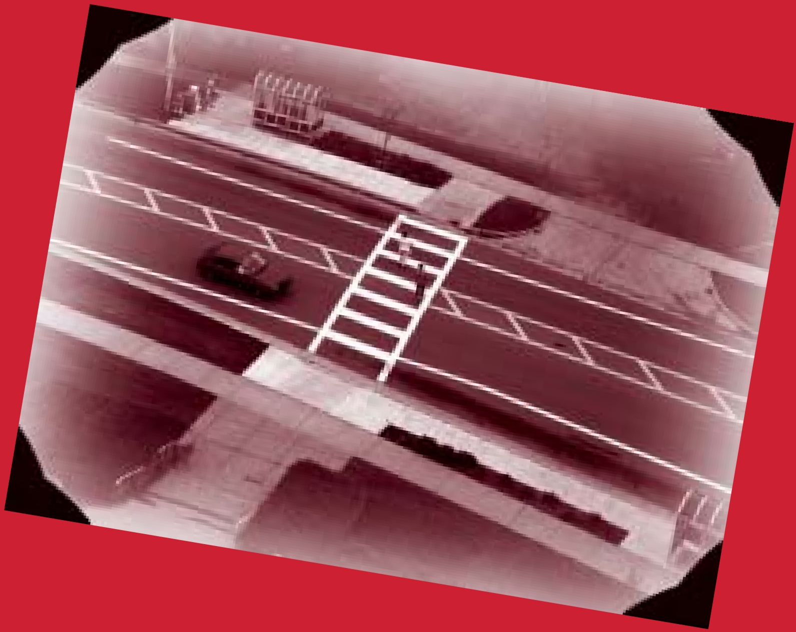
Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations

Final Report and Recommended Guidelines

FHWA PUBLICATION NUMBER: HRT-04-100

SEPTEMBER 2005



U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

Pedestrian and Bicycle Safety

FOREWORD

The Federal Highway Administration's (FHWA) Pedestrian and Bicycle Safety Research Program's overall goal is to increase pedestrian and bicycle safety and mobility. From better crosswalks, sidewalks, and pedestrian technologies to expanding public educational and safety programs, FHWA's Pedestrian and Bicycle Safety Research Program strives to pave the way for a more walkable future. The following document presents the results of a study that examined the safety of pedestrians at uncontrolled crosswalks and provides recommended guidelines for pedestrian crossings. The crosswalk study was part of a large FHWA study, "Evaluation of Pedestrian Facilities," that has produced a number of other documents regarding the safety of pedestrian crossings and the effectiveness of innovative engineering treatments on pedestrian safety. It is hoped that readers also will read the reports documenting the results of the related pedestrian safety studies. The results of this research will be useful to transportation engineers, planners, and safety professionals who are involved in improving pedestrian safety and mobility.

Michael F. Trentacoste
Director, Office of Safety
Research and Development

NOTICE

QUALITY ASSURANCE STATEMENT

Technical Report Documentation Page

1. Report No. FHWA–HRT–04–100	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines		5. Report Date August 2005 6. Performing Organization Code
7. Author(s): Charles V. Zegeer, J. Richard Stewart, Herman H. Huang, Peter A. Lagerwey, John Feaganes, and B.J. Campbell		8. Performing Organization Report No.
9. Performing Organization Name and Address University of North Carolina Highway Safety Research Center 730 Airport Rd., CB # 3430 Chapel Hill, NC 27599-3430		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH61–92–C–00138
12. Sponsoring Agency Name and Address Office of Safety Research and Development Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296		13. Type of Report and Period Covered Final Report: October 1996–March 2001 14. Sponsoring Agency Code

15. Supplementary Notes

This report is part of a larger study for FHWA entitled "Evaluation of Pedestrian Facilities." FHWA Contracting Officer's Technical Representatives (COTRs): Carol Tan and Ann Do, HRDS.

16. Abstract

Pedestrians are legitimate users of the transportation system, and they should, therefore, be able to use this system safely. Pedestrian needs in crossing streets should be identified, and appropriate solutions should be selected to improve pedestrian safety and access. Deciding where to mark crosswalks is only one consideration in meeting that objective. The purpose of this study was to determine whether marked crosswalks at uncontrolled locations are safer than unmarked crosswalks under various traffic and roadway conditions. Another objective was to provide recommendations on how to provide safer crossings for pedestrians. This study involved an analysis of 5 years of pedestrian crashes at 1,000 marked crosswalks and 1,000 matched unmarked comparison sites. All sites in this study had no traffic signal or stop sign on the approaches. Detailed data were collected on traffic volume, pedestrian exposure, number of lanes, median type, speed limit, and other site variables. Poisson and negative binomial regressive models were used.

The study results revealed that on two-lane roads, the presence of a marked crosswalk alone at an uncontrolled location was associated with no difference in pedestrian crash rate, compared to an unmarked crosswalk. Further, on multilane roads with traffic volumes above about 12,000 vehicles per day, having a marked crosswalk alone (without other substantial improvements) was associated with a higher pedestrian crash rate (after controlling for other site factors) compared to an unmarked crosswalk. Raised medians provided significantly lower pedestrian crash rates on multilane roads, compared to roads with no raised median. Older pedestrians had crash rates that were high relative to their crossing exposure.

More substantial improvements were recommended to provide for safer pedestrian crossings on certain roads, such as adding traffic signals with pedestrian signals when warranted, providing raised medians, speed-reducing measures, and others.

17. Key Words	18. Distribution Statement
Marked crosswalk, safety, pedestrian crashes	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19 Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	112	

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

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER 1. BACKGROUND AND INTRODUCTION

Pedestrians are legitimate users of the transportation system, and they should, therefore, be able to use this system safely and without unreasonable delay (figure 1). Pedestrians have a right to cross roads safely, and planners and engineers have a professional responsibility to plan, design, and install safe and convenient crossing facilities. Pedestrians should be included as design users for all streets.

As a starting point, roads should be designed with the premise that there will be pedestrians, that they must be able to cross the street, and that they must be able to do it safely. The design question is, “How can this task best be accomplished?”

Providing marked crosswalks traditionally has been one measure used in an attempt to facilitate crossings. Such crosswalks commonly are used at uncontrolled locations (i.e., sites not controlled by a traffic signal or stop sign) and sometimes at midblock locations. However, there have been conflicting studies and much controversy regarding the safety effects of marked crosswalks. This study evaluated marked crosswalks at uncontrolled locations and offers guidelines for their use.

Figure 1. Pedestrians have a right to cross the road safely and without unreasonable delay.

HOW TO USE THIS STUDY

Marked crosswalks are one tool used to direct pedestrians safely across a street. When considering marked crosswalks at uncontrolled locations, the question should not be simply, “Should I provide a marked crosswalk or not?” Instead, the question should be, “Is this an appropriate tool for directing pedestrians across the street?” Regardless of whether marked crosswalks are used, there remains the fundamental obligation to get pedestrians safely across the street.

In most cases, marked crosswalks are best used in combination with other treatments (e.g., curb extensions, raised crossing islands, traffic signals, roadway narrowing, enhanced overhead lighting, traffic calming measures). Marked crosswalks should be one option in a progression of design treatments. If one treatment does not accomplish the task adequately, then move on to the next one. Failure of one particular treatment is not a license to give up and do nothing. In all cases, the final design must accomplish the goal of getting pedestrians across the road safely.

WHAT IS THE LEGAL DEFINITION OF A CROSSWALK?

The 2000 *Uniform Vehicle Code and Model Traffic Ordinance* (Uniform Vehicle Code) (Section 1-112) defines a crosswalk as: [1]

(a) "That part of a roadway at an intersection included within the connections of the lateral lines of the sidewalks on opposite sides of the highway measured from the curbs, or in the absence of curbs, from the edges of the traversable roadway; and in the absence of a sidewalk on one side of the roadway, the part of a roadway included within the extension of the lateral lines of the existing sidewalk at right angles to the centerline.

(b) Any portion of a roadway at an intersection or elsewhere distinctly indicated for pedestrian crossing by lines or other markings on the surface."

Thus, a crosswalk at an intersection is defined as the extension of the sidewalk or the shoulder across the intersection, regardless of whether it is marked or not. The only way a crosswalk can exist at a midblock location is if it is marked. Most jurisdictions have crosswalk laws that make it legal for pedestrians to cross the street at any intersection, whether marked or not, unless the pedestrian crossing is specifically prohibited.

According to Section 3B.17 of the *Manual on Uniform Traffic Control Devices* (MUTCD), crosswalks serve the following purposes:[2]

> "Crosswalk markings provide guidance for pedestrians who are crossing roadways by defining and delineating paths on approaches to and within signalized intersections, and on approaches to other intersections where traffic stops.
>
> Crosswalk markings also serve to alert road users of a pedestrian crossing point across roadways not controlled by traffic signals or STOP signs.
>
> At intersection locations, crosswalk markings legally establish the crosswalk."

The MUTCD also provides guidance on marked crosswalks, including:

- Crosswalk width should not be less than 1.8 meters (m) (6 feet (ft)).
- Crosswalk lines should extend across the full width of the pavement (to discourage diagonal walking between crosswalks).
- Crosswalks should be marked at all intersections that have "substantial conflict between vehicular and pedestrian movements."
- Crosswalk markings should be provided at points of pedestrian concentration, such as at loading islands, midblock pedestrian islands, and/or where pedestrians need assistance in determining the proper place to cross the street.

The MUTCD further states that: "Crosswalk lines should not be used indiscriminately. An engineering study should be performed before they are installed at locations away from traffic signals or STOP signs."

However, the MUTCD does not provide specific guidance relative to the site condition (e.g., traffic volume, pedestrian volume, number of lanes, presence or type of median) where marked crosswalks should or should not be used at uncontrolled locations. Such decisions have historically been left to the judgment of State and local traffic engineers.

Furthermore, practices on where to mark or not mark crosswalks have differed widely among highway agencies, and this has been a controversial topic among researchers, traffic engineers, and pedestrian safety advocates for many years. More specific safety research and guidelines have been needed on where to mark or not mark crosswalks at uncontrolled locations.

Designated marked or unmarked crosswalks are also required to be accessible to wheelchair users if an accessible sidewalk exists. The level of connectivity between pedestrian facilities is directly related to the placement and consistency of street crossings.

Why Are Marked Crosswalks Controversial?

There has been considerable controversy in the United States about whether marked crosswalks increase or decrease pedestrian safety at crossing locations that are not controlled by a traffic signal or stop sign. Many pedestrians consider marked crosswalks as a tool to enhance pedestrian safety and mobility. They view the markings as proof that they have a right to share the roadway, and in their opinion, the more the better. Many pedestrians do not understand the legal definition of a crosswalk and think that there is no crosswalk unless it is marked. They may also think that a driver can see the crosswalk markings as well as they can, and they assume that it will be safer to cross where drivers can see the white crosswalk lines.

When citizens request the installation of marked crosswalks, some engineers and planners still refer to the 1972 study by Herms as justification for not installing marked crosswalks at uncontrolled locations.[3] That study found an increased incidence of pedestrian collisions in marked crosswalks, compared to unmarked crosswalks, at 400 uncontrolled intersections in San Diego, CA. Questions have been asked about the validity of that study, and the study results have sometimes been misquoted or misused. Some have misinterpreted the results of that study. The study did not conclude that all marked crosswalks are unsafe, and the study also did not include school crosswalks. A few other studies have also tried to address this issue since the Herms study was completed. Some were not conclusive because of their methodology or sample size problems, while others have fueled the disagreements and confusion on this matter.

Furthermore, most of the previous crosswalk studies have analyzed the overall safety effects of marked crosswalks but did not investigate their effects for various numbers of lanes, traffic volumes, or other roadway features. Like other traffic control devices, crosswalks should not be expected to be equally effective or appropriate under all roadway conditions.

Where Are Crosswalks Typically Installed?

The practice of where to install crosswalks differs considerably from one jurisdiction to another across the United States, and engineers have been left with using their own judgment (sometimes influenced by political and/or public pressure) in reaching decisions. Some cities have developed their own guidelines on where marked crosswalks should or should not be installed. At a minimum, many cities tend to install marked crosswalks at signalized intersections, particularly in urban areas where there is pedestrian crossing activity. Many jurisdictions also commonly install marked crosswalks at school crossing locations (especially where adult crossing guards are used), and they are more likely to mark crosswalks at intersections controlled by a stop sign. At uncontrolled locations, some agencies rarely, if ever, choose to install marked crosswalks; other agencies install marked crosswalks at selected pedestrian crossing locations, particularly in downtown areas. Some towns and cities have also chosen to supplement selected marked crosswalks with advance overhead or post-mounted pedestrian warning signs, flashing lights, "Stop for Pedestrians in Crosswalk" signs mounted at the street centerline (or mounted along the side of the street or overhead), and/or supplemental pavement markings.

STUDY PURPOSE AND OBJECTIVE

Many highway agencies routinely mark crosswalks at school crossings and signalized intersections. While questions have been raised concerning marking criteria at these sites, most of the controversy on whether to mark crosswalks has pertained to the many uncontrolled locations in U.S. towns and cities. The purpose of this study was to determine whether marked crosswalks at uncontrolled locations are safer than unmarked crosswalks under various traffic and roadway conditions. Another objective was to provide recommendations on how to provide safer crossings for pedestrians. This includes providing assistance to engineers and planners when making decisions on:

- Where marked crosswalks may be installed.
- Where an existing marked crosswalk, by itself, is acceptable.
- Where an existing marked crosswalk should be supplemented with additional improvements.
- Where one or more other engineering treatments (e.g., raised median, traffic signal with pedestrian signal) should be considered instead of having only a marked crosswalk.
- Where marked crosswalks are not appropriate.

The results of this study should not be misused as justification to do nothing to help pedestrians cross streets safely. Instead, pedestrian crossing problems and needs should be identified routinely, and appropriate solutions should be selected to improve pedestrian safety and access. Deciding where to mark or not mark crosswalks is only one consideration in meeting that objective.

This final report is based on a major study for the Federal Highway Administration (FHWA) on the safety effects of pedestrian facilities. The report titled, "Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Executive Summary and Recommended Guidelines" also was prepared as a companion document.[(4)]

PAST RESEARCH

Studies of the effects of marked crosswalks have yielded contradictory results. Some studies reported an association of marked crosswalks with an increase in pedestrian crashes. Other studies did not show an elevated collision level associated with marked crosswalks, but instead showed favorable changes. As to the negative findings, assertions were made that marked crosswalks somehow induced incautious behavior on the part of pedestrians, triggered perhaps by what they thought the markings signified. The following paragraphs describe the findings of some of these studies.

Crash Studies

An early and oft-quoted study in California performed by Herms investigated pedestrian crash risk at marked and unmarked crosswalks.[(3)] This study evaluated pedestrian crashes at 400 intersections where at least 1 crosswalk was painted and another was not. There are thousands of other intersections in San Diego, CA, where neither crosswalk was painted or both were painted, but those were not included in the Herms study. That study rightly emphasizes the difficulty of "maintaining equivalent conditions" in comparing marked and unmarked crosswalks, and lists 12 factors to try to address such difficulties. Since the study was confined to intersections that had one marked and one unmarked crosswalk across the same main thoroughfare, it is not surprising that the vehicle traffic exposure was quite similar between the marked and unmarked crosswalks. However, pedestrian volume was three times as high on the marked crosswalks as on the unmarked crosswalks. Herms stated:

> "Evidence indicates that the poor crash record of marked crosswalks is not due to the crosswalk being marked as much as it is a reflection on the pedestrian's attitude and lack of caution when using the marked crosswalk."[3]

The Herms study, however, does not say what evidence the author had in mind regarding incautious pedestrian behavior. No behavioral data was presented. Other authors have advanced similar assertions with regard to pedestrian behavior in marked crosswalks.

One of the issues involved in this crosswalk controversy relates to questions on the warrants used in San Diego, CA, to determine where to paint crosswalks. Specifically, the warrant directive for San Diego (January 15, 1962), established a point system calling for painting crosswalks when: (1) traffic gaps were fewer rather than more numerous; (2) pedestrian volume was high; (3) speed was moderate (not low, not high); and (4) other prevailing factors were present, such as previous crashes. Thus, it is possible that crosswalks may have been more likely to be painted in San Diego, CA, where the conditions were most ripe for pedestrian collisions (compared to sites which were unmarked). This could at least partly explain the increase in pedestrian crashes at marked crosswalks in the Herms study. Furthermore, the city of San Diego did not eliminate the use of marked crosswalks at uncontrolled locations based on the results of this study. The study recommended against the indiscriminate use of markings at uncontrolled locations. It should be mentioned that the Herms study did not distinguish whether the results would have differed, for example, for two-lane versus multilane roads, or for low-volume versus high-volume roads.

Gibby et al. later revisited the issue.[5] Their report contains a thorough review of the literature and also includes an analysis of pedestrian crashes at 380 highway intersections in California. These intersections were picked after a detailed, multistep selection process in which more than 10,000 intersections were initially considered, and all but 380 were excluded. Their results showed that pedestrian crash rates at these 380 unsignalized intersections were 2 or 3 times higher in marked than in unmarked crosswalks when expressed as crash rates per unit pedestrian-vehicle volume. This study had the advantage of including a relatively large sample of intersections in cities throughout California, which may have minimized any data bias resulting from crosswalk marking criteria. However, it should be mentioned that, as with the Herms study, the Gibby study also did not determine how the results (between marked and unmarked crosswalks) might have differed for two-lane versus multilane roads, and/or for roads with low average daily traffic (ADT) compared to high ADT.

Other studies have been conducted to address this issue. Gurnett described a project to remove painted stripes from some crosswalks following a bad crash experience.[6] This was a before-after study of three locations that were selected for crosswalk removal because they had a recent bad crash record. After removing the crosswalks, crashes decreased. Such results do not show the effect of removing the paint, but are very likely the result of the well-known statistical phenomenon of regression to the mean. It is also not clear whether pedestrian crossing volumes may have dropped after the marked crosswalks were removed.[6]

Another study of marked crosswalks at unsignalized intersections was reported by the Los Angeles, CA, County Road Department in July 1967.[7] The county reported results of a before-after study of 89 intersections. Painted crosswalks were added at each site, but the basis for selecting those sites was not mentioned. Pedestrian crashes increased from 4 during the before period to 15 in the after period. The before-after design in this study is preferable to a treatment-control model in this instance, and better takes the selection effect into account. All sites that showed crash increases were intersections with an ADT rate above 10,900. Thus, at sites with a lower ADT rate, no change in pedestrian crashes was seen. Also, rear-end collisions increased from 31 to 58 after marked crosswalks were added. The report stated that rear-end collisions increased as traffic volume increased. Nevertheless, the study showed more pedestrian crashes after painting the crosswalks than before for the sites with ADT rates above 10,500. The study could have been enhanced by including an analysis of crashes within a comparison group of unpainted sites during the same time period. It is not clear whether pedestrian volumes may have increased at the crosswalks after they were marked.[7]

In contrast to the studies described above, Tobey et al. reported *reduced* crashes associated with marked crosswalks.[8] They examined crashes at marked and unmarked crosswalks as a function of pedestrian volume (*P*) multiplied by vehicle volume (*V*). When the *P* times *V* product was used as a denominator, crashes at unmarked crosswalks were found to be considerably overrepresented; crashes at marked crosswalks were underrepresented considerably. Communication with the authors indicates that this study included controlled (signalized) as well as uncontrolled crossings. It seems likely, therefore, that more marked crosswalks than unmarked crosswalks were present at controlled crossings, which could at least partially explain the different results compared to other studies. The study methodology was quite useful for determining pedestrian crash risk for a variety of human and locational features. However, the study results were not intended to be used for quantifying the specific safety effects of marked versus unmarked crosswalks for various traffic and roadway situations.[8]

In 1996, Ekman conducted an analysis of pedestrian crashes at zebra crossings compared to crossings with traffic signals and also to crossings with no facilities.[9] Zebra crossings in Sweden (figure 2) consist of high-visibility crosswalk markings on the roadway, accompanied by zebra crossing signs (figure 3). The study included 6 years of collected pedestrian crash data from crossings in five cities in southern Sweden along with pedestrian counts, traffic volume, and other information for each of the three types of pedestrian crossings.

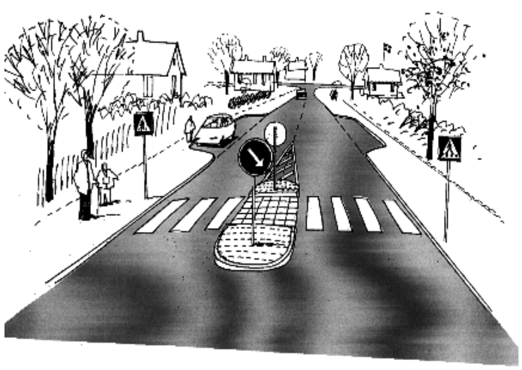


Figure 2. A zebra crossing used in Sweden.

Figure 3. Sign accompanying zebra crossings in Sweden.

The rate of pedestrian crashes was found to be higher (approximately twice as high) at intersections which had zebra crossings, compared to locations that were signalized or had no facilities. Further, pedestrians age 60 and above were most at risk, followed by pedestrians below age 16 (see figure 4). The author also controlled for motor vehicle traffic and found similar results.[9]

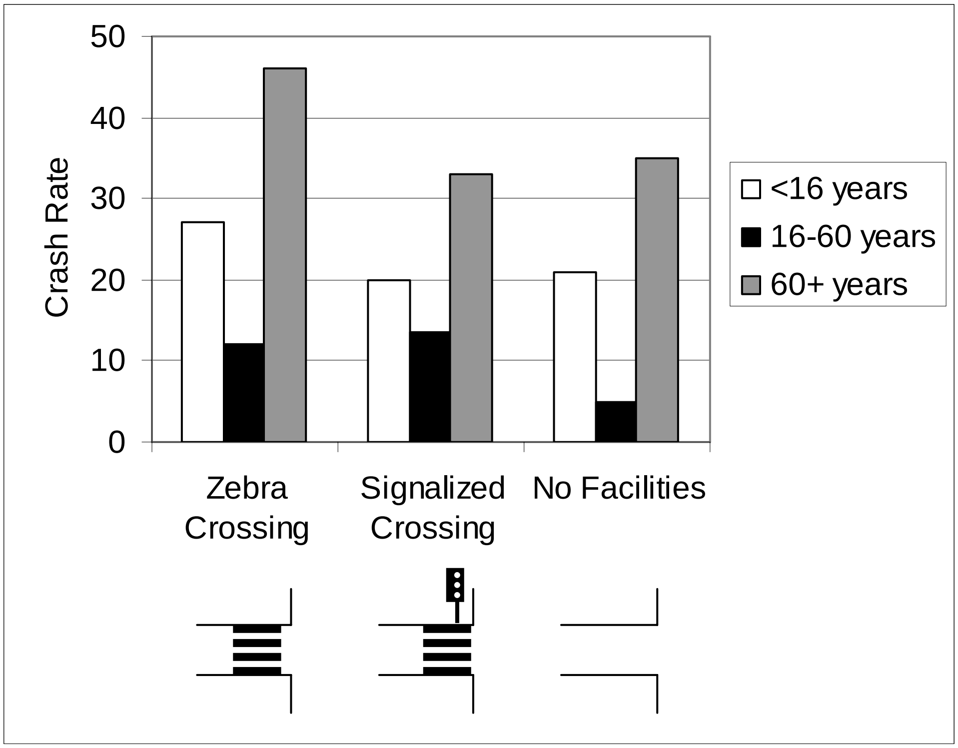


Figure 4. Pedestrian crash rates for the three crossing types by age group.

