The independent variable 5+ Axle/ADT was removed, since it had a lower **t** value than did Total Trucks/ADT. When run again with this variable removed, the resulting model was the same as acquired above with Area, Shoulder Width, and ADT as the significant independent variables.

Number of Collisions

No suitable model could be established for the dependent variable Number of Collisions. With further investigation, it was found that due to the fundamental relationship between Section Length, ADT, and Number of Collisions, it would not be possible to derive any meaningful relationship between the Number of Collisions and the remaining independent variables such as Bike Status. Due to the tremendous range of values in the independent variables Section Length and ADT, the models developed said nothing more than that longer lengths and higher ADT produce more collisions.

RESULTS

Bike Status

For both the Fatal and Injury Rate and the Actual Collision Rate, Bicycle Status dropped out early in the model procedure. On all models, before Bicycle Status dropped out it had a negative coefficient for predicting collision rates. This shows that there are fewer collisions per mile of freeway on sections that allow bicycles than on those that do not allow bicycles in Districts 5 and 6. However, as the analysis showed, Bicycle Status is <u>not</u> a good predictor of collision rates in Districts 5 and 6.

Bicycle status was statistically significant at the 10 percent level for predicting the Number of Collisions, although as stated before, since Section Length and ADT were so prevalent in those models, Bike Status contributed little, and was the least significant variable.

The variable Bike Status did correlate with Area, ADT, both Truck Volumes and Section Length at the 1 percent level on a 2-tailed test. A list of these values, their Pearson correlation coefficients, and an explanation of the relationship between each variable and Bike Status can be found in Table 6-4.

At the 5 percent level on a 2-tailed test, Bike Status also correlated with Shoulder Width, Actual Collision Rate, and both truck volume ratios. These correlation coefficients are displayed in Table 6-5.

Table 6-4: Bike Status Correlation to Variables in Districts 5 and 6 at 1% Level

	Pearsons correlation coefficient at 1% level	*Variable given as*	*Bike range*	*Explanation of correlation*
Area	-0.199	1=Rural 2=Urban 3=Urbanized	0=not allowed 1=allowed	Bike access is more common on rural freeways
ADT	-0.153	Volume in Vehicles per Day	0=not allowed 1=allowed	Bikes allowed access on freeways with lower ADT
Total Trucks	-0.121	Volume in Vehicles per Day	0=not allowed 1=allowed	Bikes allowed access on freeways with lower truck ADT
5+ Axle Trucks	-.097	Volume in Vehicles per Day	0=not allowed 1=allowed	Bikes allowed access on freeways with lower large-truck ADT
Section Length	0.086	Length in Miles	0=not allowed 1=allowed	Rural freeway sections are more uniform than urban and, therefore, longer in our database

From Tables 6-4 and 6-5, it is evident that in Caltrans Districts 5 and 6, bicycles currently are more likely to have access to rural sections with lower

ADT and truck traffic. Rural freeways also tend to have lower total truck volume, which explains the connection between bicycle access on rural routes with low truck volume.

The Caltrans Highway Design Manual lists the following as roadway factors that "should be considered" when determining if a freeway shoulder is suitable for bicycle access:[112]

- Shoulder widths;
- Bicycle hazards on shoulders;
- Number and location of ramps; and
- Traffic volumes on ramps**.**

Table 6-5: Bike Status Correlation to Variables in Districts 5 and 6 at 5% Level

	Pearsons correlation coefficient at 5% level	*Variable given as*	*Bike range*	*Explanation of correlation*
Shoulder Width	-0.045	Length in feet	0=not allowed 1=allowed	Bikes allowed on freeways with narrow shoulders
Actual Collision Rate	-0.042	Expressed in Acc/ MVM	0=not allowed 1=allowed	Bikes allowed on freeways that experience lower collision rates
5+ Axle Trucks / ADT	-0.042	Ratio of Large Trucks to ADT	0=not allowed 1=allowed	Bikes allowed on freeways with lower large-truck ADT
Total Trucks / ADT	-0.038	Ratio of All Trucks to ADT	0=not allowed 1=allowed	Bikes allowed on freeways with lower truck ADT

When comparing these factors to those variables that had a statistically significant correlatation to Bike Status, it becomes evident that Caltrans

---

[112] California Department of Transportation, *Highway Design Manual*, 1000-22.

Districts 5 and 6 are conforming to the Highway Design Manual guidelines. Shoulder width, one of the four factors considered, was found to correlate at the 5 percent level. The freeways open to bicycles had, on average, slightly narrower shoulders than the closed sections. A parallel can be drawn between the Number and Location of Ramp factor and the Area variable from the database. In rural areas, ramps tend to be fewer and spaced farther apart than in urbanized areas. Traffic volumes on ramps can be measured indirectly by the ADT and truck volumes, of which all correlate to the 1 percent level with Bike Status. There are no variables in the database to measure bicycle hazards.

Collision Rate Models

The following are both collision rate models obtained through the backward linear regression analysis and a written interpretation of the variables with their constants. Collision rates are given in collisions per million vehicle miles.

Fatality plus Injury Rate = 0.877 – (0.0064 * YEAR) + (0.045 * AREA) – (0.0076 * SHOULDER WIDTH)

with a fit to data of **F = 8.841**

YEAR—The year variable is associated with a negative constant, which tells us that collision rate decreases with time. *Year is the most significant predictor in this model*.

AREA—The range of the area variable is 0 for rural, 1 for urban, and 2 for urbanized. The positive constant relates that there will be a greater collision rate in urbanized sections than in rural.

SHOULDER WIDTH—Shoulder width is expressed in feet. The negative constant relates that as shoulder width increases, the collision rate will decrease.

Actual Collision Rate = 0.643 + (0.129 * AREA) – (0.021 * SHOULDER WIDTH) + (1.76 * (ADT/10^6))

with a fit to data of **F = 26.325**

AREA—With a positive constant, this variable will return a greater collision rate as you move from rural to urbanized. This is similar to the Fatality plus Injury model.

SHOULDER WIDTH—Similar to the above, with a negative constant; as shoulder width increases, collision rate will decrease.

ADT—The constant for ADT is positive; the collision rate increases as ADT increases.

Unlike the Fatality plus Injury model, the constants on the Actual Collision Rate model are not dominated by one variable. All variables are similar in level of significance, with Area being slightly dominant.

Bicycle Compatibility Index, BCI

Using the method described in Chapter 5, "A Study of Bicycles On Selected Bridges And Tunnels," the bicycle compatibility index (BCI) was computed here for freeways in Districts 5 and 6.[113] The calculation is complete for two separate cases: mean conditions for freeways that are open to bicycles and mean conditions for freeways that are closed to bicycles in the two districts. Speed limits on these freeways were assumed to be 65 mph. The BCI for the freeways open to bicycles was 4.97. The "mean" freeway closed to bicycle traffic had a BCI of 5.38. Two key variables that are not included in the BCI calculation are width of the shoulder and frequency of freewayside ramp terminals. When compared to Table 5-6, it can be seen that these values fall near the middle of the range calculated for bridges and tunnels.

CONCLUSION

The models we obtained here have similarities to those used by Caltrans to compute expected collision rates.

The lack of Bicycle Status as a significant variable suggests that allowing bicycles on freeways does not have an adverse effect on the vehicle collision rate. For those intermediate models, which had bicycle status as a variable, the coefficients were always negative. This is most likely due to the fact that bicycles are more likely to be on rural, low-volume freeways. In general, it appears that Caltrans policy relative to bicycles on freeways is being followed in Districts 5 and 6.

---

[113] Harkey, *Bicycle Compatibility Index*, 5.

POLICY RECOMMENDATIONS

The primary purpose of this chapter is to convey the major results of this study and subsequent recommendations.

The findings and recommendations in this chapter are divided into four sections. The first section deals with measures that could be taken to improve the data that is currently collected in order to make studies of bicycle and pedestrian collisions better and more reliable. The second looks at pedestrians on freeways; the third deals specifically with the minimum criteria for bicycles to use freeways safely. Finally, the Richmond-San Rafael Bridge is examined using these minimum criteria. This bridge is singled out because of its role in the initiation of this study. It also is of considerable interest to bicycle advocate groups. The advisory committee that assisted throughout this effort specifically asked that this bridge be considered.

DATA COLLECTION

This study discovered that a common barrier to measuring bicycle safety on freeways is the lack of data necessary to calculate a bicycle collision rate. Two values are needed to calculate a bicycle collision rate: the number of collisions over a given period of time and an estimate of the miles traveled by bicyclists during the same time period. The miles traveled can be determined through bicycle counts, which are rarely if ever done on freeways. The number of collisions on freeways is likewise difficult to determine.

Caltrans currently has no program to count bicycles on freeways. Bicycle travel is difficult to measure and quantify. There is no question that bicycle average daily traffic on freeways is low relative to motor vehicles— but how low?

As a multimodal agency, Caltrans should make some modest effort to measure bicycle travel on freeways and all state highways. A bicycle-counting program would not need to be comprehensive, in that not all state highways need bicycle counts. Locations to count need to be established where there appear to be concentrations of bicycle travel, where concentrations of bicycle collisions have been identified, or where there is public demand for bicycle-related improvements. Most districts will need to identify only a few (three to five) count locations. Districts, such as District 1, that have all freeways open to bicycles, will have dozens of count locations. Counts should be done at three-year intervals to identify trends. Like the motor vehicle counting program, counts need to be seasonal. One three-day daylight hour count during the peak season and counts of four peak hours on one day in each of the remaining three seasons of a count year would serve as a good start to a bicycle-counting program.

Currently, all reported collisions on California State Highways are tabulated in the Traffic Accident \ and Analysis System (TASAS). Through this system one can request collision reports in specialized forms. Unless care is taken, the system may produce erroneous results. This study found that of the 213 reported bicycle collisions that were coded as having taken place on freeway routes in three districts over the nine years, only 41 (19.2 percent) actually involved bicycles riding on the freeway or on freeway ramps.