In a 1999 study involving the relationship between crashes or conflicts and exposure, Ekman and Hyden compared intersections with and without zebra crossings on major streets in the cities of Malmö and Lund, Sweden. Among other conclusions, the study found that “Zebra crossings seem to have higher crash rate than approaches without zebra,” and “The increased crash rate for approaches with zebra crossings is only valid on locations where the car flow is larger than 10 cars per hour.” Conflict rates were about twice as high with zebra crossings compared to crossings with no control. The authors reported that the dataset did not include enough sites with car exposure greater than 250 cars per hour. The study also found that the positive effects of pedestrian refuge islands “seem to be stronger than the negative effect of zebra crossing, at least in the lower region of car exposure.” This finding supports the safety benefit of having a raised pedestrian refuge island at pedestrian crossings.[(10)]

Yagar reported the results of introducing marked crosswalks at 13 Toronto, Canada intersections.[(11)] The basis for selecting the particular intersections was not described. A before-after study was conducted, and it was found that crashes had been increasing during the before period and continued to increase after crosswalks were installed. It is not apparent from the graphs that there was any change in slope associated with the time of painting the crosswalks; it would appear that marking the crosswalks did not have much of an effect on crashes. However, the author points to an increase in tailgating crashes at the intersections after crosswalk painting. He also reports that the increased crashes during the after phase seemed to be entirely explained by an increase in crashes involving out-of-town drivers. Perhaps the increase in crashes by out-of-town motorists was because they were not expecting any change in pedestrian or motorist behavior of the local residents, who may have been more familiar with the new markings. However, no behavioral data was included in the study.

In summary, there are no clear-cut results from the studies reviewed to permit concluding with confidence that either marked or unmarked crosswalks are safer. The selection bias (on where crosswalks are marked) could certainly affect the results of a given study. Units of pedestrian crash experience were also inconsistent from one study to another. Another important question relates to whether analyzing sites separately by site type (e.g., two-lane versus multilane road, high volume versus low volume) would produce different results on the safety effects of marked versus unmarked crosswalks.

Behavioral Studies Related to Marked Crosswalks

In addition to crash-based studies, it is also important to review studies that evaluate the effects of crosswalk marking on pedestrian and motorist behavior. Such review can reveal changes in behavior, which can lead to crashes for different crosswalk conditions. The following paragraphs discuss some of these behavioral studies.

Katz et al. conducted an experimental study of driver and pedestrian interaction when the pedestrian crossed a street.(12) The pedestrians in question were members of the study team, and they crossed a street under a variety of conditions (960 trials). It was found that drivers stop for pedestrians as a function of several variables. Drivers stop more frequently when the vehicle's approach speed is low, when the pedestrian is in a marked crosswalk, when the distance between vehicle and pedestrian is greater rather than less, when pedestrians are in groups, and when the pedestrian does not make eye contact with the driver. Thus, the marked crosswalk is a specific factor in positive driver behavior in this study.

A study by Knoblauch et al. was conducted to determine the effect of crosswalk markings on driver and pedestrian behavior at unsignalized intersections.(13) A before-after evaluation of crosswalk markings was conducted at 11 locations in 4 U.S. cities. The observed behaviors included pedestrian crossing location, vehicle speed, driver yielding, and pedestrian crossing behavior. It was found that drivers approach a pedestrian in a crosswalk somewhat more slowly, and that crosswalk usage increases, after markings are installed. No evidence was found indicating that pedestrians are less vigilant in a marked crosswalk. No changes were found in driver yielding or pedestrian assertiveness as a result of adding the marked crosswalk. Marking pedestrian crosswalks at relatively low-speed, low-volume, unsignalized intersections was not found to have any measurable negative effect on pedestrian or motorist behavior at the selected sites (which were all two- or three-lane roads with speed limits of 56 or 64 kilometers per hour (km/h) or 35 or 40 miles per hour (mi/h)).

In a comparison study to the one discussed above, Knoblauch and Raymond conducted a before-after evaluation of pedestrian crosswalk markings in Maryland, Virginia, and Arizona.(14) Six sites that had been recently resurfaced were selected. All sites were at uncontrolled intersections with a speed limit of 56 km/h (35 mi/h). The before data were collected after the centerline and edgeline delineations were installed but before the crosswalk was installed. The after data were collected after the crosswalk markings were installed. Speed data were collected under three conditions: no pedestrian present, pedestrian looking, and pedestrian not looking. All pedestrian conditions involved a staged pedestrian. The results indicate a slight reduction in vehicle speed at most, but not all, of the sites. Overall, there was a significant reduction in speed under both the no pedestrian and the pedestrian not looking conditions. (Note: This study and the 2001 behavioral study by Knoblauch et al. mentioned above were both conducted as part of the larger FHWA study conducted in conjunction with the current study described here.)

These studies found pedestrian behavior to be, if anything, slightly better in the presence of marked crosswalks compared to unmarked crosswalks. Certainly the results showed no indication of an increase in reckless or incautious pedestrian behavior associated with marked crosswalks. All of the sites used in the Knoblauch studies were two-lane and three-lane roads, and all had speed limits of 56 or 64 km/h (35 or 40 mi/h). No formal behavioral studies were found which have studied pedestrian and motorist behaviors and conflicts on roads with four or more lanes with and without marked crosswalks. Such multilane situations may pose different types of risks for pedestrians, particularly where high traffic volume exists and/or where vehicle speeds are high.

Finally, Van Houten studied factors that might cause motorists to yield for pedestrians in marked crosswalks.[15] He measured several behaviors at intersections in Dartmouth, Nova Scotia, where interventions were introduced sequentially to increase the "vividness" of crosswalks. Researchers added signs, then a stop line, and then amber lights activated by pedestrians and displayed to motorists. The percentage of vehicles stopping when they should increased by up to 50 percent. Conflicts dropped from 50 percent to about 10 percent at one intersection, and from 50 percent to about 25 percent at another. The number of motorists who yielded increased from about 25 percent to 40 percent at one intersection, and from about 35 percent to about 45 percent at another.[15]

Behavioral Studies Related to Crosswalk Signs and Other Treatments

The preceding discussion of the literature has dealt primarily with the safety and behavioral effects of marked versus unmarked crosswalks at uncontrolled intersections. Of course, a wide variety of supplemental measures have been used with or without marked crosswalks at pedestrian crossing locations in the United States. Examples of these treatments include:

- Pedestrian warning signs on the approach and/or at the crossing.
- Advance stop lines with supplemental signs (e.g., "Stop Here for Crosswalk").
- Rumble strips on the approaches to the crosswalk.
- Pedestrian crossing pavement stencils on the approach to the crosswalk.
- In-pavement flashing lights (activated by push-button or by automatic pedestrian detectors).
- Flashing beacons.
- Variations of overhead pedestrian crosswalk signs. Such signs may be warning or regulatory and may be illuminated and/or convey a message when activated (examples of such signs are shown in figures 5–10).
- Crosswalk lighting.
- Raised medians or refuge islands.
- Flat-topped speed humps (sometimes called speed tables) where pedestrians may cross the street on the raised flat top.
- Traffic-calming measures such as curb extensions and lane reductions.
- Various combinations of these and other measures.
- Traffic signals (with pedestrian signals) are sometimes added at pedestrian crossings when warranted.

Numerous research studies have been conducted in the United States and abroad in recent years to evaluate such treatments and/or to summarize research results. Some of these include:

- *A Review of Pedestrian Safety Research in the United States and Abroad.*[16]
- *Pedestrian Safety in Sweden* (www.walkinginfo.org/rd/international.htm).[17]

- *Research, Development, and Implementation of Pedestrian Safety Facilities in the United Kingdom* (www.walkinginfo.org/rd/international.htm).[18]

- *Canadian Research on Pedestrian Safety* (www.walkinginfo.org/rd/international/htm).[19]

- *Pedestrian Safety in Australia* (www.walkinginfo.org/rd/international.htm).[20]

- *Dutch Pedestrian Safety Research Review* (www.walkinginfo.org/rd/inernational.htm).[21]

In addition to these research summaries, several other documents, which describe a wide range of pedestrian and traffic calming measures, include:

- *Pedestrian Facilities User Guide: Providing Safety and Mobility* (www.walkinginfo.org/rd/international.htm).[22]

- *Alternative Treatments for At-Grade Pedestrian Crossings* (http://www.ite.org/bookstore/index.asp).[23]

- *Traffic Calming: State of the Practice* (http://www.ite.org/traffic/tcstate.htm#tcsop).[24]

The study described in this report was primarily intended to compare the safety effects of marked versus unmarked crosswalks at uncontrolled locations. It did not focus on evaluating various signs, traffic calming, or other measures and devices. Instead, several companion studies were conducted as part of the larger FHWA effort, which presents evaluation results of innovative devices. These research reports may be found at www.walkinginfo.org/rd/devices.htm.

Figure 5. High visibility crossing with pedestrian crossing signs in Kirkland, WA.

Figure 6. Experimental pedestrian regulatory sign in Tucson, AZ.

Figure 7. Overhead crosswalk sign in Clearwater, FL.

Figure 8. Overhead crosswalk sign in Seattle, WA.

Figure 9. Example of overhead crosswalk sign used in Canada.

Figure 10. Regulatory pedestrian crossing sign in New York State.

Figures 5–10. Examples of crosswalk signs.[25]

CHAPTER 2. DATA COLLECTION AND ANALYSIS METHODOLOGY

For the purpose of assessing pedestrian safety, an ideal study design would involve removing all crosswalks in several test cities, then randomly assigning sites for crosswalk markings and to serve as unmarked control sites. However, due to liability considerations, it would be impossible to get the level of cooperation needed from the cities to conduct such a study. Also, such random assignment of crosswalk marking locations would result in many crosswalks not being marked at the most appropriate locations.

Given such real-world constraints, a treatment and matched comparison site methodology was used to quantify the pedestrian crash risk in marked and unmarked crosswalks. This study design allowed for selection of a large sample of sites in cities throughout the United States where marked crosswalks and similar unmarked comparison sites were available. At intersections, the unmarked crosswalk comparison site was typically the opposite leg of the same intersection as the selected marked crosswalk site. For each marked midblock crosswalk, a nearby midblock *crossing* location was chosen as the comparison site on the same street (usually a block or two away) where pedestrians were observed to cross. (Even though an unmarked midblock crossing is not technically or legally a crosswalk, it was a suitable comparison site for a midblock crosswalk). The selection of a matched comparison site for each crosswalk site (typically on the same route and very near the crosswalk site) helped to control for the effects of vehicle speeds, traffic mix, and a variety of other traffic and roadway features.

A before-after study design was considered impractical because of regression-to-the-mean problems, limited sample sizes of new crosswalk installations, and other factors. A total of 1,000 marked crosswalk sites and 1,000 matched unmarked (comparison) crossing sites in 30 cities across the United States (see figure 11) were selected for analysis. In this study, no attempt was made to actually paint any of the 1,000 unmarked crosswalks to determine any crash effects in a before and after study. Instead, a separate (companion) study was conducted to monitor the effects of marking crosswalks on pedestrian and motorist behaviors. These study results are discussed in chapter 3 of this report.

Figure 11. Cities and States used for study sample.

Test sites were chosen without any prior knowledge of their crash history. School crossings were not included in this study because the presence of crossing guards and/or special school signs and markings could increase the difficulty of quantifying the safety effects of crosswalk markings.

Test sites were selected from the following cities:

- East: Cambridge, MA; Baltimore, MD (city and county); Pittsburgh, PA; Cleveland, OH; Cincinnati, OH.
- Central: Kansas City, MO; Topeka, KS; Milwaukee, WI; Madison, WI; St. Louis, MO (city and county).
- South: Gainesville, FL; Orlando, FL; Winter Park, FL; New Orleans, LA; Raleigh, NC; Durham, NC.
- West: San Francisco, CA; Oakland, CA; Salt Lake City, UT; Portland, OR; Seattle, WA.
- Southwest: Austin, TX; Ft. Worth, TX; Phoenix, AZ; Scottsdale, AZ; Glendale, AZ; Tucson, AZ; Tempe, AZ.

Detailed information was collected at each of the 2,000 sites, including pedestrian crash history (average of 5 years per site), daily pedestrian volume estimates, ADT volume, number of lanes, speed limit, area type, type of median, type and condition of crosswalk marking patterns, location type (midblock or intersection), and other site characteristics. It was recognized that pedestrian crossing volumes would likely be different in marked and unmarked crosswalks. This study design involved collecting pedestrian volume counts at each of the 2,000 sites, and controlled for differences in pedestrian crossing exposure. The study computed pedestrian crashes per million crossings to normalize the crash data for pedestrian crossing volumes, as described below in more detail.

All of the 1,000 marked crosswalks had one of the marking patterns shown in figure 12 (i.e., none had a brick pattern for the crosswalk). Of the 2,000 crosswalks, 1,622 (81.2 percent) were at intersections; the others were at midblock. Very few of the marked crosswalks had any type of supplemental pedestrian warning signs. While not much information currently exists on the safety effects of various types of warning signs (under various conditions), a behavioral evaluation of several innovative signs performed in 2000 by Huang et al. may be found at www.walkinginfo.org/rd.[25] Furthermore, none of the test sites had traffic-calming measures or special pedestrian devices (e.g., in-pavement flashing lights). Estimates of daily pedestrian volumes at each crosswalk site and unmarked comparison site were determined based on pedestrian volume counts at each site, which were expanded to estimated daily pedestrian volume counts based on hourly adjustment factors. Specifically, at each of the 2,000 crossing locations, trained data collectors conducted onsite counts of pedestrian crossings and classified pedestrians by age group based on observations.

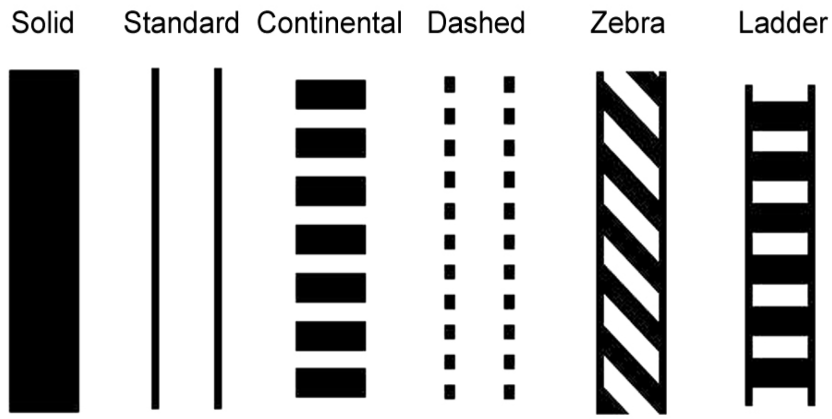


Figure 12. Crosswalk marking patterns.

Pedestrian counts were collected simultaneously for 1 hour at each of the crosswalk and comparison sites. Full-day (8- to 12-hour) counts were conducted at a sample of the sites and were used to develop adjustment factors by area type (urban, suburban, fringe) and by time of day. The adjustment factors were then used to determine estimated daily pedestrian volumes in a manner similar to that used by many cities and States to expand short-term traffic counts to average annual daily traffic (AADT). Performing the volume counts simultaneously at each crosswalk site and its matched comparison site helped to control for time-related influences on pedestrian exposure. Further details of the data collection methodology are given in appendix A.

STATISTICAL ANALYSIS

Analysis Approach

This study was structured to address a variety of questions related to crosswalks and pedestrian crashes. The primary analysis question was, "What are the safety effects of marked versus unmarked crosswalks?"

Several other analysis questions needed to be answered as well, including:

- What traffic and roadway features have a significant effect on pedestrian cashes? Specifically, how are pedestrian crashes affected by traffic volume, pedestrian volume, number of lanes, speed limit, presence and types of median, area type, type of crosswalk marking, condition of marked crosswalks, and other factors?

- Do pedestrian crashes differ significantly in different cities and/or regions of the country?

- How does pedestrian crash risk differ by pedestrian age group?

The amount of pedestrian crash data varied somewhat from city to city and averaged approximately 5 years per site (typically from about January 1, 1994 to December 31, 1998). Police crash reports were obtained from each of the cities except for Seattle, WA, (where detailed computerized printouts were obtained for each crash). Crashes were carefully reviewed to assign crash types to ensure accurate matching of the correct location and to determine whether the crash occurred at the crossing location (i.e., at or within 6.1 m (20 ft) of the marked or unmarked crossing of interest).

Standard pedestrian crash typology was used to review police crash reports and determine the appropriate pedestrian crash types (e.g., multiple threat, midblock dartout, intersection dash), as discussed later in this report. All treatment (crosswalk) and comparison sites were chosen without prior knowledge of crash history. All sites used in this study were intersection or midblock locations with no traffic signals or stop signs on the main road approach (i.e., uncontrolled approaches). This study focused on pedestrian safety and, therefore, data were not collected for vehicle-vehicle or single-vehicle collisions, even though it is recognized that marking crosswalks may increase vehicle stopping, which may also affect other collision types.

The selected analysis techniques were deemed to be appropriate for the type of data in the sample. Due to relatively low numbers of pedestrian crashes at a given site (many sites had zero pedestrian crashes in a 5-year period), Poisson modeling and negative binomial regression were used to analyze the data. Using these analysis techniques allowed determination of statistically valid safety relationships. In fact, there were a total of 229 pedestrian crashes at the 2,000 crossing sites over an average of 5 years per site. This translates to an overall average of one pedestrian crash per crosswalk site every 43.7 years.

While this rate of pedestrian crashes seems small on a per-site basis, it must be understood that many cities have hundreds or thousands of intersections and midblock locations where pedestrians regularly cross the street. Considering that pedestrian collisions with motor vehicles often result in serious injury or death to pedestrians, it is important to better understand what measures can be taken by engineers to improve pedestrian safety under various traffic and roadway conditions.

All analyses of crash rates at marked and unmarked crosswalks took into account traffic volume, pedestrian exposure, and other roadway features (e.g., number of lanes). To supplement the pedestrian crash analysis, a corresponding study was conducted on pedestrian and driver behavior before and after marked crosswalks were installed at selected sites in California, Minnesota, New York, and Virginia, as discussed earlier.[13,14]

Statistical Techniques

The Poisson and negative binomial regression modeling were conducted in two ways in terms of how the comparison sites were handled. These were:

- Including all of the comparison (unmarked) crosswalk sites in one group and all of the treated (marked) crosswalks in another group. In other words, no direct matching of sites was used in the modeling.

- Analyzing 1,000 site pairs; each pair had a marked crosswalk and an unmarked, matched comparison site.

Analyses were conducted using both assumptions to insure that the results were not influenced merely by the manner in which the matching was conducted.

The analyses revealed very similar results using either of the assumptions listed above in terms of:

- The variables found to be significantly related to pedestrian crashes.

- The individual and interaction effects.

- The magnitude of the effects of each traffic and roadway variable on pedestrian crashes, including the effect of marked versus unmarked crosswalks.

In short, using either analysis approach—grouping comparison sites or using an analysis that matches marked and unmarked sites—produced nearly identical results. The discussion below includes results of both analysis approaches.

Estimation of Daily Pedestrian Volume

At each of the 2,000 crossing sites, at least 1 hour-long count of pedestrian street crossings was conducted. Based on the time of day of the count, an expansion factor was used to compute an approximate pedestrian ADT. At a given observation site, i, a count n_i is made of pedestrians crossing the street during some interval of time T_i. Now, from a standard pedestrian volume by time of day distribution, the proportion p_i of daily pedestrian traffic expected during T_i can be determined. If $n_i \neq 0$, an estimate of the daily total pedestrian volume is made by, $N_i = n_i/p_i$.

This estimate has the property that if N_i was known, then the estimated pedestrian volume during the interval T_i would be $N_i p_i = n_i$, the observed number.

A detailed discussion of how pedestrian ADTs were determined based on short-term pedestrian crossing counts is given in appendix A.

Calculation of Pedestrian Crash Rates

Assuming that motor vehicle volumes, speeds, and other site features remain constant, it is reasonable to expect that the number of pedestrian crashes will increase as the number of pedestrians crossing the street (pedestrian exposure) increases. When comparing sites to see which has the greatest risk of a pedestrian crash, it is necessary to control for the number of pedestrians. The pedestrian crash rate is a more appropriate measure of safety than the total number of pedestrian crashes for comparing the relative safety of marked and unmarked crosswalks, particularly since pedestrian crossing volumes differ at marked and unmarked crosswalks. In this study, crash rates were calculated in terms of crashes per million pedestrian crossings. For example, if an average of 1,000 pedestrians cross an intersection every day, then there will be 365,000 (or 0.365 million) pedestrian crossings in a year. The number of pedestrian crashes in a year is then divided by 0.365 million times the number of years to get the pedestrian crash rate.

Determination of Crash-Related Variables

The following analysis was conducted to determine which traffic and roadway variables have a significant effect on pedestrian crashes. Table 1 shows some summary values of pedestrian volumes and crashes for marked and unmarked crosswalks categorized by number of lanes.