The Richmond-San Rafael Bridge Feasibility Study reported, "there were 2,739 freeway collisions" statewide in a 10-year period.[114] Most of these collisions did not involve a bicycle traveling on the freeway; they involved bicycles traveling on surface streets and at or near freeway-surface street ramp junctions.

Uncertainty lies in the coding of the location of the collision. Currently, TASAS codes the location of highway collisions in the following manner:

HWY- Highway section
1- Ramp Exit
2- Ramp
3- Ramp Entry
4- Ramp Related Local Street
5- In Intersection
6- Intersection Cross Street

With this coding system, it is impossible to determine (without specific study of each ramp) where the collisions coded 1 or 3 have actually taken place. There is no distinction made between the end of the on-/off-ramps at the freeway side or at the surface street side.

To obtain the most readily available and accurate collision count for bicycles on freeways, it would be necessary to count only the collisions at the freeway ends of on- and off-ramps. Adding this distinction to the data would allow

---

[114] California Department of Transportation, *Richmond-San Rafael*, 4-45 (59).

districtwide and statewide bicycle collisions on freeways to be counted readily. Now, it is necessary to look at the collision reports or at each ramp individually to get an accurate count. The freewayside ramp collisions are important and special consideration is warranted.

Another criterion of bicycle collision statistics that TASAS was unable to produce is the party at fault. Currently, the primary collision factor is the only data for determining fault. For motor vehicle collisions this may be sufficient, but for collisions involving bicycle(s), pedestrians(s), and motor vehicle(s) it is often necessary to identify fault; TASAS does not provide this information. The Statewide Integrated Traffic Records System (SWITRS) provides the party at fault in its data tabulations; TASAS should do likewise.

Caltrans legal division, as part of a peer review, stated that vehicle-at-fault information should not be added to the TASAS database under any circumstances. The legal division stated that it could be used as an admission by Caltrans in any kind of litigation arising from the subject collision. Certainly, Caltrans will not implement this recommendation given the legal opinion. It is difficult to understand how merely repeating what is in the traffic collision report, and labeling it likewise, will add to liability. A alternative recommendation is that Caltrans could direct researchers who require vehicle-at-fault information to use SWITRS data in their research.

PEDESTRIAN USE OF FREEWAYS

A total of 327 freeway pedestrian collisions for two Caltrans districts were carefully tabulated over the nine-year study period. These collisions have a high severity rate, with 71 percent injury and 24 percent fatal collisions. Most, 65 percent, involve pedestrians leaving their vehicles. A disproportionate share of collisions, 38 percent, were on wet, snowy, or icy road surfaces.

How to improve pedestrian safety on freeways poses a dilemma. Questions relating to exactly what is “the pedestrian on freeway problem to be solved” have not been asked. For the 35 percent of pedestrians involved in collisions after entering the freeway illegally, the collision prevention solution is to stop them from entering. However the majority of pedestrians involved left their vehicles and may not have acted illegally. The problem may be that any pedestrian in, or near, the freeway-traveled right-of -way is in jeopardy.

The solution then is to continue and enhance efforts to inform drivers that they should avoid exiting their vehicles on freeways. When absolutely necessary to leave the vehicle, it is imperative to get as far from the traveled way as possible. Many of the pedestrian on-freeway collisions are related to placing or removing chains from vehicles. Drivers need to be informed of the risks involved while out of their vehicles and on freeways under snow and ice conditions.

No mention is made of the pedestrian-on-freeway problem in the California Drivers Handbook.[115] Attention to the prohibition of pedestrians on freeways and the risks involved in exiting a vehicle while on a freeway is warranted. Public service announcements relating to the safety and risks of placing and removing tire chains within the freeway right-of way should be considered. These could be timed to correspond to the onset of winter. The Highway Advisory Radio network is one source to use for these announcements.

Good facilities along highways are necessary for placement and removal of chains. It is recommended that Caltrans evaluate the existing chain on-and-off areas. Where adequate width, lighting, and signing do not exist, improvements should be made.

BICYCLE USE OF FREEWAYS

Level Of Risk

Riding a bicycle on a high-speed highway involves considerably more risk than riding in, or driving, a motor vehicle. Collision rates, per vehicle mile, for bicycles are difficult to establish with certainty. Still, there is sufficient information available to clearly state that bicycle collision rates for highways are at least one order of magnitude higher than motor vehicle collision rates.

Three of the collision rates in Table 7-1 are based on collisions reported to authorities. The others are based on surveys of bicycle riders. As expected, the reported collision rates are lower.

The rate of 16 reported bicycle collisions per million bicycle miles cited in Table 7-1 for bridges and tunnels is based upon six facilities with no collisions, estimated rates of 24 and 40 for two facilities, and assumed rates of 32 (mean of 24 and 40) for two facilities. There is considerable uncertainty related to this figure.

---

[115] California Department of Motor Vehicles, *California Driver Handbook*, 2000, 1-81.

Table 7-1: Summary of Bicycle Collision Rates

Source/Location	*Bicycle-Involved Collisions per Million Bicycle Miles*
Kaplan [a]	113
Moritz[b]	66
Expressways in Santa Clara County	19+ reported
Bridges/Tunnels Studied From Chapter 5	16 reported
Internet Survey	24
SR 101, Humbolt County, CA, District 1	5 reported

a. Kaplan, *Characteristics of Adult Bicycle User*, 45.
b. Moritz, *Adult Bicycle in U.S.*, 6 - Table 4.