For each marked crosswalk, a closely matched unmarked comparison site was chosen—usually a nearby site on the same street. Quite often, the comparison site was the opposite approach to the same intersection (on the same road). As a result of this matching, the distributions of site characteristics, including traffic volumes, should be essentially the same for marked and unmarked sites. Pedestrian volumes were recorded at a marked crosswalk and its matched unmarked location at essentially the same time of day and for an equal period of time. Thus, pedestrian volumes were free to vary between marked and unmarked sites but were collected in such a way as to represent equal proportions of expected daily pedestrian traffic at the respective locations.

Table 1. Pedestrian crashes and volumes for marked and unmarked crosswalks.

No. of Lanes	Type	Sites	Ped. Vol.*	Avg. Ped. ADT/site	Number of Ped. Crashes	Avg. Yrs.**
2	Marked	456	176,345	387	37	4.81
	Unmarked	458	104,922	229	23	4.81
3 or 4	Marked	401	104,237	260	94	4.59
	Unmarked	395	37,941	96	12	4.60
5 or more	Marked	143	31,266	219	57	4.65
	Unmarked	147	11,955	81	6	4.60
All	Marked	1,000	311,848	312	188	4.70
	Unmarked	1,000	154,818	155	41	4.70

*Ped. Vol. = Sum of the pedestrian ADT at sites within a given grouping (by number of lanes).
**Avg. Yrs. = Average number of years of crash data per site.

The pedestrian ADT per site was 312 at marked crosswalks and 155 at unmarked crosswalks, as shown in table 1. Thus, 66.8 percent of this pedestrian volume occurred at marked crosswalk sites. A total of 229 pedestrian crashes were recorded at these 2,000 sites over a period of roughly 5 years. If marked and unmarked crosswalks were equally safe (or unsafe), then given that 229 crashes occurred, it would be expected that 66.8 percent of them (153 crashes) would have occurred at marked crosswalk sites. This expected number is considerably smaller than the actual number of 188 observed at marked crosswalks. Under the hypothesis of equal safety, and conditional on 229 total crashes, the probability of observing 188 or more crashes at the marked sites can be obtained from the binomial distribution with parameters, $\underline{p} = .668$ and $\underline{n} = .229$, as

$$P\,(A \geq 188 \mid \underline{p}, \underline{n}) = .000002 \tag{1}$$

Thus, the hypothesis of equal safety across the entire set of sites would be rejected.

On the other hand, there may be subsets defined by various site characteristics where such a hypothesis would not be rejected. For example, consider the first two rows of table 1, which refer to sites on streets having two lanes. At these sites, 62.7 percent of the pedestrian volume occurred on marked crosswalks. Of the 60 crashes that occurred at these sites, 37.6 crashes would be expected at the marked crosswalk sites compared with the observed count of 37. Clearly, the hypothesis of equal safety could not be rejected for this subset of sites. In other words, for the two-lane road sites in the database, there was no significant difference in pedestrian crashes between marked and unmarked crosswalks.

From the rows of table 1 corresponding to three- or four-lane roads and roads with five or more lanes, the observed crash frequencies for the marked crosswalk sites are 94 and 57, respectively. Both totals considerably exceed the expected values of 77.6 and 45.7 based on proportions of pedestrian exposure at these sites. The probabilities of observing values this extreme by chance are:

$$P\,(A \geq 94 \mid p_1 = .7324,\ n_1 = 106) = .0001 \tag{2}$$

and

$$P\,(A \geq 57 \mid p_2 = .7256,\ n_2 = 63) = .0005 \tag{3}$$

In the expressions given above, the parameters p_1 and p_2 represent proportions of pedestrian volumes at marked sites adjusted for slight differences in exposure times over which crash data were obtained. These results suggest that, in general, marked crosswalks are less safe than unmarked crosswalks on streets having more than two lanes, but that the two types do not differ significantly on streets with two lanes. Note that the analysis described above did not require adjustment for motor vehicle volume, since matched pairs of marked and unmarked sites typically were selected at or near the same intersection where vehicle volumes were similar.

To investigate the relationship between other factors and combinations of factors on crosswalk pedestrian crashes, generalized linear regression models were fit to the data to predict crashes as functions of these variables. Consider a model based on pedestrian volumes (ADP); traffic volumes (ADT); and two indicator variables, one which indicates one or two travel lanes (L_2), and the other which indicates three or four travel lanes (L_4). The resulting model has the form

$$E\,(\text{Accs}_i) = \text{yrs}_i e^{\beta_0}(\text{ADP}_i)^{\beta_1}(\text{ADT}_i)^{\beta_2}\, e^{\beta_2 L_{2i}}\, e^{\beta_2 L_{4i}} \tag{4}$$

where E (Accs$_i$) is expected pedestrian crashes at site i, yrs$_i$ is the number of years over which crash data was available for site i, and β_0, $\beta_{1,\ldots,}$ β_4 are parameters to be estimated. Models of this form were fit to data from marked and unmarked crosswalks separately. The models were fit by maximum likelihood methods using Procedure for General Models (PROC GENMOD) software, as developed by the SAS Institute. Crashes were assumed to follow a negative binomial distribution.

Parameter estimates for these basic models are shown in table 2.

Table 2. Parameter estimates for basic marked and unmarked crosswalk models.

Parameter	Marked Crosswalks			Unmarked Crosswalks		
	Estimate	S.E.*	*p*-Value	Estimate	S.E.*	*p*-Value
Constant (β_0)	-14.55	1.95	< .0001	-10.25	2.72	.0002
ADP (β_1)	.381	.065	< .0001	.602	.134	< .0001
ADT (β_2)	1.006	.184	< .0001	.304	.258	.2388
L_2 (β_3)	-.599	.328	.0678	-.066	.592	.9115
L_4 (β_4)	.075	.247	.7608	-.208	.553	.7076

*S.E. = Standard Error

For marked crosswalks, the results in table 2 show that expected crashes increased to a significant degree with both increasing pedestrian volume and increasing traffic volumes, with a much steeper increase for traffic volume. The lane variables compare two-lane roads with roads having five or more lanes, and three- or four-lane roads with roads having five or more lanes. The two-lane variable is marginally significant, while the three- or four-lane variable is not. The overall lanes effect (not shown) is significant (*p*-value of .0262). In subsequent models, a two-level lanes effect comparing two lanes with three or more is used. This variable is usually significant at a level of about .02.

The results for unmarked crosswalks show the only statistically significant effect to be for pedestrian volume. Thus, expected crashes on unmarked crosswalks increased consistently with increasing pedestrian volumes (at a somewhat higher rate than that at marked crosswalks), but did not change consistently with increasing traffic volumes or with number of lanes. These results suggest that multilane streets with low traffic volumes might represent another subset of the data where marked and unmarked crosswalks might not differ significantly with respect to safety. This issue is addressed in more detail later in the report.

In addition to the variables included in the models presented above, data were available for several other factors potentially associated with crosswalk safety. These included:

- Speed limit.
- Location of crosswalk (intersection or midblock).
- Presence and type of median.
- Type of crosswalk marking (marked only).

Neither speed limit nor crosswalk location (intersection or midblock) had a significant effect in the models for marked or unmarked crosswalk crashes. Initially, three types of medians were compared with no median. These were:

- Raised medians.
- Painted medians.
- Two-way left turn lanes.

Several specific types of crosswalks were represented in the data, but the primary comparison came down to a comparison between the standard markings (two parallel lines) versus designs with more markings (e.g., continental or ladder patterns shown in figure 12).

In attempting to estimate these more detailed models, it was also a concern to consider effects due to specific locations (i.e., cities, States, regions) from which the data were obtained since crashes, types of medians and crosswalks, and other variables were not uniformly distributed across these locations. To this end, two sets of regions were identified (North-South and East-Midwest-West), and class variables indicating these regions were included in the models. A second approach was to estimate a model using data from all locations, then to re-estimate the model while omitting the data from each of the eight cities where the most data had been obtained, one step at a time, to see how the estimates changed. These eight cities and the total number of observation sites at each are listed below.

- Seattle, WA (204).
- San Francisco, CA (182).
- New Orleans, LA (160).
- Milwaukee, WI (136).
- Cleveland, OH (110).
- Cambridge, MA (92).
- Oakland, CA (90).
- Gainesville, FL (90).

A few iterations of this process resulted in a model for marked crosswalk crashes summarized in table 3. The model for table 3 contains no variable pertaining to crosswalk type, a single variable indicating a raised median as opposed to no median or another median type, and another variable indicating the western region of the country as opposed to the East or Midwest.

In some preliminary models, there was an indication that the crosswalk types with more markings were associated with slightly lower crash rates than the standard type. These results were not consistent across models and became quite nonsignificant when regional variables were included. Similarly, preliminary models indicated that raised medians were marginally better (associated with lower crash rates) than crosswalks having no median or painted medians, while two-way left turn lanes were significantly worse than the other types. With the addition of the East-Midwest-West regional variables, the two-way left turn lane effect became nonsignificant, and the raised median effect became more significant. All of the two-way left turn lanes in the study sample were in the western region. The two-way left turn lanes did not account for the estimated West effect, however, since this estimate remained virtually unchanged when the data from the two-way left turn lane sites were deleted from the model.

Table 3. Results for a marked crosswalk pedestrian crash model.

Parameter	Estimate	S.E.*	95% Confidence Limits	*p*-Value
Intercept	−15.09	1.65	(−18.33, −11.86)	< .0001
Log (ADP)	.33	.06	(.20, .45)	< .0001
Log (ADT)	.99	.17	(.65, 1.19)	< .0001
Two lanes	−.68	.26	(−1.19, -.18)	.0074
Raised median	−.58	.27	(−1.12, −.04)	.0338
West region	.77	.19	(.40, 1.14)	< .0001
Dispersion	1.48	.41	(.85, 2.55)	–

*S.E. = Standard Error

The North-South regional variable was not statistically significant. East-to-West effects were modeled as two variables, one comparing West to East, and the other comparing Midwest to East. The West-to-East comparison was significant, while the Midwest-to-East comparison was not. These variables were then collapsed to a single variable contrasting West with Midwest and East combined, which is the form used in the model of table 3. The apparent effect due to the western region was investigated further to see if this effect could be attributed to differing distributions of speed limits and/or numbers of lanes. This did not prove to be the case.

Table 4 shows estimates of the same model parameters on the data subsets obtained by leaving out the data from each of the major cities. In general, the estimates are quite consistent across the subsets. All estimates listed were statistically significant at a .05 level with the exception of the two marked with an asterisk. These were the raised median effects on the datasets that omitted data from New Orleans, LA, and from Milwaukee, WI. The *p*-values for these estimates were .10 and .08, respectively.

Results from the more detailed crash modeling on unmarked crosswalks are presented in tables 5 and 6. In contrast to the results of table 2, table 5 shows that when a variable indicating the presence of a median was included in the model, the effect of traffic volume (ADT) became statistically significant. As with marked crosswalks, various median types were also considered; in this case, a variable indicating a median of any type versus no median was the most relevant characterization. For unmarked crosswalks, the East, Midwest, and West comparisons showed the eastern region to have significantly lower crash rates than either the West or Midwest. Thus, a two-level variable contrasting east with the other two regions was used. The North-South comparison was again not significant.

Table 4. Parameter estimates for marked subset models.

Parameters	Estimates on Subsets							
	Seattle	San Francisco	Oakland	New Orleans	Milwaukee	Cleveland	Gainesville	Cambridge
Intercept	−15.16	−15.22	−15.07	−14.91	−15.52	−14.97	−14.99	−15.54
Log (ADP)	.32	.34	.36	.31	.34	.30	.34	.34
Log (ADT)	1.01	1.00	.97	.95	1.04	1.00	.98	1.05
Two lanes	−.68	−.77	−.69	−.96	−.64	−.69	−.65	−.53
Raised median	−.59	−.71	−.59	−.49*	−.50*	−.60	−.58	−.60
Western region	.86	.75	.58	.87	.71	.77	.70	.70

*Not statistically significant at .05 level.

Table 5. Results for an unmarked crosswalk model.

Parameter	Estimate	S.E.*	95% Confidence Limits	*p*-Value
Intercept	−12.11	2.59	(−17.18, −7.04)	< .0001
Log (ADP)	.64	.13	(.37, .90)	< .0001
Log (ADT)	.55	.26	(.04, 1.05)	.0319
Median	−1.27	.45	(−2.14, −.39)	.0047
Eastern region	−1.31	.48	(−2.25, −.38)	.0060
Dispersion	1.18	1.30	(.14, 10.23)	–

*S.E. = Standard Error

Table 6 shows the estimates of these model parameters were again consistent across the eight data subsets. The estimates marked with an asterisk (which were not significant at a .05 level) were the ADT effect on the subset with Seattle, WA, data omitted, and the ADT effect and eastern region effects on the subset with New Orleans, LA, data omitted. The *p*-values for these estimates were .06 in each case.

Table 6. Parameter estimates for unmarked subset models.

Parameters	Estimates on Subsets							
	Seattle	**San Francisco**	**Oakland**	**New Orleans**	**Milwaukee**	**Cleveland**	**Gainesville**	**Cambridge**
Intercept	−11.19	−12.43	−11.89	−11.80	−11.92	−12.72	−11.94	−12.48
Log (ADP)	.56	.69	.64	.52	.64	.69	.66	.65
Log (ADT)	.48*	.54	.52	.54*	.52	.58	.52	.58
Median	−1.24	−1.17	−1.17	−1.07	−1.25	−1.16	−1.24	−1.30
Eastern region	−1.28	−1.23	−1.25	−.93*	−1.56	−1.29	−1.03	1.03

* Not statistically significant at .05 level.

While the models presented above examine the effects of medians, crosswalk designs, and other factors on pedestrian crashes, the primary factors associated with these crashes were shown to be pedestrian volumes and traffic volumes. Analyses based on the data shown in table 1 indicated no significant difference in the safety of marked and unmarked crosswalks on streets having two or fewer lanes, while marked crosswalks were less safe overall on multilane roads. The models suggest a further examination of multilane roads as a function of varying traffic volumes and the presence of raised medians.

Table 7 shows pedestrian volumes, crashes, and average exposure years for a number of categories defined by number of lanes, traffic volumes, and median type. Using the same approach as for table 1, a marked crosswalk exposure proportion, p_{mi}, was computed for category *i*, as

$$P_{mi} = \frac{X_{mi}}{X_{mi} + X_{umi}} \qquad (5)$$

where

$$X_{mi} = \sum_{S=1}^{S_i} (\text{marked pedestrian volume})_s X \text{ years} \qquad (6)$$

where the sum extends over all sites (S) in category *i*, X_{mi} is the total exposure for marked crosswalks in category *i*, and X_{umi} is similarly defined as the total exposure for unmarked crosswalks in category *i*.

Table 7. Pedestrian crashes and volumes for marked and unmarked crosswalks.

Lanes	Median	Traffic Volume	Type	Sites	Pedestrian Volume	Crashes	Avg. Yrs.*
Two	None	≤ 8,000	Marked	248	110,697	15	4.85
			Unmarked	252	67,793	10	4.86
Two	None	> 8,000	Marked	199	62,530	19	4.74
			Unmarked	200	35,957	13	4.75
Multi	No raised median	≤ 3,000	Marked	10	1,446	0	3.80
			Unmarked	13	998	0	4.08
Multi	No raised median	3,000–6,000	Marked	33	6,382	3	4.58
			Unmarked	29	3,298	1	4.48
Multi	No raised median	6,000–9,000	Marked	37	20,608	0	4.43
			Unmarked	39	5,397	2	4.49
Multi	No raised median	9,000–12,000	Marked	47	23,024	12	4.87
			Unmarked	52	6,721	4	4.90
Multi	No raised median	12,000–15,000	Marked	76	20,719	23	4.82
			Unmarked	73	7,825	2	4.79
Multi	No raised median	> 15,000	Marked	210	39,835	91	4.57
			Unmarked	207	12,700	6	4.57
Multi	With raised median	≤ 9,000	Marked	30	5,024	2	4.87
			Unmarked	23	1,182	0	4.83
Multi	With raised median	9000–15,000	Marked	22	4,924	3	4.18
			Unmarked	25	1,671	0	4.28
Multi	With raised median	> 15,000	Marked	88	16,659	20	4.60
			Unmarked	87	11,276	3	4.56

*Avg. Yrs. = Average number of years of crash data per site.

Then conditional on total crashes, N_i in category *i*, expected marked crosswalk crashes under the hypothesis of equal safety were estimated as $\hat{A}_{mi} = N_i\, p_{mi}$. The probability under this hypothesis of observing as many or more crashes in marked crosswalks as actually occurred was obtained from the binomial distribution with parameters p_i and N_i. Table 8 lists these quantities for the various crosswalk categories.

The results in table 8 suggest that on two-lane roads, multilane roads without raised medians and traffic volumes below 12,000 ADT, and multilane roads having raised medians and traffic volumes below 15,000 ADT, the hypothesis of equal safety for marked and unmarked crosswalks cannot be rejected.

In other words, there was no significant effect of marked versus unmarked crosswalks on pedestrian crashes under the following conditions:

- Two-lane roads.
- Multilane roads without raised medians and with ADTs below 12,000.
- Multilane roads with raised medians and with ADTs below 15,000.

For multilane roads with ADTs above these values, there was a significant increase in pedestrian crashes on roads with marked crosswalks, compared to roads with unmarked crosswalks (after controlling for traffic ADT and pedestrian ADT).

Table 8. Crashes, exposure proportions, expected crashes, and binomial probabilities for categories of marked crosswalks.

Number of Lanes	Median Type	Traffic Volume (ADT)	A_m	p_m	$E(A_m)$	$P(a \geq A_m)$
Two	–	$\leq$ 8,000	15	.6173	15.43	.6541
Two	–	> 8,000	19	.6382	20.42	.7631
Multi	Not raised	$\leq$ 3,000	0	.6443	0	–
Multi	Not raised	3,000–6,000	3	.6612	2.64	.8529
Multi	Not raised	6,000–9,000	0	.7985	1.60	1.00
Multi	Not raised	9,000–12,000	12	.7741	12.39	.7149
Multi	Not raised	12,000–15,000	23	.7383	18.46	.0242
Multi	Not raised	> 15,000	91	.7535	73.08	.000002
Multi	Raised	$\leq$ 9,000	2	.8035	1.61	.6456
Multi	Raised	9,000–15,000	3	.7500	2.25	.4219
Multi	Raised	$\geq$ 15,000	20	.5919	13.61	.0041

p_m= Proportion of pedestrian exposure at marked crosswalks.
A_m = Actual number of pedestrian crashes at the marked crosswalks.
$E(A_m)$ = Estimated (predicted) number of pedestrian crashes at marked crosswalks.
$P(a \geq A_m)$ = Binomial probabilities.

Comparisons of Pedestrian Age Distribution Effects

Each pedestrian in both the crash and exposure samples was classified into one of seven age categories: 12 and under, 13–18, 19–25, 26–35, 36–50, 51–64, and 65 and over. Across the entire set of sites, the two age distributions differed substantially, with a considerably higher proportion of young adults (19–35) in the exposure sample (compared to other age groups), and a much higher proportion of the oldest age group in the crash sample. The difference was statistically significant, χ^2_{6df} = 216.86, $\underline{p}$ = .001.

The data were then partitioned into four subsets determined by marked or unmarked crosswalks on streets having two lanes or having three or more lanes. The same general pattern of the exposure and crash age distributions tended to hold on the subsets. In particular, the crash distribution tended to always be higher for the oldest pedestrian group. The relatively small sample sizes of crashes in some of the subsets necessitated combining some of the age categories to obtain a valid statistical comparison of the distributions.

Marked crosswalks on two-lane roads. There were 33 crashes in this subset. With seven age categories, several cells had expected counts of fewer than five, so the two youngest and the two oldest age groups were combined. It might be noted, however, that 7 of the 33 crashes (21.2 percent) involved pedestrians in the 65-and-over age group, compared to 3.4 percent in the exposure sample. The five-category collapsed distributions differed significantly (χ^2_{4df}= 11.00, $\underline{p}$ = .027). Of the crash-involved pedestrians, 30.3 percent were in the 51-and-over age category, compared to 13.2 percent in the exposure sample.

Unmarked crosswalks on two-lane roads. Only 21 pedestrian crashes occurred in this subset. Again, five-category age distributions were used for the statistical test. While the percentage of crash-involved pedestrians in the oldest age category (51 and older) was higher than that of the exposure sample (19.1 percent versus 10.8 percent), the distributions overall did not differ significantly (χ^2_4 = 4.40, $\underline{p}$ = 0.354).

Marked crosswalks on multilane roads. Nearly 70 percent of the pedestrian crosswalk crashes occurred in this subset. Comparison of the seven-category age distributions was quite similar to that of the overall samples, with the proportion of young adults being lower in the crash sample and the proportion in the 65+ age group being much higher in the crash sample (18.1 percent versus 2.2 percent. The distributions differed significantly ($\chi^2_{6df} = 166.88$, $p = .001$).

Unmarked crosswalks on multilane roads. Only 16 pedestrian crashes occurred at unmarked crosswalks on multilane roads, 6 of which involved pedestrians 51 years old or older. A simple comparison of this age category versus younger pedestrians between the two samples yielded a significant result ($\chi^2_{1df} = 18.48$, $p = .001$). There were 37.5 percent of crashes involving pedestrians 51 and older in the crash sample compared with 8.1 percent of this age group in the exposure sample.

The multilane marked crosswalk subset was further subdivided on the basis of traffic volume (ADT). In the subset with ADT $\leq$ 15,000, there were 39 pedestrian crashes; 10 (25.6 percent) of these involved pedestrians more than 50 years old. Only 13.9 percent of the exposure sample was over 50. A one-degree-of-freedom chi-square test indicated a significant difference ($\chi^2_{1df} = 4.51$, $p = .034$).

Lowering the ADT cutoff to 12,000 reduced the size of the crash sample to 15. The percentages of pedestrians over 50 in the two samples were essentially unchanged (26.7 percent versus 13.9 percent), but with the smaller sample size the difference was no longer significant ($\chi^2_{1df} = 2.04$, $p = .1540$).

In summary, older pedestrians were more at risk than younger pedestrians on virtually all types of crosswalks. This difference seemed most pronounced for marked crosswalks on multilane roads with high traffic volumes (ADT above 12,000), where crash occurrence was highest.

COMPARISONS OF CROSSWALK CONDITIONS

Data were collected on the condition of marked crosswalks. Conditions were coded as E (excellent), G (good), F (fair), and P (poor). This variable was entered as a class variable in the model for crashes on marked crosswalks to assess its effect on crashes. The estimated effect was not statistically significant ($p = .1655$).