The rate for SR 101 in Humboldt County found in Table 7-1 is for a 21.5-mile section of freeway. Counts are sparse, and the cited rate was estimated from minimal count data. The actual bicycle collision rate is most likely higher than that which was calculated. The rate is based on 17 collisions over a nine-year period.

Severity

Bicycle-on-freeway collisions result in injury and occasionally death. Of the 41 on-freeway bicycle collisions studied in detail, 7 percent were fatal and 85 percent involved injuries.

Comparison of Collision Rates

Statewide, the 1998 freeway collision rate for all vehicles was 0.91 collisions per million vehicle miles. Thirty-one percent of freeway collisions involved injuries or fatalities.[116]

Definition of a Freeway

The *Highway Design Manual* (HDM) defines a freeway as having “full control of access and with grade separations at intersections.” The issue is the crossing

---

[116] California Department of Transportation, *1998 Accident Data*, 11.

conflicts that are not grade separated.[117] Drivers expect that when traveling on a freeway, crossing conflicts are eliminated. Adding bicycles along the shoulder of a freeway adds unexpected crossing conflicts at freewayside ramp merge and diverge areas.

No single collision pattern dominates the bicycle on-freeway collision experience. Table 7-2 summarizes the patterns identified in reviewing traffic collision reports over nine years in California Districts 1, 2, and 3.

This speed differential between a motor vehicle and a bicycle traveling on a freeway causes additional concern. It is a widely held traffic engineering principle that mixing vehicles of different speeds causes conflicts and relates to higher collision rates. David Solomon presented data on speed differential and motor vehicle collision rates in a 1964 Bureau of Public Roads publication. It is likely that this principle will apply to bicycle-motor vehicle relationships. For this reason, in the recommendations that follow, an effort is made to separate the bicycles from the motor vehicles using a freeway.

Riding a bicycle on freeways produces a greater risk than operating a motor vehicle because of the higher-than-average collision severity. Furthermore, bicycles traveling on freeways are contrary to normal freeway operation. Therefore, allowing bicyclists to ride on the freeway requires some specific actions. Recommendations are made in the following sections. However, bicyclists should never be encouraged to use a freeway.

---

[117] California Department of Transportation, *Highway Design Manual*, 60-2.

Table 7-2: Bicycle-On-Freeway Collision Patterns

15 Single-Bicycle Collisions
9 Hit Object
4 Hit Drain Inlet
1 Hit Pedestrian
1 Equipment Failure
14 Collisions with Motor Vehicle at Ramp Terminal
10 Off Freeway Ramp Locations
4 On Freeway Ramp Locations
12 Mainline Freeway Motor Vehicle Collisions
7 Motor Vehicles Entered Shoulder
5 Bicycles in Freeway Lane

Age Limit and Helmet Recommendations

Although freeway sections statewide are currently open to bicycle travel, it is assumed that bicyclists riding there are of a certain level of maturity. The question at hand is, What is the minimum age a bicyclist needs to be in order to ride on the freeway?

Rather than use age, which would be hard to enforce, the possession of a driver’s license should be considered as a requirement to operate a bicycle on a freeway. Using a driver’s license as a requirement theoretically meets the following criteria: The user is at least 16 years of age and has a basic understanding of the movements of motor vehicles using freeways, and applicable state laws. Because of the unknown and likely high level of risk, children should not be allowed to ride bicycles on freeways.

Because of the high severity rate for collisions involving bicycles on freeways, cyclists should be required to wear helmets while riding on freeways.

Vehicle code changes would be necessary to implement these recommendations.

Amendments could also be made to the California Driver Handbook to educate motor vehicle operators that bicycles occasionally use freeways.[118] Currently, there is no mention of bicycles on freeways in the booklet. It is especially important to educate both bicyclists and motor vehicle users of the dangers of the conflicting movements found at ramps.

Roadway Requirement Recommendations

Shoulder Width

With the current trend of adding rumble strips to freeway shoulders, the width of freeway shoulders is a concern if bicycles are to be allowed there. Because of wind forces and geometric space requirements, bicycles should not be expected to ride in, or directly alongside, the traveled way. Therefore, if bicycles are to be given access to freeway shoulders, they should ride on the shoulder, to the right of the rumble strip.

The width from the edge of the traveled way to the outside of the rumble strips is up to 3 feet. The remaining width of 5 feet provides an area that is potentially comfortable and safe for a bicycle. This gives a total shoulder width of 8 feet as a minimum that should be provided on freeways open to bicycles. Eight feet also provides room for the bicyclist to maintain distance from fast-moving heavy vehicles, and the problem of wind pushing the bicyclist is diminished. Caltrans should take steps to provide continuous shoulders of at least 8 feet on freeways open to bicycles.