Furthermore, there is no assurance that the condition of the crosswalk markings was consistent over the data collection period.

Pedestrian Crash Severity on Marked and Unmarked Crosswalks

Overall, crashes tended to be more severe in marked crosswalks on multilane roads, but sample sizes were too small to draw any firm conclusions in that regard. In particular, there were six fatal crashes in marked crosswalks and none in unmarked crosswalks. The fatal crashes all occurred on multilane roads with traffic volumes greater than 12,000 ADT (5 with ADT > 15,000). Crash severity distributions did not differ significantly between marked and unmarked crosswalks on two-lane roads, based on a χ^2-statistic comparing A or B level injury crashes with lesser or no injuries ($\chi^2_{1df} = .268$, $p = .604$). Similarly, on multilane roads with ADT < 12,000, the χ^2-statistic and p-value ($\chi^2_{1df} = .210$, $p = .647$) showed no significant difference.

FINAL PEDESTRIAN CRASH PREDICTION MODEL

Previous models shown in this report used subgroups of the 2,000 crosswalks and modeled marked and unmarked separately. A final model (which incorporates the aforementioned results) also was fitted to all 2,000 crosswalks, and it includes direct correlation or matching of marked and unmarked crosswalks. To develop the final model form, generalized estimating equations (GEEs) were used, since they provide a practical method to analyze correlated data with reasonable statistical efficiency. PROC GENMOD uses GEE and permits the analysis of correlated data. Another feature of the final model is that the distribution of pedestrian crashes at a crosswalk is assumed to follow a negative binomial distribution. The negative binomial is a distribution with an additional parameter (*k*) in the variance function. PROC GENMOD estimates *k* by maximum likelihood. (Refer to McCullagh and Nelder (chapter 11),[26] Hilbe,[27] or Lawless[28] for discussions of the negative binomial distribution.)

The final model is a negative binomial regression model that was fitted with the observed number of pedestrian crashes as the dependent measure. A negative binomial model is an extension of traditional linear models that allows the mean of a population to depend on a linear predictor through a nonlinear link function and allows the response probability distribution to be a negative binomial distribution. PROC GENMOD is capable of performing negative binomial regression GENMOD using GEE methodology.[29]

The final model uses the observed number of pedestrian crashes at a crosswalk as the dependent measure. The independent measures are estimated average daily pedestrian volume (pedestrian ADT), average daily traffic volume (traffic ADT), an indicator variable for marked crosswalks (C_M); two indicator variables for number of lanes (one that indicates two travel lanes, L_2; the other indicates three or four travel lanes, L_4); and two indicators for median type (no raised median, M_{none}, and raised median, M_{raised}).

There are two interactions in the model. The first interaction in an interaction between pedestrian ADT and the indicator for marked crosswalk, ADP*C_M. The second interaction in the model is between traffic ADT and the indicator for marked crosswalk, ADT*C_M.

The linear predictor has the form:

$$\eta_i = \beta_0 + \beta_1 * ADP_i + \beta_2 * ADT_i + \beta_3 * C_{M,i} + \beta_4 * L_{2,i} + \beta_5 * L_{4,i} + \beta_6 * M_{none,i} + \beta_7 * M_{raised,i} + \beta_8 * ADP_i * C_{M,i} + \beta_9 * ADT_i * C_{M,i}. \qquad (7)$$

where η_i is the linear predictor for site *i* = 1 ,2, ..., 2,000. The number of years of accident data available for a site is used as an offset. $\beta_0, \beta_{1,\ldots,}\beta_9$ are parameters to be estimated. The estimates of the parameters were obtained using PROC GENMOD. Parameter estimates for the final model are shown in table 9.

Table 9. Parameter estimates for final model combining marked and unmarked crosswalks.

Parameter	Marked		
	Estimate	**S.E.***	***p*-Value**
Constant (β_0)	−8.2455	0.4633	< 0.0001
ADP (β_1)	0.0011	0.0004	0.0149
ADT (β_2)	0.0000	0.0000	0.7842
C_M (β_3)	0.3257	0.3988	0.4141
L_2 (β_4)	−0.4786	0.3180	0.1323
L_4 (β_5)	0.0053	0.2638	0.9840
M_{none} (β_6)	0.1541	0.2090	0.4610
M_{raised} (β_7)	−0.5439	0.3064	0.0759
ADP*C_M (β_8)	−0.0008	0.0004	0.0780
ADT*C_M (β_9)	0.0001	0.0000	0.0016
Dispersion	2.1970	0.5898	–

*S.E. = Standard Error

The final model provides a framework to test the hypothesis of whether marked crosswalks have the same expected number of pedestrian crashes in 5 years controlling for the effects of pedestrian ADT, vehicle traffic ADT, number of lanes, and presence of a raised median. Because the interaction between traffic ADT and the indicator for marked crosswalk, ADT*C_M (β_9), was statistically significant, it was concluded that the presence of a marked crosswalk increases the expected number of pedestrian crashes in 5 years; however, the effect size is dependent on the traffic ADT and number of lanes.

There is also a statistically significant interaction between pedestrian volume and the indicator for marked crosswalk, which was interpreted as the effect size of the presence of a marked crosswalk as dependent on the pedestrian volume. The lane indicator variables compare two lanes with five or more, and three or four lanes with five lanes or more. A two-degrees-of-freedom test for any lane effect has an associated p-value of 0.1071. The two median variables compare no median with other median, and raised median with other median. A two-degrees-of-freedom test for any median effect has an associated p-value of 0.0531. The number of lanes, type of median, pedestrian volume, and ADT are all intracorrelated. This correlation is evidenced by the fact that ADT increases as the number of lanes increases. Also, sites with two lanes do not have a median. The number of lanes was also included in the model and probably is expressed indirectly through ADT and median type. In the final model form, the regional effect was only marginally significant, and including the regional variables (i.e., western versus eastern region) into the model had virtually no influence on the crash effects of the other variables. Thus, the regional variable was not included in the final model.

Further discussion of the final model relative to the goodness-of-fit measures, residuals, and possible biases of multicollinearity is contained in appendix B. In short, the final model was found to be valid and appropriate for the available database. A considerable amount of data exploration was also conducted during the analysis phase of study before developing the final model.

Pedestrian Crash Plots

The final pedestrian crash prediction model can be illustrated by inputting various values of pedestrian ADT, traffic ADT, number of lanes (two lanes, four lanes, or more), and median type (raised median or no raised median). All values used in the following figures (and in appendix B) are well within the actual distributions of the data sample.

Figures 13 through 17 and the figures in appendix C (figures 45 through 64) all contain plots of response curves based on the final negative binomial prediction model. Each of these graphs shows a solid line for both marked and unmarked locations. For each solid line, there is a dashed line above and below it representing the upper and lower bounds of the 95 percent confidence intervals.

The relationship of pedestrian crashes in a 5-year period is shown in figure 13 for a range of pedestrian ADTs for traffic ADT of 5,000 using the final crash prediction model. Notice that there is no difference in predicted pedestrian crashes in marked versus unmarked crosswalks for these conditions.

Plots of pedestrian crashes in a 5-year period from the model are shown for two-lane roads as a function of traffic ADT in figure 14 (where pedestrian ADT = 300). Note that there is little if any difference in pedestrian crashes between marked and unmarked crosswalks, even for traffic ADTs as high as 15,000. In fact, for marked crosswalks with traffic ADT of 15,000 and 300 pedestrians per day, expected pedestrian crashes are 0.10 per 5 years, or 1 pedestrian crash per 50 years per site.

Figure 15 illustrates the predicted pedestrian crashes for a five-lane pedestrian crossing with no median and a pedestrian ADT of 250. As traffic ADT increases, pedestrian crashes stay relatively consistent on unmarked crosswalks (approximately 0.10 or less per 5 years). However, on marked crosswalks, pedestrian crashes increase as traffic ADT increases.

Plots of the final model are given for five-lane crosswalks with a raised median in figures 16 and 17. Average pedestrian ADT is plotted versus pedestrian crashes in figure 16 for traffic ADT of 10,000, and there is little difference in pedestrian crashes at marked versus unmarked crosswalks. Note in figure 17, however, that marked crosswalks have an increasingly greater number of pedestrian crashes than unmarked crosswalks, as ADT increases from 15,000 to 50,000.

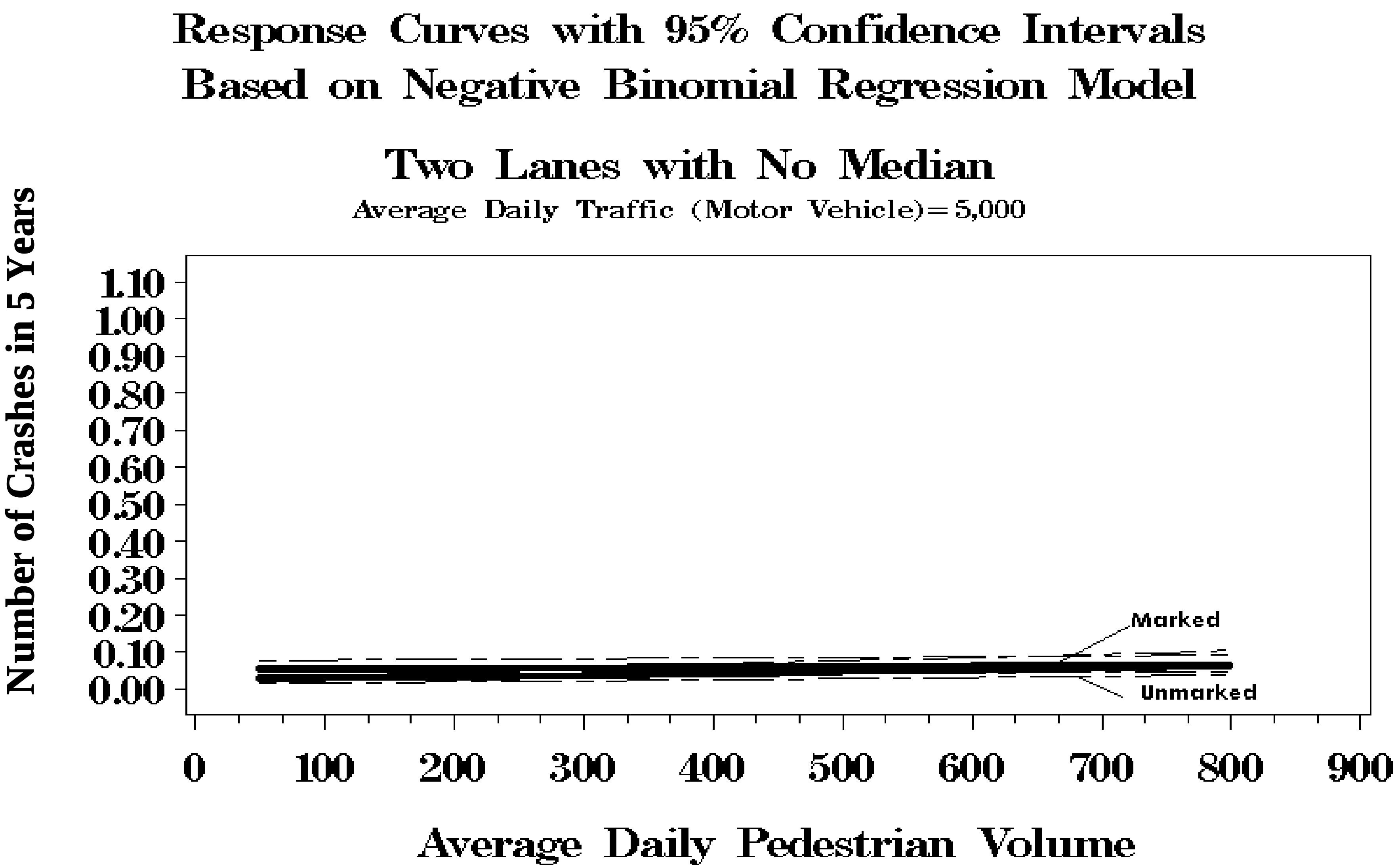


Figure 13. Predicted pedestrian crashes versus pedestrian ADT for two-lane roads based on the final model.

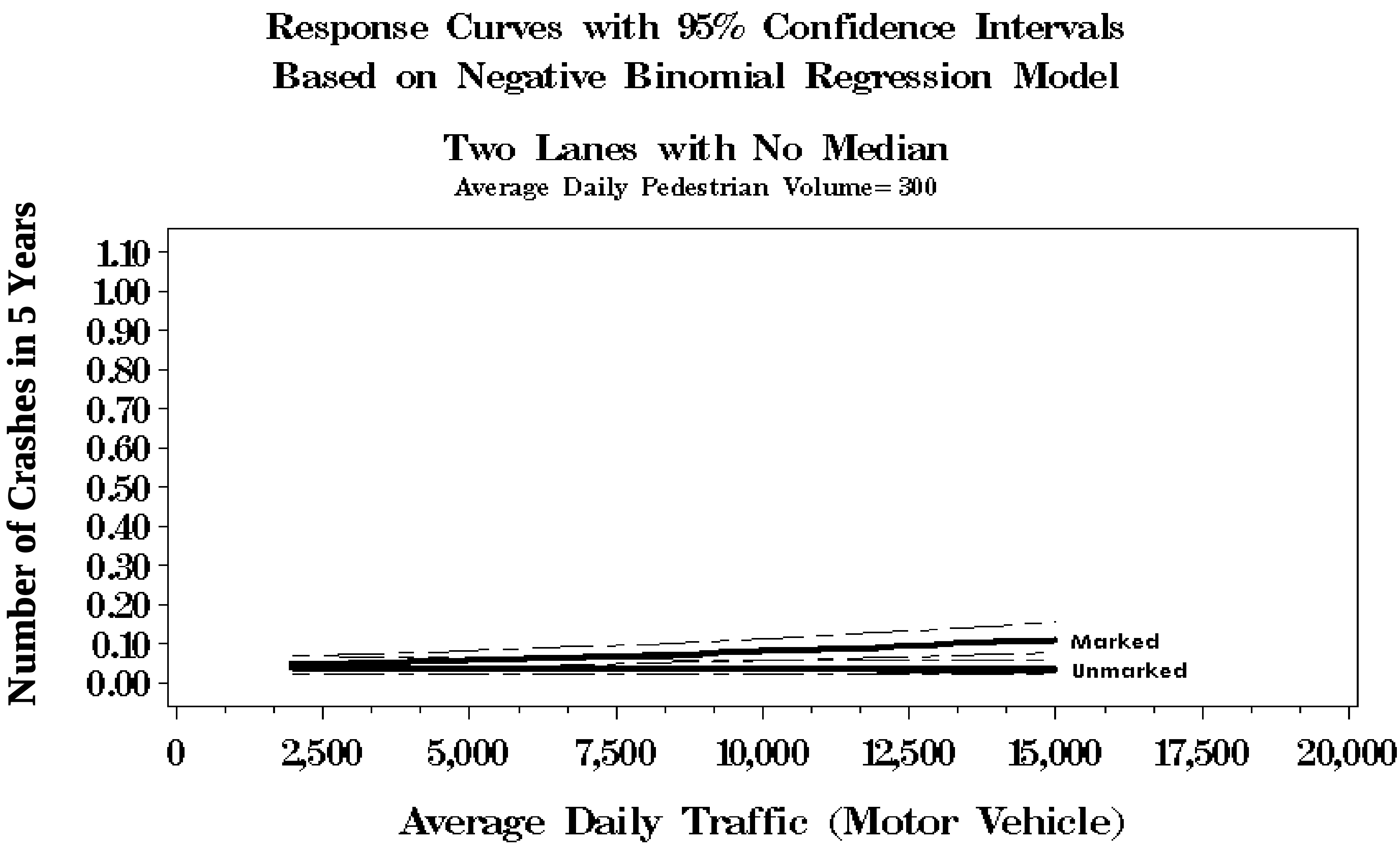


Figure 14. Predicted pedestrian crashes versus traffic ADT for two-lane roads based on the final model (pedestrian ADT = 300).

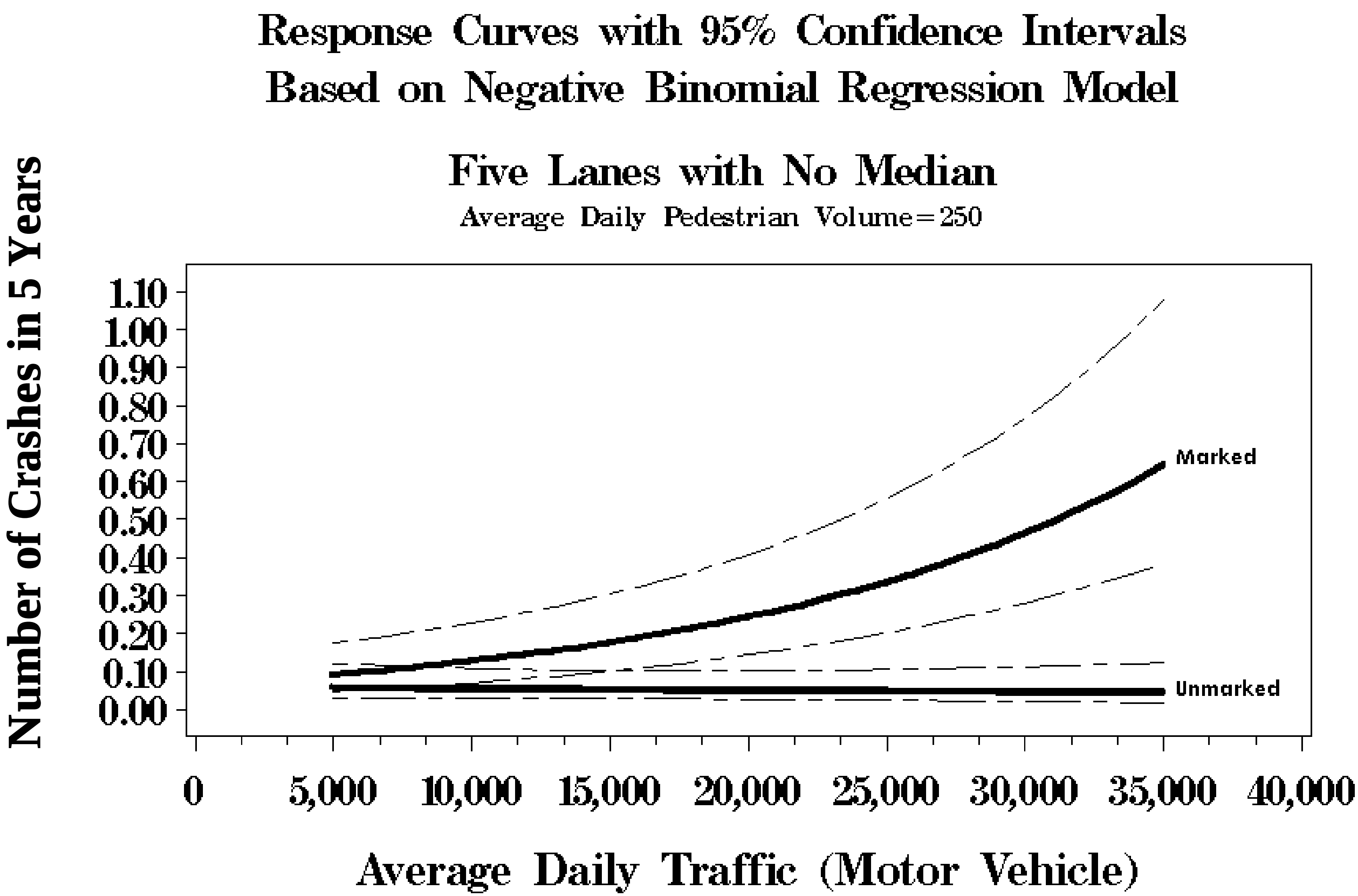


Figure 15. Predicted pedestrian crashes versus traffic ADT for five-lane roads (no median) based on the final model.

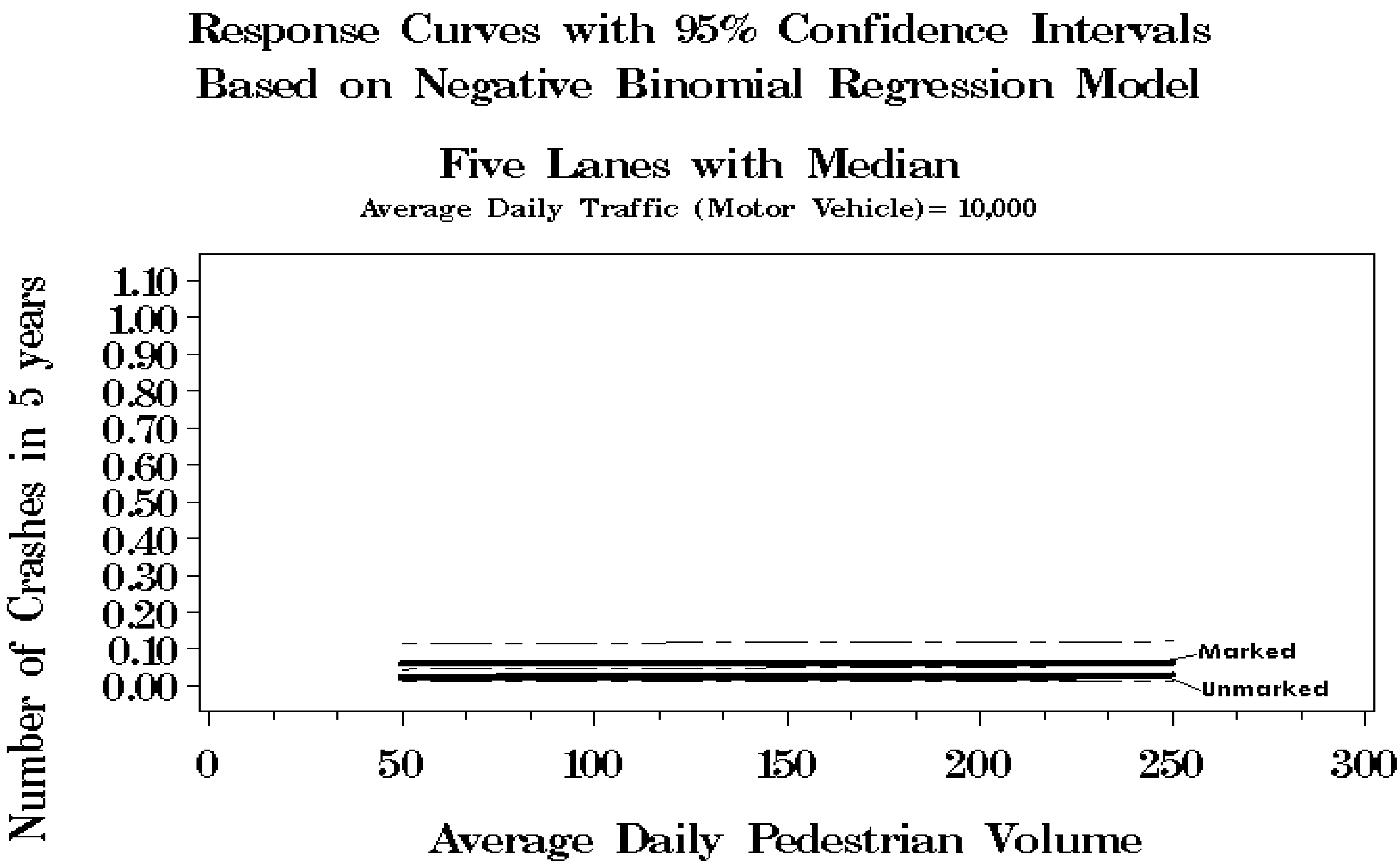


Figure 16. Predicted pedestrian crashes versus pedestrian ADT for five-lane roads (with median) based on the final model.

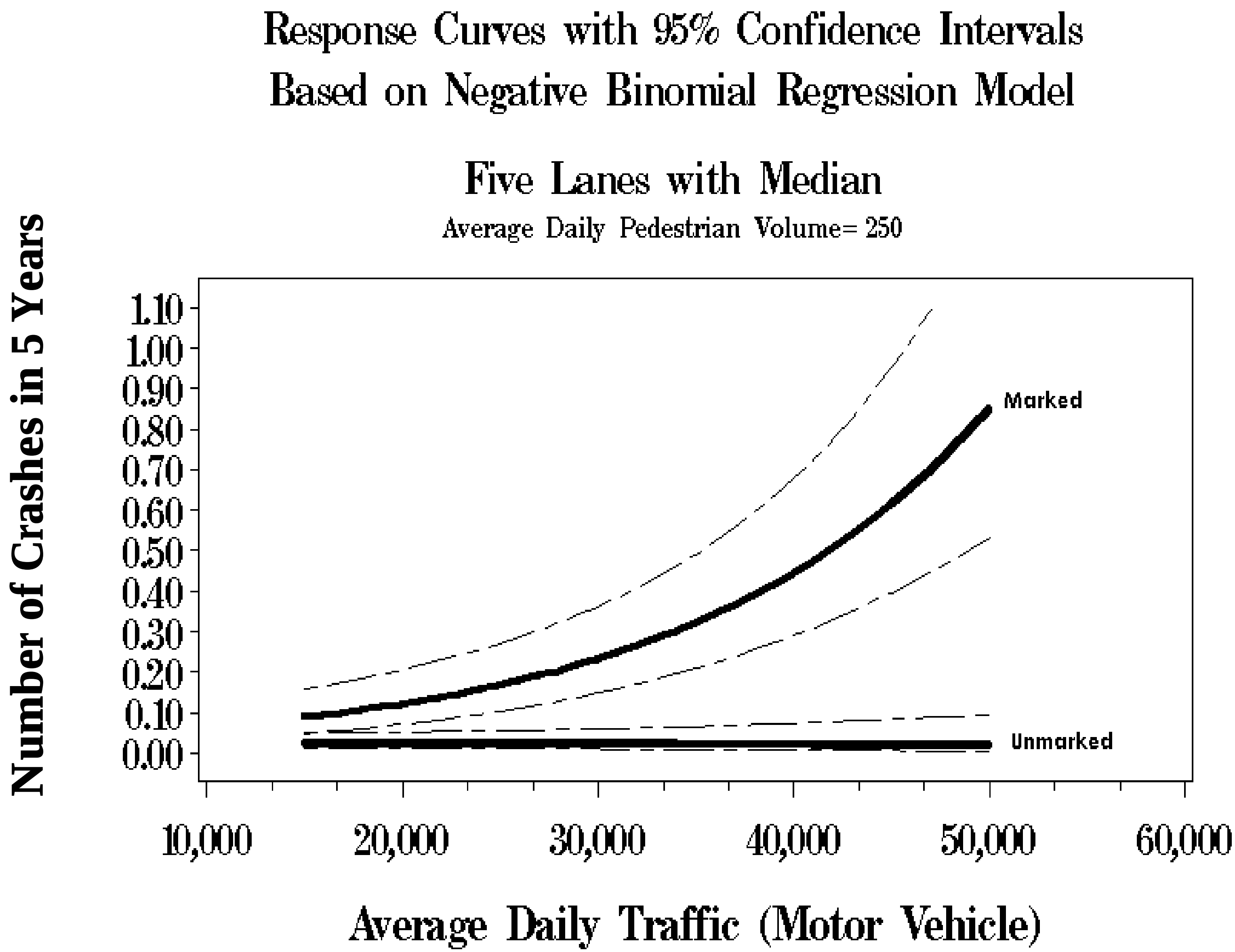


Figure 17. Predicted pedestrian crashes versus traffic ADT for five-lane roads (with median) based on the final model (pedestrian ADT = 250).

Additional plots of pedestrian crashes using the final crash prediction model are given in appendix C for various combinations of the input variables. Tables of estimated pedestrian crashes per 5-year period are given in appendix D using the final model and inputting various combinations of traffic ADT, pedestrian ADT, numbers of lanes, and median type. Table 10 provides estimated pedestrian crashes for marked and unmarked five-lane crossings with a raised median. For example, from table 10, consider a marked crosswalk on a five-lane road (with a raised median) with 150 pedestrian crossings per day and a traffic ADT of 28,000. There would be 0.20 expected pedestrian crashes per 5-year period, or 1 pedestrian crash every 25 years, unless a pedestrian crossing improvement (e.g, traffic signals with pedestrian signals if warranted) is installed. In all cases, values of input variables are chosen well within actual ranges of the study database. A detailed discussion of potential pedestrian safety improvements at uncontrolled locations is in chapter 4 of this report.

Table 10. Estimated number of pedestrian crashes in 5 years based on negative binomial model.

		Five Lanes with Median					
Average Daily Pedestrian Volume	**Average Daily Traffic (Motor Vehicle)**	**Unmarked Lower 95%**	**Unmarked Predicted**	**Unmarked Upper 95%**	**Marked Lower 95%**	**Marked Predicted**	**Marked Upper 95%**
150	9,000	0.01	0.03	0.05	0.03	0.06	0.11
150	10,000	0.01	0.02	0.05	0.03	0.06	0.12
150	11,000	0.01	0.02	0.05	0.03	0.07	0.12
150	12,000	0.01	0.02	0.05	0.04	0.07	0.13
150	13,000	0.01	0.02	0.05	0.04	0.07	0.14
150	14,000	0.01	0.02	0.05	0.04	0.08	0.15
150	15,000	0.01	0.02	0.05	0.05	0.08	0.15
150	16,000	0.01	0.02	0.05	0.05	0.09	0.16
150	17,000	0.01	0.02	0.05	0.06	0.10	0.17
150	18,000	0.01	0.02	0.05	0.06	0.10	0.18
150	19,000	0.01	0.02	0.05	0.06	0.11	0.19
150	20,000	0.01	0.02	0.05	0.07	0.12	0.20
150	21,000	0.01	0.02	0.05	0.07	0.13	0.21
150	22,000	0.01	0.02	0.05	0.08	0.13	0.22
150	23,000	0.01	0.02	0.05	0.09	0.14	0.24
150	24,000	0.01	0.02	0.05	0.09	0.15	0.25
150	25,000	0.01	0.02	0.05	0.10	0.16	0.26
150	26,000	0.01	0.02	0.05	0.11	0.17	0.28
150	27,000	0.01	0.02	0.05	0.12	0.19	0.30
150	28,000	0.01	0.02	0.05	0.13	0.20	0.31
150	29,000	0.01	0.02	0.05	0.13	0.21	0.33
150	30,000	0.01	0.02	0.05	0.14	0.23	0.35
150	31,000	0.01	0.02	0.05	0.15	0.24	0.37
150	32,000	0.01	0.02	0.05	0.17	0.26	0.40
150	33,000	0.01	0.02	0.06	0.18	0.27	0.42
150	34,000	0.01	0.02	0.06	0.19	0.29	0.45
150	35,000	0.01	0.02	0.06	0.20	0.31	0.48
150	36,000	0.01	0.02	0.06	0.22	0.33	0.51
150	37,000	0.01	0.02	0.06	0.23	0.36	0.54
150	38,000	0.01	0.02	0.06	0.25	0.38	0.58
150	39,000	0.01	0.02	0.06	0.27	0.40	0.62
150	40,000	0.01	0.02	0.07	.028	0.43	0.66

CHAPTER 3. STUDY RESULTS

SIGNIFICANT VARIABLES

Poisson and negative binomial regression models were fit to pedestrian crash data from marked and unmarked crosswalks. These analyses showed that several factors in addition to crosswalk markings were associated with pedestrian crashes. Traffic and roadway factors found to be related to a greater frequency of pedestrian crashes included higher pedestrian volumes, higher traffic ADT, and a greater number of lanes (i.e., multilane roads with three or more lanes had higher pedestrian crash rates than two-lane roads). For this study, a center two-way left-turn lane was considered to be a travel lane and not a median.

Surprisingly, after controlling for other factors (e.g., pedestrian volume, traffic volume, number of lanes, median type), speed limit was not significantly related to pedestrian crash frequency. Certainly, one would expect that higher vehicle speed would be associated with an increased probability of a pedestrian crash (all else being equal). However, the lack of association between speed limit and pedestrian crashes found in this analysis may be due to the fact that there was not much variation in the range of vehicle speed or speed limit at the study sites (i.e., 93 percent of the study sites had speed limits of 40.2 to 56.3 km/h (25 to 35 mi/h). Another possible explanation, as hypothesized by Garder, is that pedestrians may be more careful when crossing streets with higher speed limits; that is, they may avoid short gaps on high-speed roads, which may minimize the effect of vehicle speed on pedestrian crash rates.[30] In terms of speed and crash severity, the analysis showed that speed limits of 56.3 km/h (35 mi/h) and greater were associated with a higher percentage of fatal and type A (serious or incapacitating) injuries (43 percent) compared to sites having lower speed limits (23 percent of the crashes resulting in fatal or type A injuries).

The presence of a raised median or raised crossing island was associated with a significantly lower pedestrian crash rate at multilane sites with both marked and unmarked crosswalks. These results were in basic agreement with a major study by Bowman and Vecellio[31] and also a study by Garder[32] that found safety benefits for pedestrians due to raised medians and refuge islands, respectively. Furthermore, on multilane roads, medians that were painted (but not raised) and center two-way left-turn lanes did not offer significant safety benefits to pedestrians, compared to multilane roads with no median at all.

There did appear to be some regional effect. Marked and unmarked crosswalks in western U.S. cities had a significantly higher pedestrian crash rate than eastern U.S. cities (after controlling for pedestrian exposure, number of lanes, median type, and other site conditions). The reason(s) for these regional differences in pedestrian crash rate is not known, although it could be related to regional differences in driver and pedestrian behavior, higher vehicle speeds in western cities, differences in pedestrian-related laws or enforcement levels, variations in roadway design features, and/or other factors. However, this effect was only marginally significant in the final crash prediction model, and excluding it from the model had little effect on the model results.

All of the variables related to pedestrian crashes (i.e., pedestrian volume, traffic ADT, number of lanes, existence of median and median type, and region of the country) then were included in the models for determining the effects of marked and unmarked sites. Factors having no significant effect on pedestrian crash rate included: area (e.g., residential, central business district (CBD)), location (i.e., intersection versus midblock), speed limit, traffic operation (one-way or two-way), condition of crosswalk marking (excellent, good, fair, or poor), and crosswalk marking pattern (e.g., parallel lines, ladder type, zebra stripes). One may expect that crosswalk marking condition may not necessarily be related to pedestrian crash rate, since the condition of the markings may have varied over the 5-year analysis period, and the condition of the markings was observed only once. Furthermore, in some regions, the crosswalk markings may be less visible during or after rain or snow storms. It is also recognized, however, that some agencies may maintain and restripe crosswalks more often than other agencies included in the study sample.

MARKED AND UNMARKED CROSSWALK COMPARISONS

The results revealed that on two-lane roads, there were no significant differences in pedestrian crashes for marked and unmarked crosswalk sites. In other words, pedestrian safety on two-lane roads was not found to be different, whether the crosswalk was marked or unmarked. This conclusion is based on a sample size of 914 crossing sites on two-lane roads (out of 2,000 total sites). Specifically, binomial comparison of pedestrian crash rates were computed for marked and unmarked sites within subsets by ADT, median type, and number of lanes, as shown in figure 18.

On multilane roads with ADT of 12,000 or less, there were also no differences in pedestrian crash rates between marked and unmarked sites. On multilane roads with no raised medians and ADTs greater than 12,000, sites with marked crosswalks had higher pedestrian crash rates than unmarked crossings. On multilane roads (roads with three to eight lanes) with raised medians and vehicle ADTs greater than 15,000, a significantly higher pedestrian crash rate was associated with marked crosswalk sites compared to unmarked sites.

Best-fit curves for multilane undivided roads were produced for pedestrian crashes (per million pedestrian crossings) at marked and unmarked crosswalks as a function of vehicle volume (ADT), as shown in figure 19. The data points of figure 19 were obtained by aggregating sites into traffic volume categories. Since each marked crosswalk site and its matched comparison (unmarked) site usually had the same traffic volume, each traffic volume category usually contained the same number of marked and unmarked sites (there were a few exceptions). Pedestrian crash rates were computed based on total pedestrian crashes and total pedestrian crossings within each traffic volume category. In figure 19, these rates are plotted at the midpoints of the traffic volume categories. Smooth curves were then fit to the data points. Similar analyses were conducted for multilane divided roads. A final negative binomial model was also developed. The analysis for multilane undivided roads revealed that:

- For traffic volumes (ADTs) of about 10,000 or less, pedestrian crash rates were about the same (i.e., less than 0.25 pedestrian crashes per million pedestrian crossings) between marked and unmarked crosswalks.

- For ADTs greater than 10,000, the pedestrian crash rate for marked crosswalks became increasingly higher as the ADTs increased. The pedestrian crash rate at unmarked crossings increased only slightly as the ADTs increased.

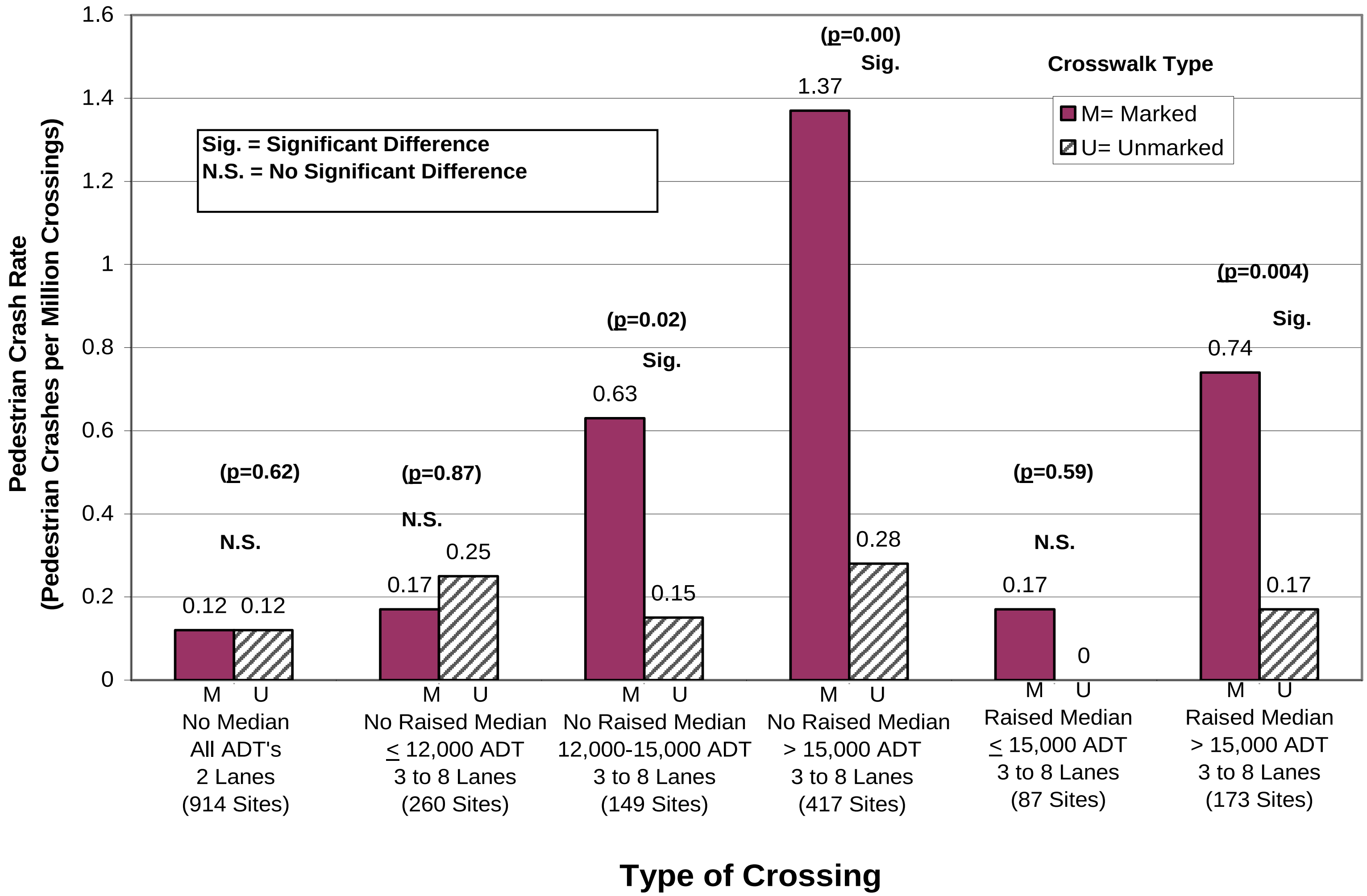


Figure 18. Pedestrian crash rate versus type of crossing.

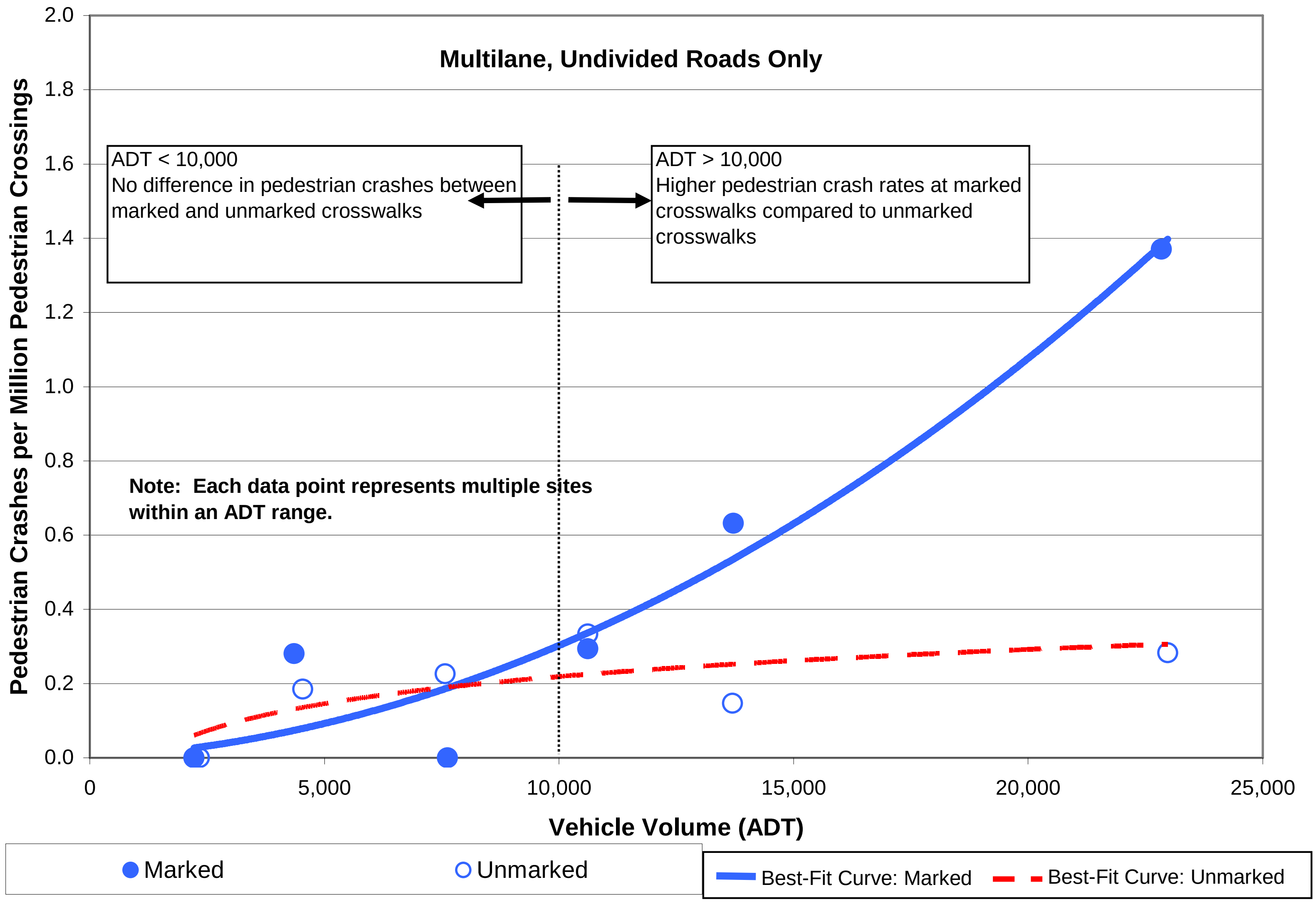


Figure 19. Pedestrian crash rates by traffic volume for multilane crossings with no raised medians—marked versus unmarked crosswalks.