Developing full 8-foot shoulders is no small task. Many of the narrow shoulders that currently exist are on bridge structures. The recommendation to provide 8-foot or greater shoulders will have to be implemented over the long term. Caltrans should consider the presence of bicyclists on the freeway when deciding priorities for widening shoulders. No new freeway sections should be opened to bicyclists without a continuous 8-foot shoulder in place.

The shoulder must also be suitable for accommodating bicycles. On highway sections open to bicycles, drainage inlets must be safe for bicycles to travel over or be moved off the shoulder.

Ramps

When traveling on freeways, motorists do not expect to experience any crossing conflicts. The purpose of ramps is for vehicles to be able to merge or diverge from the mainline traveled way without an at-grade crossing conflict.

---

[118] California Department of Motor Vehicles, *Driver Handbook*, 1-81.

The addition of bicycles, which must cross ramps, creates such a conflict. A majority of motorists may not be aware of, and therefore will not expect to maneuver around, a bicycle while merging or diverging.

On mainline sections between ramps, bicycles that are being properly operated will not cross the path of a motor vehicle. Unfortunately, there are no easy methods to prevent conflicts at ramps. Therefore, bicycles should not be allowed on freeways with a high number of closely spaced ramps, especially on ramps with high volumes. Conversely, for freeways with widely spaced, low-volume ramps, bicyclists may be allowed to cross ramps on the freeway end, assuming that the bicyclist would use excellent judgment.

The responsibility of crossing a freeway ramp safely should rest with the bicyclist. Because bicycles are physically smaller than cars and provide less protection, bicyclists are at a major disadvantage when involved with a motor vehicle collision. Reasonable expectations include the following:

- Cyclists understand they must cross high-speed motor vehicle traffic.
- Motorists are expecting to merge and diverge smoothly without crossing conflicts.

All freeway ramps where bicycles are allowed to cross on the freeway side need to be reviewed by Caltrans. While the quantitative recommendations here are based on estimates and not statistically verified by experience, they serve as a starting point for future study and refinement.

A safe crossing sight distance at least equal to the distances cited in Chapter 4, “Freeway Bicycle and Pedestrian Collision Analysis for Districts 1, 2, and 3” would need to be available to the bicyclist at the location where the ramp normally would be crossed. For freeway off-ramps where approaching traffic has a 70-mph speed limit, a safe crossing sight distance of 760 feet is warranted. This assumes an 85th percentile speed of 74 mph. For freeway on-ramps with prevailing approach speeds of 45 mph, a sight distance of 460 feet would be needed.

The volumes of ramps to be crossed by a bicycle must provide adequate gaps to make a safe crossing. Bicyclists should not be given access to cross ramps with repeated peak hour volumes at or above 500 vehicles per hour.

Readers need to recognize that the 500-vehicle-per-hour recommendation as an upper limit to allow bicycles across freeway ramps on the freeway side is not based on safety and collision data. This threshold is likely too high for freeway off-ramps that have considerable motor vehicle volume in the right-hand lane. It will be difficult for a bicyclist to judge when it is safe to cross the ramp. The cyclist may not be able to determine which freeway vehicles will use the ramp and which will continue on the freeway.

Good freeway operation practice calls for the elimination of crossing conflicts. Application of this concept and the high-speed differentials between bicycles and motor vehicles on a freeway provide considerable rationale to prohibit bicycles crossing freeway ramps on the freeway side altogether. The recommendation here, to allow bicycles to cross low-volume ramps on the freeway side, is a recommendation to continue current practice. This recommendation is based on the unavailability of observations of bicycles crossing freeway ramps and substantial collision data related to that maneuver.

High-volume ramps and locations without safe crossing sight distance need to be signed to require that bicyclists leave the freeway. Multilane ramp crossings, weave areas, and areas where a bicycle may be forced to approach an on-ramp that does not meet the ramp crossing criteria cited above should be closed to bicycle travel and alternate routes provided.

Santa Clara County is currently modifying expressway ramps that are crossed by bicycles on the expressway end. The shoulder stripe is being dropped in advance of an off-ramp and is not continued along the ramp. The W79 bicycle warning sign is placed 100 to 200 feet in advance of the ramp crossing area.

The same sign is being placed on on-ramps in advance of the areas where bicycles may cross a ramp. Expressways are not freeways, as drivers expect some crossing conflicts to occur. The speed limits are between 40 and 50 miles per hour.

The county does not anticipate doing a formal evaluation of the results of the changes in ramp area and signing. The effectiveness of these modifications should be studied. Such studies ideally would include bicycle volumes, collision counts, and input from both bicyclists and motor vehicle operators. Bicycle collision history needs to be compiled now and preserved. Current sample counts of bicycles crossing each ramp are necessary, as is a continuous count program. It will take at least five years of operation with the stripe and sign modifications to determine if there is any apparent effect on bicycle collision numbers.

At this time, it is not recommended that Caltrans modify striping and signing on freeway ramps to accommodate bicycle crossings. Sections of freeways that experience a fair amount of bicycle travel may be signed with the W79 sign to remind motorists that bicycles might be present. These would be at the beginning of the entire freeway section that would have bicycle use, not at specific ramp terminals. Eliminating the shoulder stripe is not recommended. No single ramp area was identified as having more than a single bicycle collision during the nine-year, three-district study of freeway bicycle collisions. The benefits of the shoulder stripe to all freeway users would seem to exceed the unknown benefit of dropping the shoulder stripe in the vicinity of ramps.