Note that each point on the graph in figure 19 represents dozens of sites, that is, all of the sites corresponding to the given ADT group. For example, the data point for marked crosswalks with ADTs greater than 15,000 corresponds to more than 400 sites. All analyses in this study took into account differences in pedestrian crossing volume, traffic volume, and other important site variables.

These results may be somewhat expected. Wide, multilane streets are difficult for many pedestrians to cross, particularly if there is an insufficient number of adequate gaps in traffic due to heavy traffic volume and high vehicle speed. Furthermore, while marked crosswalks in themselves may not increase measurable unsafe pedestrian or motorist behavior (based on the Knoblauch et al. and Knoblauch and Raymond studies[(13,14)]) one possible explanation is that installing a marked crosswalk may increase the number of at-risk pedestrians (particularly children and older adults) who choose to cross at the uncontrolled location instead of at the nearest traffic signal.

The pedestrian crossing counts at the 1,000 marked crosswalks and 1,000 unmarked comparison crossings in this study may partially explain the difference. Overall, 66.1 percent of the observed pedestrians crossed at marked crosswalks, compared to 33.9 percent at unmarked crossings. More than 70 percent of pedestrians under age 12 and above age 64 crossed at marked crosswalks, while about 35 percent of pedestrians in the 19- to 35-year-old range crossed at unmarked crossings, as shown in figure 20. The age group of pedestrians was estimated based on site observation.

An even greater percentage of older adults (81.3 percent) and young children (76.0 percent) chose to cross in marked crosswalks on multilane roads compared to two-lane roads. Thus, installing a marked crosswalk at an already undesirable crossing location (e.g., wide, high-volume street) may increase the chance of a pedestrian crash occurring at such a site if a few at-risk pedestrians are encouraged to cross where other adequate crossing facilities are not provided. This explanation might be evidenced by the many calls to traffic engineers from citizens who state, “Please install a marked crosswalk so that we can cross the dangerous street near our house.” Unfortunately, simply installing a marked crosswalk without other more substantial crossing facilities often does not result in the majority of motorists stopping and yielding to pedestrians, contrary to the expectations of many pedestrians.

On three-lane roads (i.e., one lane in each direction with a center two-way left-turn lane), the crash risk was slightly higher for marked crosswalks compared to unmarked crosswalks, but this difference was not significant (based on a sample size of 148 sites).

CRASH TYPES

The greatest difference in pedestrian crash types that occurred at marked and unmarked crosswalks involved multiple-threat crashes. A multiple-threat crash involves a driver stopping in one lane of a multilane road to permit pedestrians to cross, and an oncoming vehicle (in the same direction) strikes the pedestrian who is crossing in front of the stopped vehicle. This crash type involves both the pedestrian and driver failing to see each other in time to avoid the collision (see figure 21). To avoid multiple-threat collisions, drivers should slow down and look around stopped vehicles in the adjacent travel lane, and pedestrians should stop at the outer edge of a stopped vehicle and look into the oncoming lane for approaching vehicles before stepping into the lane.

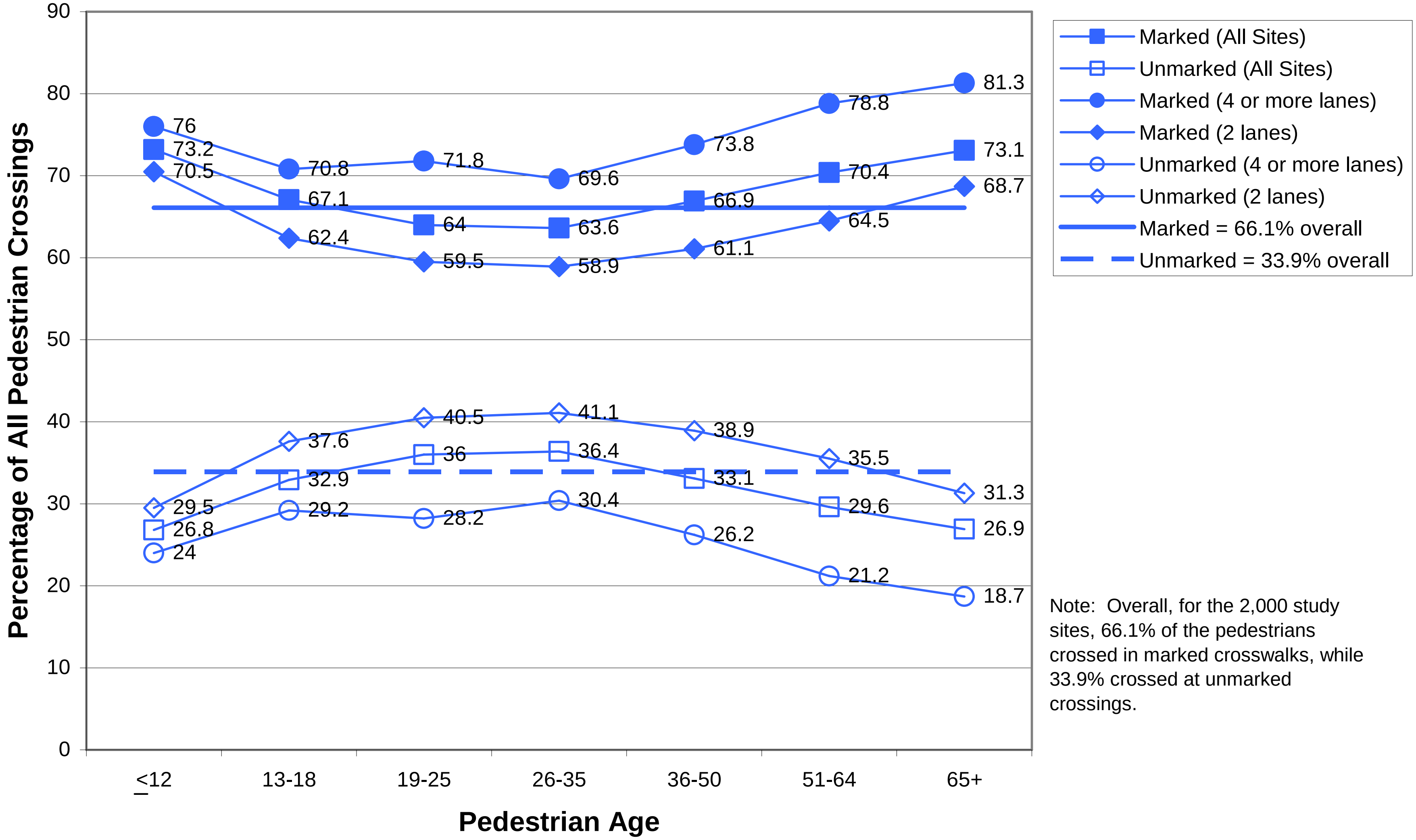


Figure 20. Percentage of pedestrians crossing at marked and unmarked crosswalks by age group and road type.

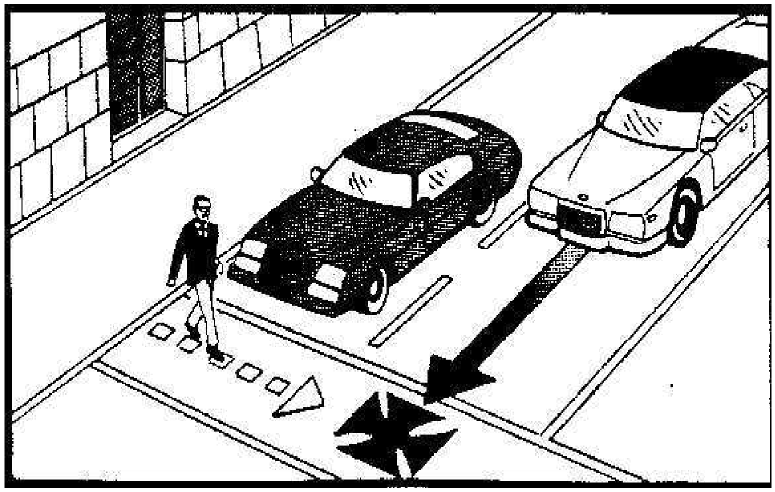


Figure 21. Illustration of multiple-threat pedestrian crash.

A total of 17.6 percent (33 out of 188) of the pedestrian crashes in marked crosswalks were classified as multiple threat. None of the 41 pedestrian crashes in unmarked crosswalks was a multiple-threat crash. This finding may be the result of one or more of the following factors:

- Drivers may be more likely to stop and yield to pedestrians in marked crosswalks compared to unmarked crossings, since at least one motorist must stop for a pedestrian to set up a multiple-threat pedestrian collision. Also, pedestrians may be more likely to step out in front of oncoming traffic in a marked crosswalk than at an unmarked location in some instances.

- A second explanation is related to the fact that most of the total pedestrians who are crossing multilane roads are crossing in a marked crosswalk (66.1 percent), as shown earlier in figure 14. Furthermore, of the pedestrian age groups most at risk (the young and the old), an even greater proportion of these pedestrians are choosing to cross multilane roads in marked crosswalks (76 percent and 81.3 percent, respectively).

- Another possible explanation could be that some pedestrians crossing in a marked crosswalk may be less likely to search properly for vehicles (compared to an unmarked crossing) when stepping out past a stopped vehicle and into an adjacent lane (i.e., pedestrians not realizing that they need to search for other oncoming vehicles after one motorist stops for them).

Further research on pedestrian and motorist behavior could help to gain a better understanding of the causes and potential effects of countermeasures (e.g., advance stop lines) related to these crashes. There is also a need to examine the current laws and level of police enforcement (and a possible need for changes in the laws) on motorist responsibility to yield to pedestrians and how these laws differ between States. A distribution of pedestrian crash types, which includes all of the 229 pedestrian collisions at the 2,000 study sites, is shown in figure 22.

Motorists failing to yield (on through movements) represented a large percentage of pedestrian crashes in marked crosswalks (41.5 percent) and unmarked crosswalks (31.7 percent). Likewise, vehicle turn and merge crashes, also generally the fault of the driver, accounted for 19.2 percent (marked crosswalks) and 12.2 percent (unmarked crosswalks) of such crashes (see figure 22). These results indicate a strong need for improved driver enforcement and education programs that emphasize the importance of yielding or stopping for pedestrians. More pedestrian-friendly roadway designs may also be helpful in reducing such crashes by slowing vehicles, providing pedestrian refuge (e.g., raised medians), and/or better warning to motorists about pedestrian crossings.

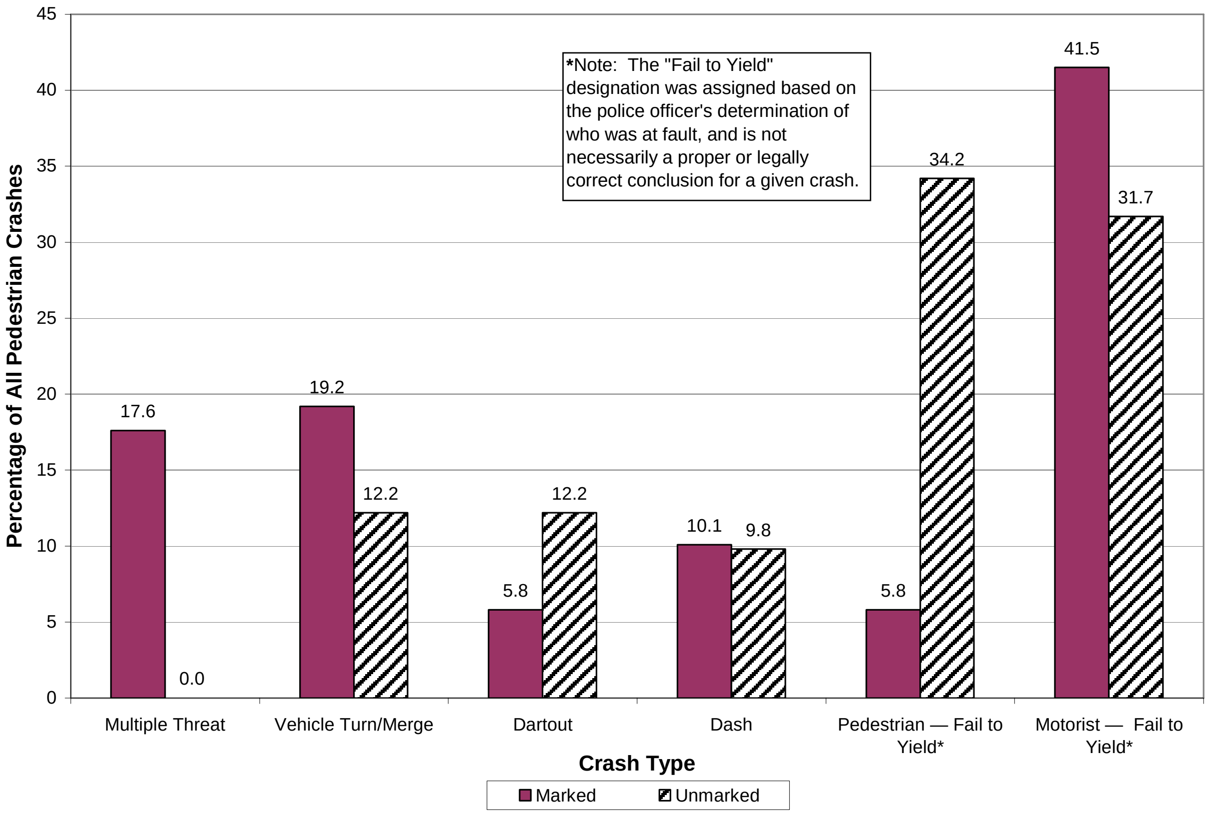


Figure 22. Pedestrian crash types at marked and unmarked crosswalks.

A substantial proportion of pedestrian crashes involved dartout, dash, and other types of crashes in which the pedestrian stepped or ran in front of an oncoming vehicle at unmarked crosswalks (23 of 41, or 56.1 percent) and a lesser proportion occurred at marked crosswalks (41 of 188, or 21.8 percent). Police officers sometimes unjustifiably assign fault to the pedestrian, which suggests the need for more police training. Specifically, it may be questioned why so many pedestrian crashes were designated by the police officer as "pedestrian fails to yield," since in most States, motorists are required legally to yield the right-of-way to pedestrians who are crossing in marked or unmarked crosswalks. Of course, some State ordinances do specify that pedestrians also bear some responsibility for avoiding a collision by not stepping out into the street directly into the path of an oncoming motorist who is too close to the crosswalk to stop in time to avoid a collision. It is likely that police officers often rely largely on the statement of the motorist (e.g., "the pedestrian ran out in front of me" or "came out of nowhere") in determining fault in such crashes, particularly when the driver was not paying proper attention to the road, the pedestrian is unconscious, and there are no other witnesses at the scene. However, it is also true that a major contributing factor is the unsafe behavior of pedestrians. Dartouts, dashes, and failure of the pedestrians to yield were indicated by police officers as contributing causes in 27.9 percent (64 of 229) of the pedestrian crashes at the study sites. These results are indicative of a need for improved pedestrian educational programs, which is in agreement with recommendations in other important studies related to improving the safety of vulnerable road users.[(33)] Furthermore, speeding drivers often contribute to dartout crashes, in addition to unsafe pedestrian behaviors. Creating more pedestrian-friendly crossings by including curb extensions, traffic-calming measures, and other features may also be useful in reducing many of these crashes. It should be mentioned that alcohol use by pedestrians and motorists may also contribute to pedestrian crash experience. However, reliable information on alcohol involvement was not available from local crash reports; therefore, such analysis was not possible for this study.

CRASH SEVERITY

An analysis was conducted to compare pedestrian crash severity on marked and unmarked crosswalks (figure 23). Crash severity did not differ significantly between marked and unmarked crosswalks on two-lane roads. On multilane roads, there was evidence of more fatal (type K) and type A injury pedestrian crashes at marked crosswalks compared to unmarked crosswalks, although the sample sizes were too small for statistical reliability. This result probably is due to older pedestrians being more likely than other age groups to walk in marked rather than unmarked crosswalks. Furthermore, older pedestrians are much more likely to sustain fatal and serious injuries than younger pedestrians. As mentioned earlier, speed limits of 56.3 km/h (35 mi/h) and higher were associated with a greater percentage of fatal and/or type A injuries (43 percent), whereas sites with lower speed limits had 23 percent of pedestrian crashes resulting in fatal and/or type A injuries.

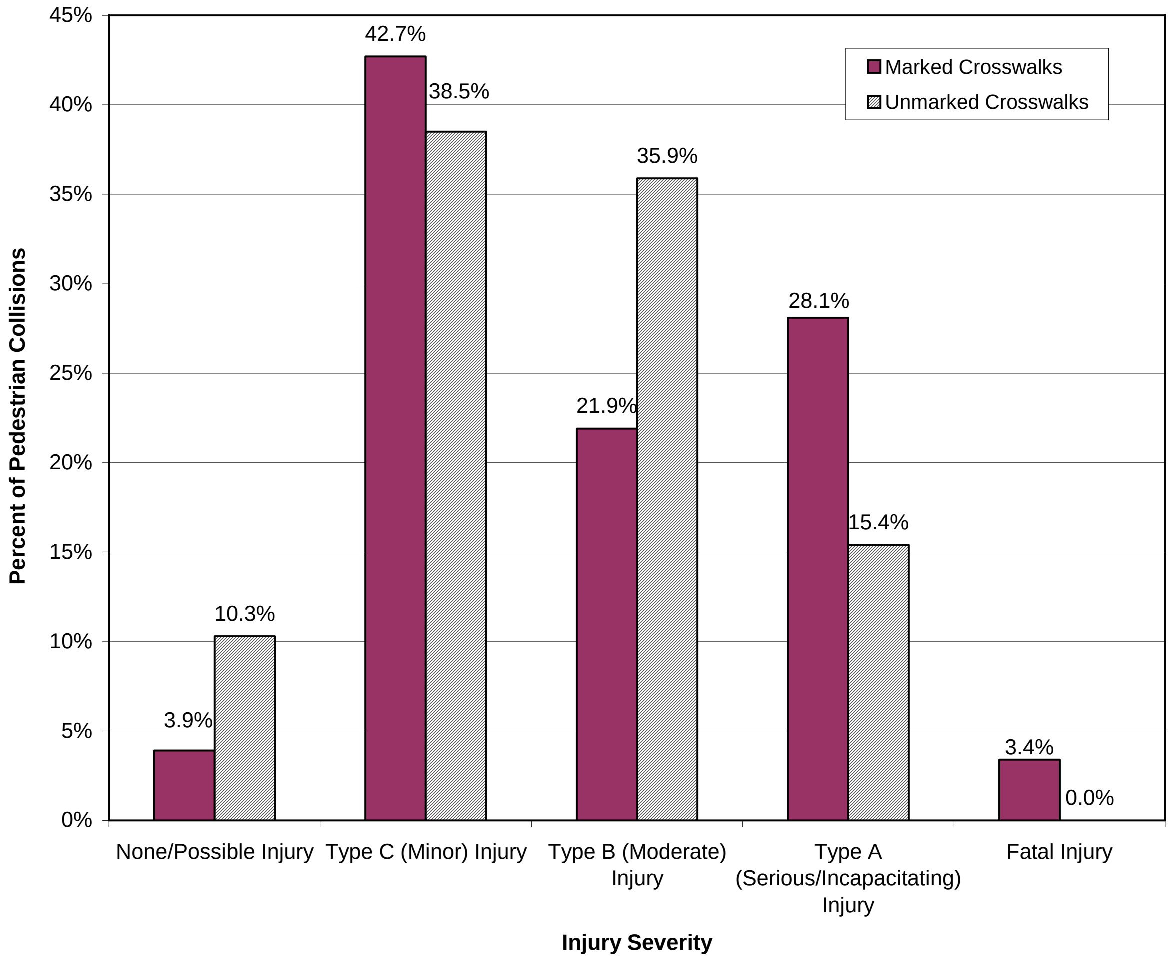


Figure 23. Severity distribution of pedestrian collisions for marked and unmarked crosswalks.

LIGHTING AND TIME OF DAY

Nighttime pedestrian crash percentages were about the same at marked and unmarked crosswalks (approximately 30 percent). In terms of time of day, the percentage of pedestrian crashes in marked crosswalks tended to be higher than for unmarked crosswalks during the morning (6 to 10 a.m.) and afternoon (3 to 7 p.m.) peak periods, but lower in the midday (10 a.m. to 3 p.m.) and evening (7 p.m. to midnight) periods (figure 24). This is probably because pedestrians are more likely to cross in marked crosswalks than in unmarked crossings during peak traffic periods (e.g., walking to and from work) than at other times. As shown in figure 25, little difference is noticeable between pedestrian collisions for marked and unmarked crosswalks with respect to light condition. However, it is apparent that adequate nighttime lighting should be provided at marked crosswalks to enhance the safety of pedestrians crossing at night.

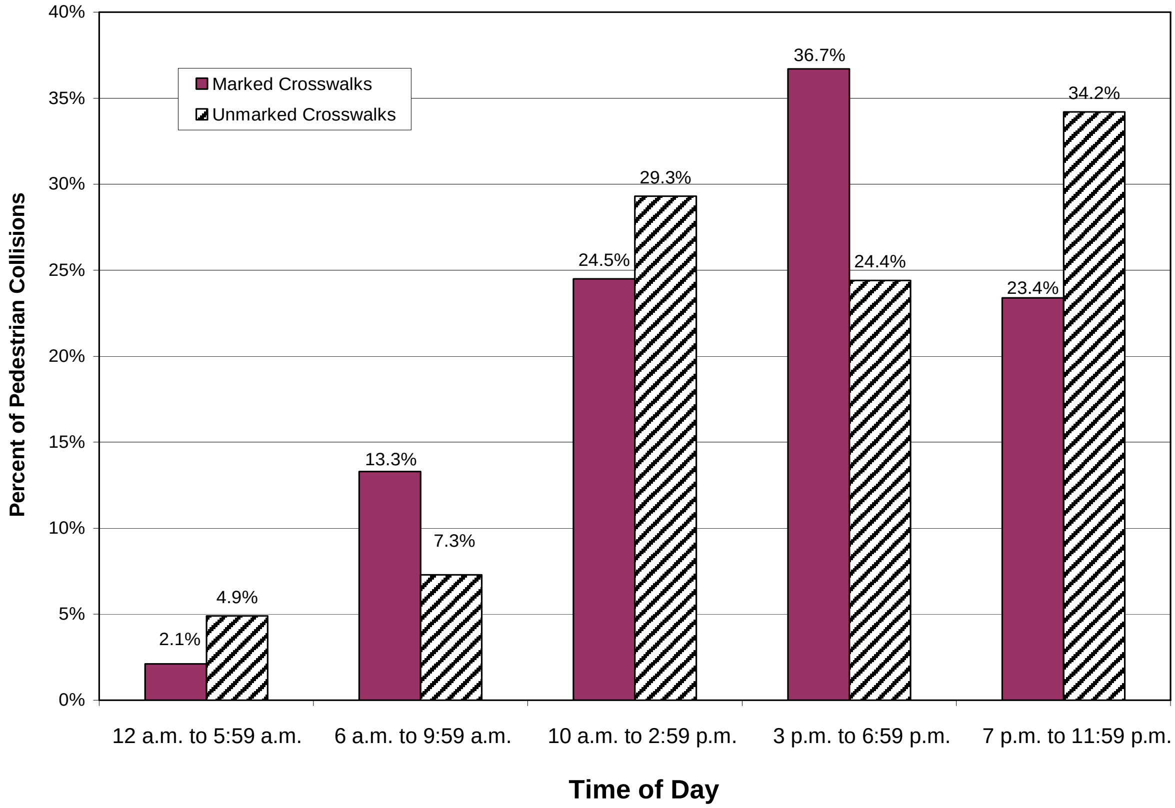


Figure 24. Distribution of pedestrian collisions by time of day for marked and unmarked crosswalks.

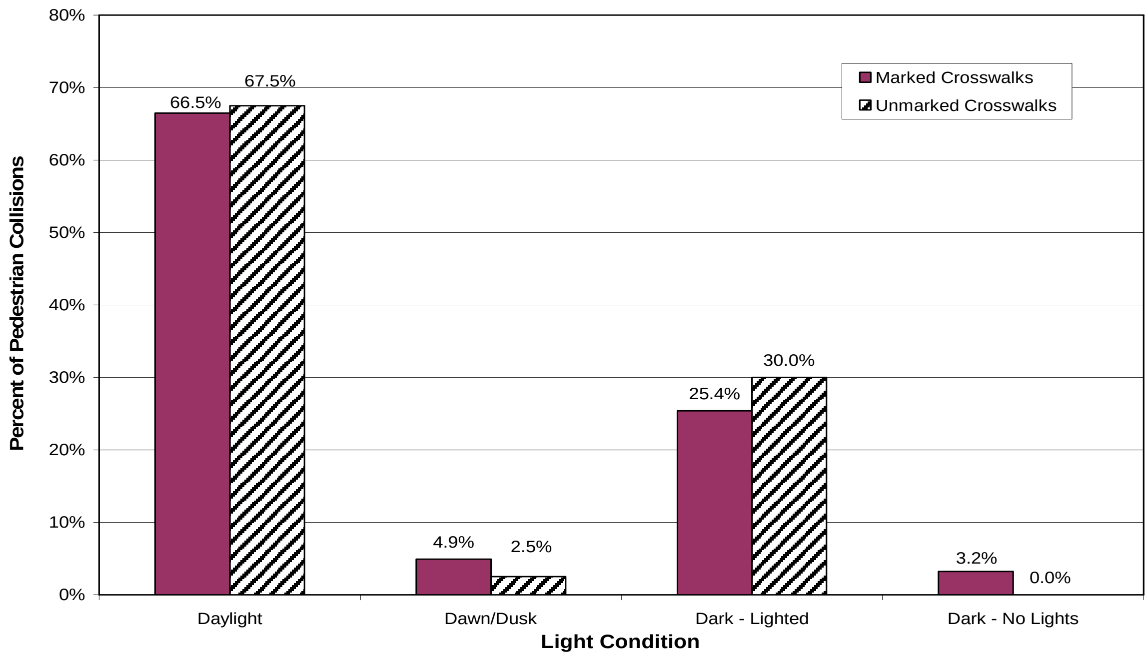


Figure 25. Pedestrian collisions by light condition for marked and unmarked crosswalks.

AGE EFFECTS

A separate analysis of pedestrian crashes and crossing volumes by age of pedestrian was conducted (figure 26). For virtually every situation studied, pedestrians age 65 and older were overrepresented in pedestrian crashes compared to their relative crossing volumes. Figures 27–30 show the relative proportion of crashes and exposure for various age groups for marked crosswalks on two-lane and multilane roads. For a given age group, when the proportion of crashes exceeds the proportion of exposure, then crashes are overrepresented; that is, pedestrians in that population group are at greater risk of being in a pedestrian crash than would be expected from their volume alone.

The pedestrian age groups younger than 65 showed no clear increase in crash risk compared to their crossing volumes. One possible reason that young pedestrians were not overly involved in crash occurrences is the fact that many crashes involving young pedestrians (particularly ages 5 to 9) occur on residential streets, whereas this study did not include school crossings; most sites were drawn from collector and arterial streets (where marked crosswalks exist) that are less likely to be frequented by unescorted young children. Also, some of the young children counted in this study were crossing with their parents or other adults, which may have reduced their risk of a crash. Some of the possible reasons that older pedestrians are at greater risk when crossing streets compared to other age groups are that older adults are more likely (as an overall group) than younger pedestrians to have:

- Slower walking speeds (and thus greater exposure time).
- Visual and/or hearing impairments.

- Difficulty in judging the distance and speed of oncoming traffic.

- More difficulty keeping track of vehicles coming from different directions, including turning vehicles.

- Inability to react (e.g., stop, dodge, or run) as quickly as younger pedestrians in order to avoid a collision under emergency conditions.

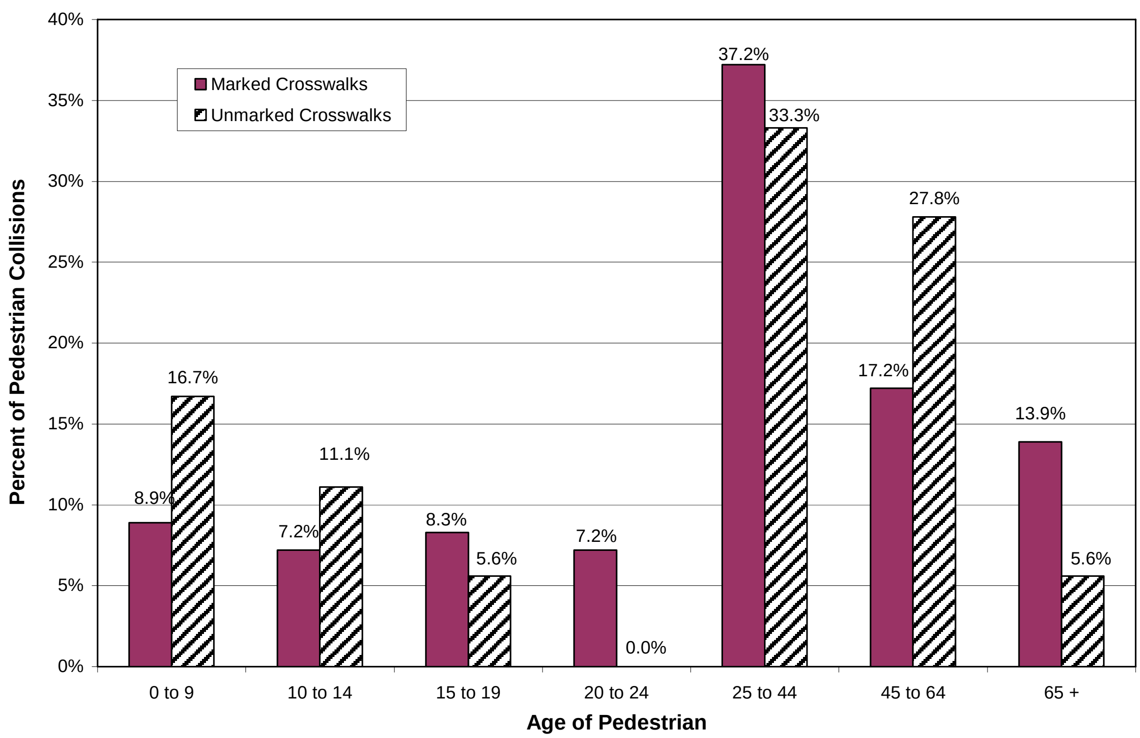


Figure 26. Age distribution of pedestrian collisions for marked and unmarked crosswalks.

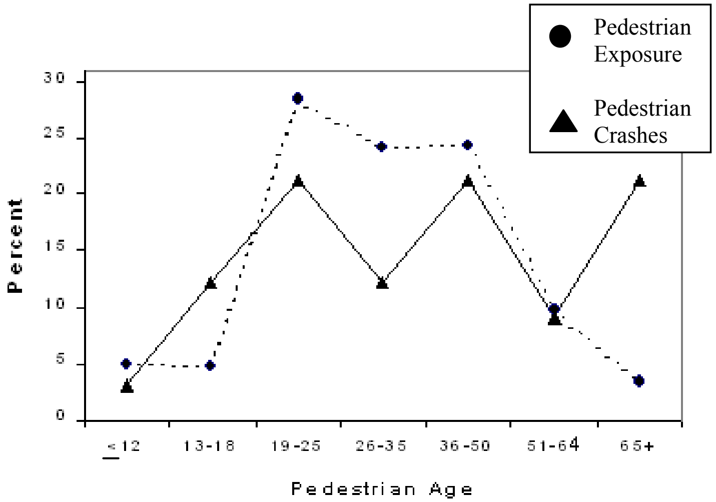


Figure 27. Two-Lane Roads, Marked Crosswalks.

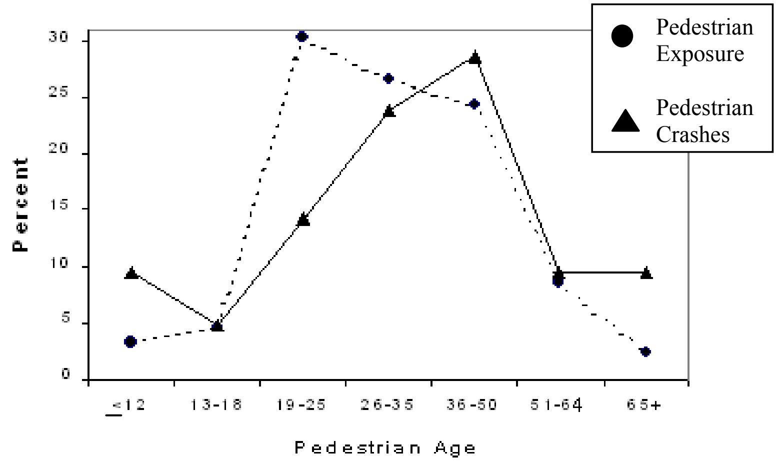


Figure 28. Two-Lane Roads, Unmarked Crosswalks.

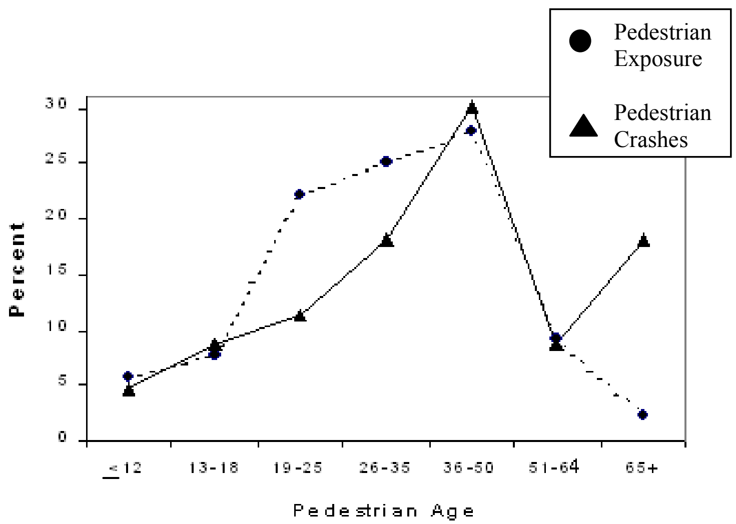


Figure 29. Multilane Roads, Marked Crosswalks.

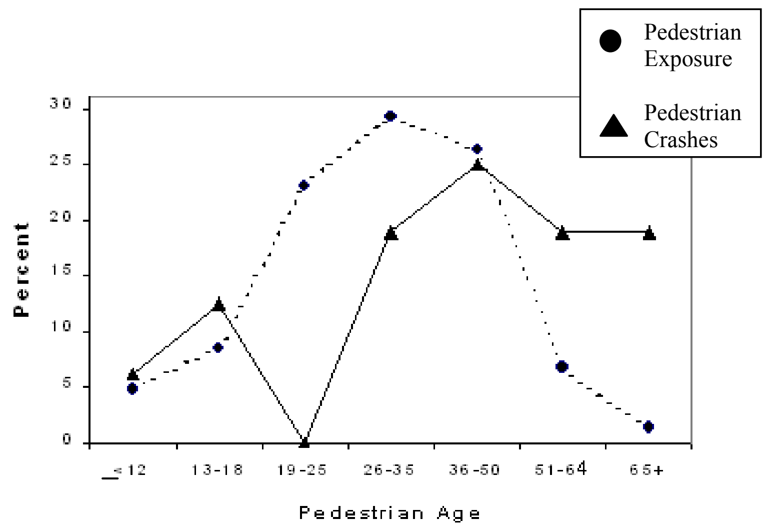


Figure 30. Multilane Roads, Unmarked Crosswalks.

Figures 27–30. Percentage of crashes and exposure by pedestrian age group and roadway type at uncontrolled marked and unmarked crosswalks.

DRIVER AND PEDESTRIAN BEHAVIOR AT CROSSWALKS

A companion study was conducted by Knoblauch et al. on pedestrian and motorist behavior and on vehicle speed before and after crosswalk installation at sites in Minnesota, New York, and Virginia (on two-lane and three-lane streets) to help gain a better understanding of the effects of marked crosswalks versus unmarked crosswalks.(13) The study results revealed that very few motorists stopped or yielded to pedestrians either before or after marked crosswalks were installed. After marked crosswalks were installed, there was a small increase in pedestrian scanning behavior before stepping out into the street. Also, there was approximately a 1.6-km/h (1-mi/h) reduction in vehicle speed after the marked crosswalks were installed.(13) These behavioral results tend to contradict the false sense of security claims attributed to marked crosswalks, since observed pedestrian behavior actually improved after marked crosswalks were installed at the study sites. However, measures such as pedestrian awareness and an expectation that motorists will stop for them cannot be collected by field observation alone. Installing marked crosswalks or other measures can affect pedestrian level of service if the measures increase the number of motorists who stop and yield to pedestrians. Furthermore, a greater likelihood of motorist stopping can also setup more multiple threat crashes on multilane roads. Future studies using focus groups of pedestrians and questionnaires completed by pedestrians in the field could shed light on such measures.

CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS

Pedestrians are legitimate users of the transportation system, and their needs should be identified routinely —and appropriate solutions selected—to improve pedestrian safety and access. Deciding where to mark crosswalks is only one consideration in meeting that objective.

The study results revealed that under no condition was the presence of a marked crosswalk alone at an uncontrolled location associated with a significantly lower pedestrian crash rate compared to an unmarked crosswalk. Furthermore, on multilane roads with traffic volumes greater than 12,000 vehicles per day, having a marked crosswalk was associated with a higher pedestrian crash rate (after controlling for other site factors) compared to an unmarked crosswalk. Therefore, adding marked crosswalks alone (i.e., with no engineering, enforcement, or education enhancement) is not expected to reduce pedestrian crashes for any of the conditions included in the study. On many roadways, particularly multilane and high-speed crossing locations, more substantial improvements often are needed for safer pedestrian crossings, such as providing raised medians, installing traffic signals (with pedestrian signals) when warranted, implementing speed-reducing measures, and/or other practices. In addition, development patterns that reduce the speed and number of multilane roads should be encouraged.

Street crossing locations should be routinely reviewed to consider the three following available options:

1. No special provisions needed.

2. Provide a marked crosswalk alone.

3. Install other crossing improvements (with or without a marked crosswalk) to reduce vehicle speeds, shorten the crossing distance, or increase the likelihood of motorists stopping and yielding.

GUIDELINES FOR CROSSWALK INSTALLATION

Marked pedestrian crosswalks may be used to delineate preferred pedestrian paths across roadways under the following conditions:

- At locations with stop signs or traffic signals to direct pedestrians to those crossing locations and to prevent vehicular traffic from blocking the pedestrian path when stopping for a stop sign or red light.

- At nonsignalized street crossing locations in designated school zones. Use of adult crossing guards, school signs and markings, and/or traffic signals with pedestrian signals (when warranted) should be considered in conjunction with the marked crosswalk, as needed.

- At nonsignalized locations where engineering judgment dictates that the number of motor vehicle lanes, pedestrian exposure, average daily traffic (ADT), posted speed limit, and geometry of the location would make the use of specially designated crosswalks desirable for traffic/pedestrian safety and mobility.

Marked crosswalks alone (i.e., without traffic-calming treatments, traffic signals and pedestrian signals when warranted, or other substantial crossing improvement) are insufficient and should not be used under the following conditions:

- Where the speed limit exceeds 64.4 km/h (40 mi/h).

- On a roadway with four or more lanes without a raised median or crossing island that has (or will soon have) an ADT of 12,000 or greater.

- On a roadway with four or more lanes with a raised median or crossing island that has (or soon will have) an ADT of 15,000 or greater.

GENERAL SAFETY CONSIDERATIONS

Since sites in this study were confined to those having no traffic signal or stop sign on the main street approaches to the crosswalk, it follows that these results do not apply to crossings controlled by traffic signals, stop or yield signs, traffic-calming treatments, or other devices. These results also do not apply to school crossings, since such sites were purposely excluded from the site selection process.

The results of this study have some clear implications on the placement of marked crosswalks and the design of safer pedestrian crossings at uncontrolled locations.

Pedestrian crashes are relatively rare at uncontrolled pedestrian crossings (1 crash every 43.7 years per site in this study); however, the certainty of injury to the pedestrian and the high likelihood of a severe or fatal injury in a high-speed crash make it critical to provide a pedestrian-friendly transportation network.

Marked crosswalks alone (i.e., without traffic-calming treatments, traffic signals with pedestrian signals when warranted, or other substantial improvement) are not recommended at uncontrolled crossing locations on multilane roads (i.e., four or more lanes) where traffic volume exceeds approximately 12,000 vehicles per day (with no raised medians) or approximately 15,000 ADT (with raised medians that serve as refuge areas). This recommendation is based on the analysis of pedestrian crash experience, as well as exposure data and site conditions described earlier. To add a margin of safety and/or to account for future increases in traffic volume, the authors recommend against installing marked crosswalks alone on two-lane roads with ADTs greater than 12,000 or on multilane roads with ADTs greater than 9,000 (with no raised median). This study also recommends against installing marked crosswalks alone on roadways with speed limits higher than 64.4 km/h (40 mi/h) based on the expected increase in driver stopping distance at higher speeds. (Few sites were found for this study having marked crosswalks where speed limits exceeded 64.4 km/h (40 mi/h).) Instead, enhanced crossing treatments (e.g., traffic-calming treatments, traffic and pedestrian signals when warranted, or other substantial improvement) are recommended. Specific recommendations are given in table 11 regarding installation of marked crosswalks and other crossing measures. It is important for motorists to understand their legal responsibility to yield to pedestrians at marked and unmarked crosswalks, which may vary from State to State. Also, pedestrians should use caution when crossing streets, regardless of who has the legal right-of-way, since it is the pedestrian who suffers the most physical injury in a collision with a motor vehicle.

On two-lane roads and lower volume multilane roads (ADTs less than 12,000), marked crosswalks were not found to have any positive or negative effect on pedestrian crash rates at the study sites. Marked crosswalks may encourage pedestrians to cross the street at such sites. However, it is recommended that crosswalks alone (without other crossing enhancements) not be installed at locations that may pose unusual safety risks to pedestrians. Pedestrians should not be encouraged to cross the street at sites with limited sight distance, complex or confusing designs, or at sites with certain vehicle mixes (many heavy trucks) or other dangers unless adequate design features and/or traffic control devices are in place.

At uncontrolled pedestrian crossing locations, installing marked crosswalks should not be regarded as a magic cure for pedestrian safety problems. However, marked crosswalks also should not be considered as a negative measure that will necessarily increase pedestrian crashes. Marked crosswalks are appropriate at some locations (e.g., at selected low-speed, two-lane streets at downtown crossing locations) to help channel pedestrians to preferred crossing locations, but other roadway improvements are also necessary (e.g., raised medians, traffic-calming treatments, traffic and pedestrian signals when warranted, or other substantial crossing improvement) when used at other locations. The guidelines presented in table 11 are intended to provide guidance for installing marked crosswalks and other pedestrian crossing facilities.

Note that speed limit was used in table 11 in addition to ADT, number of lanes, and presence of a median. In developing the table, roads with higher speed limits (higher than 64.4 km/h (40 mi/h)) were considered to be inappropriate for adding marked crosswalks alone. This is because virtually no uncontrolled, marked crosswalk sites where speed limits exceed 64.4 km/h (40 mi/h) were found in the 30 U.S. cities used in this study. Thus, these types of high-speed, uncontrolled marked crosswalks could not be included in the analysis. Also, high-speed roadways present added problems for pedestrians and thus require more substantial treatments in many cases. That may be why Germany, Finland, and Norway do not allow uncontrolled crosswalks on roads with high speed limits.[(30)]

For three-lane roads, adding marked crosswalks alone (without other substantial treatments) is generally not recommended for ADTs greater than 12,000, although exceptions may be allowed under certain conditions (e.g., lower speed limits).