Should Caltrans wish, a few experimental installations that guide bicyclists to a suitable freewayside ramp crossing location (one with good safe crossing sight distance) may be implemented. These, likewise, would need to be evaluated. Before- and after-collision evaluations will be difficult to make without a before-collision history.

Bridges

Bicycle collisions on bridges are rare events. Bridges and tunnels do not appear to have of a greater safety problem than exists on the adjacent roadways. Because of this, it is exceedingly difficult to determine which factors cause bicycle collisions on bridges and which factors provide safe bicycle passage. Common sense indicates that the following factors would influence bicycling collisions:

- Length;
- Width of lanes;
- Shoulder width;
- Traffic volume;
- Surface conditions;
- Grade; and
- Bridge rail geometry.

With so few bicycle collisions to study, it is not possible to determine which factor is the most influential. Because bridges rarely have ramps on the span, the issue of ramp crossing conflicts generally will not need to be addressed. Similarly, traffic volume will be less of an issue if there are no crossing conflicts. Surface conditions and grade are well treated in Chapter 1000 of the HDM.[119] For all practical purposes, requirements for shoulder width on bridges should not be any different than the requirements set forth earlier—8 feet, ideally with rumble strips. The issue of expansion joints on long bridges needs to be addressed. They must be covered or redesigned so a thin bicycle tire will not be trapped.

The warning signs and flashing beacons that alert motorists to the presence of bicycles at the Collier Tunnel and the Mad River Bridge appear to be effective. Concentrations of bicycle-involved collisions were not identified at those sites. Warning devices should continue to be used where frequent bicycle travel is present and shoulders are narrow.

Bridge Railing Requirements

One factor to consider when allowing bicycles access to bridges is the height of the railing next to the traveled way. It appears that a minimum height must be set in order to prevent a bicyclist from toppling over the side upon impact with the bridge rail. Railings must be continuous, so bicyclists and pedestrians cannot fall through them.

Currently, the HDM sets the minimum design height for railings on bridges that allow bicycles at 4 feet, 7 inches.[120] No consideration is given to the width of the railing.

The HDM should be amended to give consideration to the width of the railing and the minimum distance from the railing to the location where bicycles travel. Where the bicycle will be a reasonable distance from the railing and pose no danger to the bicyclist, there should be exceptions to the rail height.

RICHMOND-SAN RAFAEL BRIDGE

Using the criteria established above, the Richmond-San Rafael Bridge was analyzed for bicycle access. The specific factors were bridge railing height, shoulder width, and crossing conflicts. Conflicts with maintenance and operation needs were not studied.

---

[119] California Department of Transportation, *Highway Design Manual*, 1000-8, 1000-24.

[120] ibid., 1000-23.

Railing

The Richmond-San Rafael Bridge is one bridge that deserves an exception to the bridge rail criteria. At the minimum, the railing is 4 feet tall and 2 feet from where bicycles would travel. On the middle section of the bridge, the railing is 4 feet tall and 3.5 feet from where bicycles would travel. With such an arrangement, it would be difficult for a bicyclist to accidentally fall over the rail. The railing appears to be adequate to protect bicycles from leaving the bridge. General policy allows a lower railing if there is a shoulder on the other side of the rail or when a sidewalk separates the rail from the location where bicycles ride.[121] No provision is made for a wide rail.

Shoulder Width

This bridge has shoulders of 12 feet on most of the roadway and no rumble strips, which is more than sufficient for bicycle travel. One exception exists on the eastbound roadway at the west end of the bridge. The eastbound Main Street on-ramp merges into Highway 580 at the beginning of the bridge on the west side. The shoulder narrows to approximately 3 feet at this section, which would cause a bicyclist to travel directly alongside the traveled roadway for a short distance. This narrow shoulder width, combined with motorists attempting to merge, may create a serious conflict. The bridge should be widened there before bicycles are allowed.

Expansion joints will have to be covered to prevent entrapment of narrow bicycle tires.

Crossing Conflicts

Highway 580 at the Richmond-San Rafael Bridge is not a rural freeway. The volumes can be moderately high for a bridge with two lanes per direction, and the ramp volumes are high enough to create a serious conflict with bicycles. With minimal alterations, bicycles could be given access to the shoulder without crossing any freeway ramps. Similarly, bicycles could be directed off the bridge at each end without creating ramp-crossing conflicts. If these improvements were made, there would be no difficulty with crossing conflicts.

Richmond-San Rafael Bridge—Current Conditions

One section of the Richmond-San Rafael Bridge shoulder is currently closed due to a wildlife survey associated with the pending structural seismic retrofit.

---

[121] ibid., 1000-24.

During the retrofit construction, it is understood that many sections of the shoulder will be completely closed. With portions of the shoulder closed, niether the bridge nor any other freeway sections are good candidates for bicycle travel. Allowing bicycles on this bridge would require that the shoulders be continuous and clear of regular activity.

The preceding is not a recommendation that the Richmond-San Rafael Bridge be opened to bicycles. It was offered as an example of what needs be done to open an existing facility to bicycle travel. Caltrans has expressed concerns because the bridge shoulder will always be used for maintenance, at least intermittently. Caltrans also stated that during peak hours, motor vehicles use the shoulder illegally for passing. The wide shoulder does make it attractive to motorists. The extent that the shoulder is used for maintenance and by motor vehicles for passing must be carefully considered before any decision to open the bridge for bicycle use.

The Richmond-San Rafael Bridge will be a construction zone during the seismic retrofit. In general, bicycles are to be accommodated through construction zones. The needs of all modes (bicycles, pedestrians, and motor vehicles) should be considered when a construction zone traffic management plan is developed. One way to provide for bicycles when construction is underway is to increase bicycle transit opportunities. Scheduled buses or on-demand shuttle services are used to transport bicycles and their riders on highway segments where their presence is not allowed. Increasing bicycle transit opportunities at the Richmond-San Rafael Bridge is desirable.

ABBREVIATIONS AND ACRONYMS

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AC	Access Control
ACC	Accident
Acc/MBM	Accidents per Million Bicycle Miles
ADAAG	Americans with Disabilities Act Accessibility Guidelines
ADT	Average Daily Traffic
ASCE	American Society of Civil Engineers
B	Bicyclist
BA/MBM	Bicycle Accidents per Million Bicycle Miles
BCI	Bicyclist Compatibility Index
Caltrans	California Department of Transportation
CHP	California Highway Patrol
CSU, Chico	California State University, Chico
D.C.	District of Columbia
DHV	Design Hourly Volume
DOT	Department of Transportation
Expwy	Expressway
F & I	Fatality and Injury
FHWA	Federal Highway Administration
HDM	Highway Design Manual

HWY	Highway
ITE	Institute of Transportation Engineers
km	kilometers
LAB	League of American Bicyclists
LAW	League of American Wheelmen
LOS	Level of Service
LT	Left Turn
Max	Maximum
MB	Motor Vehicle
mbm	million bicycle miles
mkm	million kilometers
Min	Minimum
mph	miles per hour
MVM	Million Vehicle Miles
NA	Not Applicable
NHTSA	National Highway Traffic Safety Administration
No.	Number
OT	Overtake
PCF	Primary Collision Factor
PDO	Property Damage Only
RA	Right Angle Collision
S	Single
SD	Standard Deviation
SWITRS	Statewide Integrated Traffic Records System

TASAS	Traffic Accident Surveillance and Analysis System
TCR	Traffic Collision Report
U.S.	United States
UN	Unknown Fault or Not Stated
vph	Vehicles Per Hour
WABA	Washington Area Bicycle Association

BIBLIOGRAPHY

American Association of State Highway and Transportation Officials, *Guide for The Development of Bicycle Facilities*. (1999)”

_____. "Policy on Geometric Design of Highways and Streets. “Excerpts from the 1994 AASHTO.

California Department of Motor Vehicles, *California Driver Handbook, 2000.*

_____. *1998 Accident Data on California State Highways* (Road Miles, Travel, Accidents, Accident Rates).

_____. *1990-1997 Annual Average Daily Truck Traffic on the California State Highway System*.

_____. *1997 Annual Average Daily Truck Traffic on the California State Highway System* (April 2000).

_____. *1997 California State Highway Log.*

_____. *1997 California State Highway Log for Districts 5 and* 6.

_____. *1997 Traffic Volumes on California State Highways* (June 1998).

_____. *1998 Traffic Volumes on California State Highways* (June 1999).

_____.*Highway Design Manual* (July 1, 1995).

_____.*Ramp Volumes on the California State Freeway System*, July 1996.

_____. *Richmond-San Rafael Bridge Public Access Feasibility Study.* (December 1998).

City of San Jose, Santa Clara County. http://homes.wsj.com/d/profile-sanjosecalif.html. Accessed July 13, 2000.

Clark, A., and L. Tracy. *Bicycle Safety-Related Research Synthesis*. Office of Safety and Traffic Operations Reserach and Development, Federal Highway Administration (April 1995).

Forester, John. *Cycling Transportation Engineering*. Palo Alto, CA. (February 1977).

_____. *Highway Standard for Bicycle Travel*. Unpublished Report. (15 June, 1974).

_____. *Width of the Outside Lane, Traffic Volume and Speed, and Cycling Safety.* Unpublished Report (30 March, 1974).

Garder, Per. "Rumble Strips or Not Along Wide Shoulders Designated for Bicycle Traffic?" *Transportation Research Record* No. 1502 (1995).

Harkey, David L., et al. *Development of the Bicycle Compatability Index: A Level-of-Service Concept*. FHWA-RD-98-072 (December 1998).

Hunter, William W., et al. "Bicycle-Motor Vehicle Crash Types: The Early 1990's." *Transportation Research Record* 1502 (1995).

Kaplan, Jerrold A. *Characteristics of The Regular Adult Bicycle User.* Federal Highway Administration (1975).

Khan, A. M., and A. Bacchus. "Bicycle Use of Highway Shoulders." *Transportation Research Record* 1502 – Bicycles and Pedestrian Research. (1995.)

Khorashadi, Ahmad. <Ahmad_Khorashadi@dot.ca.gov> "RE: Bicycle Accidents," 8 July 2000, personal e-mail (9 July 2000).

Klop, Jeremy R., and Asad J. Khattak, "Factors Influencing Bicycle Crash Severity on Two-Lane, Undivided Roadways in North Carolina." *Transportation Research Record* No. 1674 (1999).

Louisiana Department of Transportation, *Statewide Bicycle and Pedestrian Master Plan* (May 1998).

May, Adolf D. *Traffic Flow Fundamentals*, 1990.

Missouri Department of Transportation, *Pedestrian Facility Guidelines* (August 1999).

Moeur, Richard C., P.E., *Bicycle-Motor Vehicle Collisions on Controlled Access Highways in Arizona 5-Year Analysis – May 1, 1993 to April 30 1998*. Arizona DOT (16 October, 1998).

Moritz, William E. "Adult Bicycle in the United States: Characteristics and Riding Experience in 1996." *Transportation Research Record* No. 1636 (1998).

New Jersey Department of Transportation, *Pedestrian Compatible: Planning and Design Guidelines* (April 1996).

Oregon Department of Transportation, *Oregon Bicycle and Pedestrian Plan* (June 1995).

Smith, D. T., Jr. *Safety and Location Criteria for Bicycle Facilities*. FHWA-RD-75-113 (1976).

Stanford University. http:// www-portfolio.Stanford.edu/105432. Accessed July 23, 2000.

State of Vermont Agency of Transporation, *Bicycle and Pedestrian Plan* (November 1999).

Washington State Department of Transportation, *Pedestrian Facilities Guidebook* (September 1997).

Wilkinson, W. C., A. Clarke, B. Epperson, and R. Knoblauch, *Effects of Bicycle Accommodations of Bicycle/Motor Vehicle Safety and Traffic Operations*. Center for Applied Research, Incorporated (July 1994).

Zeeger, Charles V., ITE Chair, *Design and Safety of Pedestrian Facilities* (March 1998).

ABOUT THE AUTHORS

Thomas C. Ferrara is a Professor of Civil Engineering at California State University, Chico, and served as department chair form 1987 to 1993. He has taught more than 20 different courses since joining the faculty in 1971. His dissertation was on bicycles and motor vehicles at intersections—receiving a Ph.D. in Transportation Engineering from University of California, Davis, in 1975. He has served as a project director and consultant on five statewide highway research studies and does professional traffic engineering on a regular basis. He holds registrations as a civil and traffic engineer in California. Dr. Ferrara is the principal investigator on this project and made contributions throughout this report. Mr. Solorio and Dr. Ferrara were the primary authors of Chapter 7, Policy Recommendations, of this report.

A. Reed Gibby is a Professor of Civil Engineering at California State University, Chico. After graduating from BYU with a bachelor of engineering science degree in 1967, he began his career designing freeways for the Washington Department of Highways. He obtained a master's degree from University of California at Berkeley in 1970, then worked in traffic engineering, including some time as a city traffic engineer. He also worked a number of years in transportation planning in Oregon, California, and Alaska. Since joining the California State University, Chico, Civil Engineering faculty in 1984, he has taught courses in transportation engineering and has been involved in nearly two dozen research projects, many of them directly related to highway safety. For a number of years he served on the Subcommittee on Bicycle Capacity for the Transportation Research Board Committee on Highway Capacity and Quality of Service. Dr. Gibby served as consultant on this project, providing weekly assistance throughout the effort. His major contributions were to the statistical analysis presented in Chapter 6 and to the policy recommendations.

Jesse Solorio has been employed by the California Public Works Studies Program in Civil Engineering at California State University, Chico, on several transportation-related studies. He has his Engineering-in-Training certificate and received his Bachelors of Science in Civil Engineering from California State University, Chico, in December 2000. He has served as president of both ITE and ASCE student chapters and is a member of Tau Beta Pi and the Golden Key National Honors Society. Mr. Solorio is also an avid bicyclist, having once used the shoulder of Interstate 5 as a bike route. He is the primary author of Chapters 1, 2, 5, and 6 of this report.

Kacie Friebel attended California State University, Chico. In May of 2001, she graduated with a degree in Economics and a minor in Business. She plans to continue her studies by attending graduate school and attaining a Masters in Business Administration. She is the primary author of Chapters 3 and 4 of this report.

Henry E. (Ed) Yarbrough graduated with a Civil Engineering degree from California State University, Chico, in December 2000. He spent more than 12 years as an Intelligence Analyst for the United States Air Force, including tours in England, Germany, and the National Security Agency at Fort Meade, Maryland, before beginning to pursue his degree. He has passed the Engineer-In-Training exam and has secured a position with Caltrans. Mr. Yarbrough diligently rewrote project working papers to create Chapters 2 through 4 and prepared the bibliography and abbreviations and acronyms sections. He made important contributions to the policy recommendations.