If nothing else is done beyond marking crosswalks at an uncontrolled location, pedestrians will not experience increased safety (under any situations included in the analysis). This finding is in some ways consistent with the companion study by Knoblauch et al. that found that marking a crosswalk would not necessarily increase the number of motorists that will stop or yield to pedestrians.[(13)] Research from Europe shows the need for pedestrian improvements beyond uncontrolled crosswalks.[(17,21)]

Table 11. Recommendations for installing marked crosswalks and other needed pedestrian improvements at uncontrolled locations.*

Roadway Type (Number of Travel Lanes and Median Type)	Vehicle ADT ≤ 9,000			Vehicle ADT >9,000 to 12,000			Vehicle ADT >12,000–15,000			Vehicle ADT > 15,000		
	Speed Limit**											
	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)
Two lanes	C	C	P	C	C	P	C	C	N	C	P	N
Three lanes	C	C	P	C	P	P	P	P	N	P	N	N
Multilane (four or more lanes) with raised median***	C	C	P	C	P	N	P	P	N	N	N	N
Multilane (four or more lanes) without raised median	C	P	N	P	P	N	N	N	N	N	N	N

* These guidelines include intersection and midblock locations with no traffic signals or stop signs on the approach to the crossing. They do not apply to school crossings. A two-way center turn lane is not considered a median. Crosswalks should not be installed at locations that could present an increased safety risk to pedestrians, such as where there is poor sight distance, complex or confusing designs, a substantial volume of heavy trucks, or other dangers, without first providing adequate design features and/or traffic control devices. Adding crosswalks alone will not make crossings safer, nor will they necessarily result in more vehicles stopping for pedestrians. Whether or not marked crosswalks are installed, it is important to consider other pedestrian facility enhancements (e.g., raised median, traffic signal, roadway narrowing, enhanced overhead lighting, traffic-calming measures, curb extensions), as needed, to improve the safety of the crossing. These are general recommendations; good engineering judgment should be used in individual cases for deciding where to install crosswalks.

** Where the speed limit exceeds 64.4 km/h (40 mi/h), marked crosswalks alone should not be used at unsignalized locations.

*** The raised median or crossing island must be at least 1.2 m (4 ft) wide and 1.8 m (6 ft) long to serve adequately as a refuge area for pedestrians, in accordance with MUTCD and American Association of State Highway and Transportation Officials (AASHTO) guidelines.

C = Candidate sites for marked crosswalks. Marked crosswalks must be installed carefully and selectively. Before installing new marked crosswalks, an engineering study is needed to determine whether the location is suitable for a marked crosswalk. For an engineering study, a site review may be sufficient at some locations, while a more indepth study of pedestrian volume, vehicle speed, sight distance, vehicle mix, and other factors may be needed at other sites. It is recommended that a minimum utilization of 20 pedestrian crossings per peak hour (or 15 or more elderly and/or child pedestrians) be confirmed at a location before placing a high priority on the installation of a marked crosswalk alone.

P = Possible increase in pedestrian crash risk may occur if crosswalks are added without other pedestrian facility enhancements. These locations should be closely monitored and enhanced with other pedestrian crossing improvements, if necessary, before adding a marked crosswalk.

N = Marked crosswalks alone are insufficient, since pedestrian crash risk may be increased by providing marked crosswalks alone. Consider using other treatments, such as traffic-calming treatments, traffic signals with pedestrian signals where warranted, or other substantial crossing improvement to improve crossing safety for pedestrians.

In some situations (e.g., low-speed, two-lane streets in downtown areas), installing a marked crosswalk may help consolidate multiple crossing points. Engineering judgment should be used to install crosswalks at preferred crossing locations (e.g., at a crossing location at a streetlight as opposed to an unlit crossing point nearby). While overuse of marked crossings at uncontrolled locations should be avoided, higher priority should be placed on providing crosswalk markings where pedestrian volume exceeds about 20 per peak hour (or 15 or more elderly pedestrians and/or children per peak hour).

Marked crosswalks and other pedestrian facilities (or lack of facilities) should be routinely monitored to determine what improvements are needed.

POSSIBLE MEASURES TO HELP PEDESTRIANS

Although simply installing marked crosswalks by themselves cannot solve pedestrian crossing problems, the safety needs of pedestrians must not be ignored. More substantial engineering and roadway treatments need to be considered, as well as enforcement and education programs and possibly new legislation to provide safer and easier crossings for pedestrians at problem locations. Transportation and safety engineers have a responsibility to consider all types of road users in roadway planning, design, and maintenance. Pedestrians must be provided with safe facilities for travel.

A variety of pedestrian facilities have been found to improve pedestrian safety and/or ability to cross the street under various conditions. (See references 16, 31, 32, 33, and 34.) Examples of pedestrian improvements include:

- Providing raised medians (figure 31) or intersection crossing islands on multilane roads, which can significantly reduce the pedestrian crash rate and also facilitate street crossing. Also, raised medians may provide aesthetic improvement and may control access to prevent unsafe turns out of driveways. Refuge islands should be at least 1.2 m (4 ft) wide (and preferably 1.8 to 2.4 m (6 to 8 ft) wide) and of adequate length to allow pedestrians to stand and wait for gaps in traffic before crossing the second half of the street. When built, the landscaping should be designed and maintained to provide good visibility between pedestrians and approaching motorists.

Figure 31. Raised medians and crossing islands can improve pedestrian safety on multilane roads.

- Installing traffic signals (with pedestrian signals), where warranted (see figures 32 and 33).

Figure 32. Pedestrian signals help accommodate pedestrian crossings on some high-volume or multilane roads.

Figure 33. Traffic signals are needed to improve pedestrian crossings on some high-volume or multilane roads.

- Reducing the effective street crossing distance for pedestrians by narrowing the roads or by providing curb extensions (figures 34 and 35) and/or raised pedestrian islands at intersections.

Figure 34. Curb extensions at midblock locations reduce crossing distance for pedestrians.

Figure 35. Curb extensions at intersections reduce crossing distance for pedestrians.

Another option is to reduce four-lane undivided road sections to two through-lanes with dual left-turn lanes or left-turn bays. Reducing the width of the lanes may result in slower speeds in some situations, which can benefit pedestrians who are attempting to cross the street. This creates enough space to provide median islands. The removal of a travel lane may also allow enough space for sidewalks and/or bike lanes.

- Installing traffic-calming measures may be appropriate on certain streets to slow vehicle speeds and/or reduce cut-through traffic, as described in a 1999 report titled *Traffic Calming: State of the Practice.*[24]

Traffic-calming measures include raised crossings (raised crosswalks, raised intersections) (see figure 36), street narrowing measures (chicanes, slow points, “skinny street” designs), and intersection designs (traffic minicircles, diagonal diverters). Note that some of these traffic-calming measures may not be appropriate on major collector or arterial streets.

Figure 36. Raised crosswalks can control vehicle speeds on local streets at pedestrian crossings.

- Providing adequate nighttime lighting for pedestrians (figure 37). Adequate nighttime lighting should be provided at marked crosswalks and areas near churches, schools, and community centers with nighttime pedestrian activity.

Figure 37. Adequate lighting can improve pedestrian safety at night.

- Designing safer intersections for pedestrians (e.g., crossing islands, tighter turn radii).

- Providing narrower widths and/or access management (e.g., consolidation of driveways).

- Constructing grade-separated crossings or pedestrian-only streets (see figure 38). Grade-separated crossings are very expensive and should only be considered in extreme situations, such as where pedestrian crossings are essential (e.g., school children need to cross a six-lane arterial street), street-crossing at-grade is not feasible for pedestrians, and no other measures are considered to be appropriate. Grade-separated crossings must also conform to Americans with Disabilities Act (ADA) requirements.

Figure 38. Grade-separated crossings sometimes are used when other measures are not feasible to provide safe pedestrian crossings.

- Using various pedestrian warning signs, flashers, and other traffic control devices to supplement marked crosswalks (figure 39). However, the effects of supplemental signs and other devices at marked crosswalks are not well known under various roadway conditions. According to the MUTCD, pedestrian crossing signs should only be used at locations that are unusually hazardous, where crossing activity is unexpected, or at locations where pedestrian crossing activity is not readily apparent.[2]

Figure 39. Pedestrian warning signs sometimes are used to supplement crosswalks.

- Building narrower streets in new communities to achieve desired vehicle speeds.

- Increasing the frequency of two-lane or three-lane arterials when designing new street networks so that fewer multilane arterials are required.

It is recommended that parking be eliminated on the approach to uncontrolled crosswalks to improve vision between pedestrians and motorists. The 2000 Uniform Vehicle Code specifies that parking should be prohibited within an intersection on a crosswalk, and within 6.1 m (20 ft) of a crosswalk at an intersection (which could be increased to 9.1 to 15.25 m (30 to 50 ft) in advance of a crosswalk on a high-speed road.[1]

Some agencies provide fences or railings in the raised medians of multilane roads that direct pedestrians to the right; this results in a two-stage crossing and increases the likelihood of pedestrians looking for vehicles coming from their right in the second half of the street (figures 40 and 41).

Figure 40. Fences or railings in the median direct pedestrians to the right and may reduce pedestrian crashes on the second half of the street.

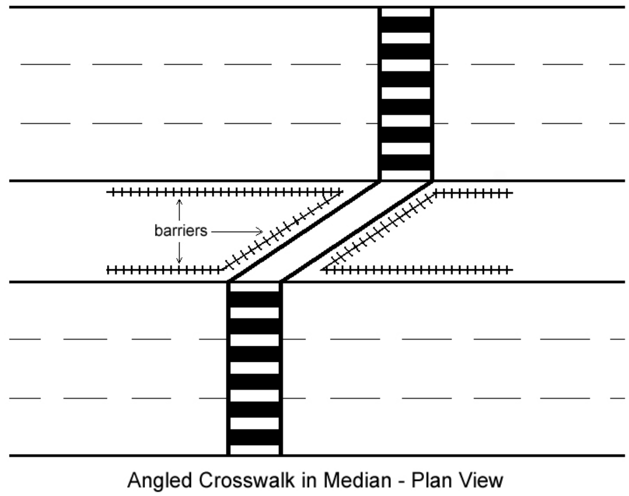


Figure 41. Angled crosswalks with barriers can direct pedestrians to face upstream and increase the pedestrian's awareness of traffic.

Proper planning and land use practices should be applied to benefit pedestrians. For example, busy arterial streets should be used as a boundary for school attendance or school busing. Major pedestrian destinations should not be separated from each other or from their parking facilities by a wide, busy street.

The MUTCD pedestrian signal warrant should be reviewed to determine whether the warrant should be modified to more easily allow for installing a traffic signal at locations where pedestrians cannot safely cross the street (and where no alternative safe crossings exist nearby).

Consideration must always include pedestrians with disabilities and proper accommodations must be provided to meet ADA requirements.

There should be continued research, development, and testing/explanation of innovative traffic control and roadway design alternatives that could provide improved access and safety for pedestrians attempting to cross streets. For example, in-pavement warning lights, variations in pedestrian warning and regulatory signs (including signs placed in the centerline to reinforce motorists yielding to pedestrians), roadway narrowing, traffic-calming measures, and automated speed-monitoring techniques deserve further research and development to determine their feasibility under various traffic and roadway conditions.

More details about these and other pedestrian facilities are contained in the *Pedestrian Facilities User's Guide: Providing Safety and Mobility,*[(22)] and in the Institute for Transportation Engineers (ITE) publications *Design and Safety of Pedestrian Facilities*[(35)] and *The Traffic Safety Toolbox* (chapter 19, "Designing for Pedestrians").[(36)]

Table 11 provides initial guidance on whether an uncontrolled location might be a candidate for a marked crosswalk alone and/or whether additional geometric and/or traffic control improvements are needed. As a part of the review process for pedestrian crossings, an engineering study should be used to analyze other factors, including (but not limited to), gaps in traffic, approach speed, sight distances, illumination, the needs of special populations, and the distance to the nearest traffic signal.

The spacing of marked crosswalks should also be considered so that they are not placed too close together. Overuse of marked crosswalks may breed driver disrespect for them, and a more conservative use of crosswalks generally is preferred. Thus, it is recommended that in situations where marked crosswalks alone are acceptable (see table 11) a higher priority be placed on their use at locations having a minimum of 20 pedestrian crossings per peak hour (or 15 or more elderly and/or child pedestrians per peak hour). In all cases, good engineering judgment must be applied.

OTHER CONSIDERATIONS

Distance of Marked Crosswalks from Signalized Intersections

Marked crosswalks should not be installed in close proximity to signalized intersections (which may or may not have marked crosswalks); instead, pedestrians should be encouraged to cross at the signal in most situations. The minimum distance from a signal for installing a marked crosswalk should be determined by local traffic engineers based on pedestrian crossing demand, type of roadway, traffic volume, and other factors. The objective of adding a marked crosswalk is to channel pedestrians to safer crossing points. It should be understood, however, that pedestrian crossing behavior may be difficult to control merely by adding marked crosswalks. The new marked crosswalk should not unduly restrict platooned traffic, and also should be consistent with marked crosswalks at other unsignalized locations in the area.

Alternative Treatments

In addition to installing marked crosswalks—or in some cases, instead of installing marked crosswalks—there are other treatments that should be considered to provide safer and easier crossings for pedestrians. Examples of these pedestrian improvements:

- Provide raised medians (or raised crossing islands) on multilane roads.

- Install traffic signals and pedestrian signals where warranted and where serious pedestrian crossing problems exist.

- Reduce the exposure crossing distance for pedestrians by:
  - Providing curb extensions.
  - Providing pedestrian median refuge islands.
  - Reducing four-lane undivided road sections to two through lanes with a left-turn bay (or a two-way left-turn lane), sidewalks, and bicycle lanes.

- Locate bus stops on the far side of uncontrolled marked crosswalks.

- Install traffic-calming measures to slow vehicle speeds and/or reduce cut-through traffic. Such measures may include:
  - Raised crossings (raised crosswalks, raised intersections).
  - Street-narrowing measures (chicanes, slow points, "skinny street" designs).
  - Intersection designs (traffic minicircles, diagonal diverters).
  - Other treatments are available; see *Traffic Calming: State of the Practice* for further details.(24)

  Some of these traffic-calming measures are better suited to local or neighborhood streets than to arterial streets.

- Provide adequate nighttime street lighting for pedestrians in areas with nighttime pedestrian activity where illumination is inadequate.

- Design safer intersections and driveways for pedestrians (e.g., crossing islands, tighter turn radii), which take into consideration the needs of pedestrians.

In developing the proposed U.S. guidelines for marked crosswalks and other pedestrian measures, consideration was given not only to the research results in this study, but also to crosswalk guidelines and related pedestrian safety research in Sweden, England, Canada, Australia, the Netherlands, Germany, Norway, and Hungary. (See references 17, 18, 19, 20, 21, 33, and 37.) More details on pedestrian facilities are given in the 2001 *Pedestrian Facilities User's Guide: Providing Safety and Mobility*,(22) *Design and Safety of Pedestrian Facilities*,(35) *The Traffic Safety Toolbox*,(36) and *Making Streets That Work—Neighborhood Planning Tool*,(38) among others.

APPENDIX A. DETAILS OF DATA COLLECTION METHODS

This study evaluated the safety of marked and unmarked crosswalks at uncontrolled locations, that is, at crossings with no traffic signals or stop signs on the approach. Therefore, the data collection activities were undertaken to: (1) select suitable marked and unmarked crosswalks, and (2) obtain pedestrian crash and exposure data. Data collection was conducted in five steps, which are discussed below.

STEP 1—INVENTORY CROSSWALKS AND CONTROL SITES

Through conversations with city traffic engineers and pedestrian/bike coordinators, 28 cities and 2 counties were selected for crosswalk inventory. Either the Highway Safety Research Center (HSRC) staff or local data collectors performed the inventory by driving along selected streets in each city. These streets were in the downtown area, other commercial areas, and built-up residential areas, where marked crosswalks at uncontrolled locations were known or expected to be present. The inventory data collection form is shown in figure 41.

STEP 2—RECORD DATA ON INVENTORY SHEETS

For most cities, the inventory of crosswalk and comparison sites was recorded on videotape. An HSRC staff member watched the videotapes and completed a crosswalk inventory form (see figure 42). Several local data collectors filled out the inventory form directly and mailed the completed forms to HSRC. This process was used both to select unmarked crosswalks (i.e., matched comparison sites—see step 3) and to extract relevant information about the marked crosswalks.

Location Description

For record-keeping purposes, each marked crosswalk and matching comparison site was assigned a site number. Street or route refers to the main road that the pedestrian crosses, and intersecting street is the side street that crosses or forms a "T" with the main road. The leg (east, west, north, south) where the crosswalk or comparison site exists was recorded. If there were crosswalks on both legs (east and west or north and south) of the same intersection, they were assigned two site numbers and listed separately. Midblock location was noted when appropriate, along with the intersecting streets to either side. A total of 827 intersection and 173 midblock marked crosswalks were used in the analysis, with an equal number of matched comparison sites.

Number of Lanes

The total number of lanes, including any turn lanes, that a pedestrian must cross was recorded. Figure 43 shows the distribution of the 1,000 marked crosswalks that were used in the analysis according to the number of lanes. Nearly half (45.8 percent) of the sites were on two-lane roads, with about one third of the sites on four-lane roads.

Median Type

The median type was recorded as either none, raised, or painted. Two-way left-turn lanes were considered to be traffic lanes. There was no median for about two-thirds of the 1,000 marked (and unmarked) crosswalks that were used in the analysis. Raised medians were present for 14 percent of the marked (and unmarked) crosswalks, and painted medians, about 15 percent.

One-Way or Two-Way

About 86 percent of the crosswalks were on two-way streets, with 14 percent on one-way streets.

City/County: ______________ Data Recorder ______________ Date ______________

State: ______________

Site No.	Location Description: Street or Route	Leg (N,E,S,W)	Intersecting Street*	Midblock Location	Number of Lanes	Median Type	1-way or 2-way	Type of Crosswalk/ Crossing Treatment	Condition of Crosswalk	Area Type: CBD	Fringe	Resid.	Estimated Ped. ADT (check one): <50	50-200	>200	Speed Limit	Traffic ADT
a. Marked																	
b. Control								None	NA								
a. Marked																	
b. Control								None	NA								
a. Marked																	
b. Control								None	NA								
a. Marked																	
b. Control								None	NA								
a. Marked																	
b. Control								None	NA								
a. Marked																	
b. Control								None	NA								
a. Marked																	
b. Control								None	NA								
a. Marked																	
b. Control								None	NA								

*Use Only for Unsignalized Crossings at Intersections or Midblocks

Figure 42. Pedestrian crosswalk inventory form.

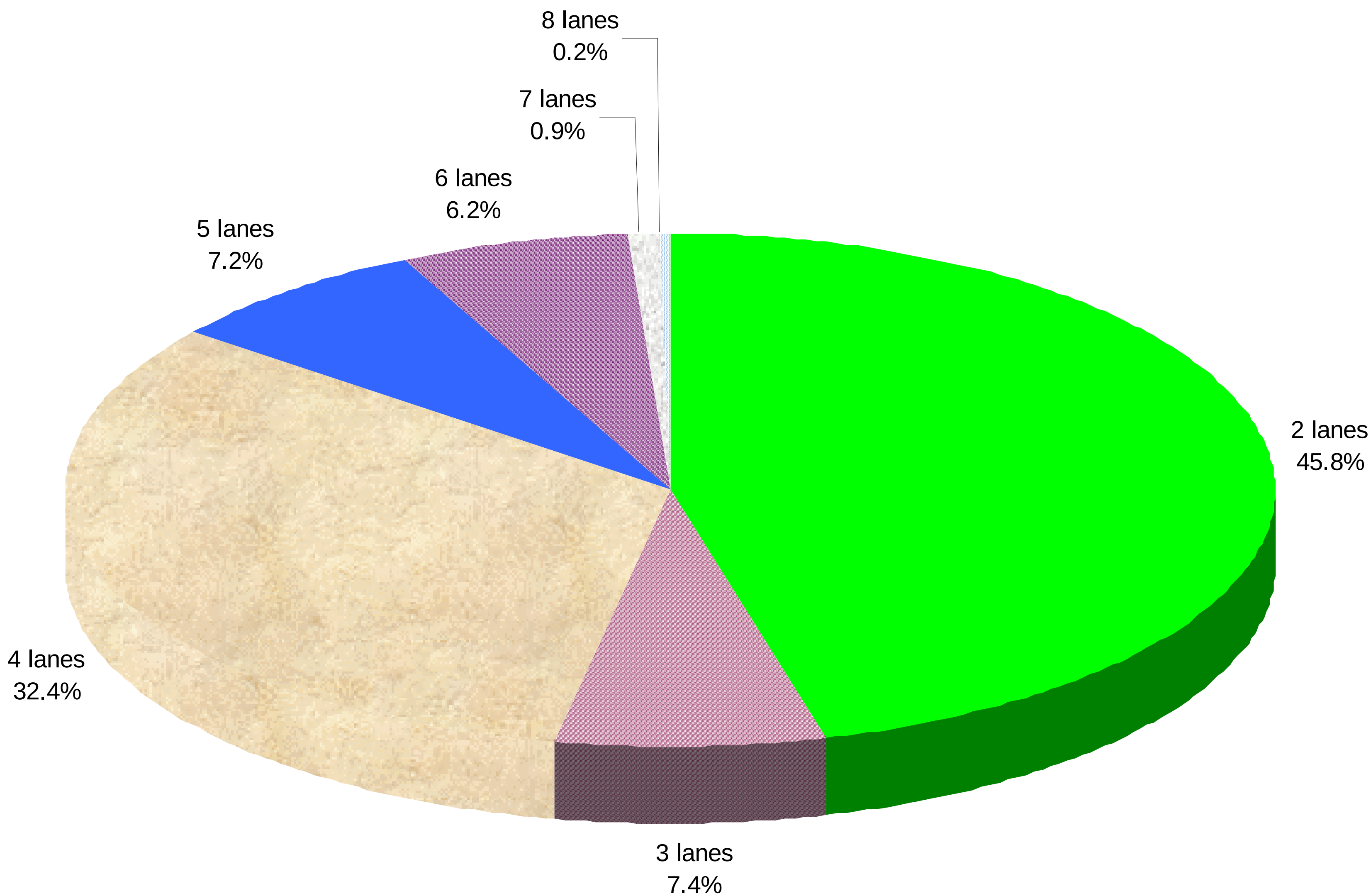


Figure 43. Number of lanes for marked crosswalks.

Type of Crosswalk

Crosswalks usually had standard markings (two parallel white lines). Various types of crosswalk markings are illustrated in figure 7 (shown in chapter 2).

The presence of any signs or beacons was also noted. Types of signs and beacons included:

Advanced Crosswalk Sign:	Mounted in advance of the crosswalk, to warn drivers that they are approaching a crosswalk.
Crosswalk Sign:	Placed at the crosswalk.
Overhead Sign:	An overhead pedestrian warning sign (in advance or at the crosswalk).
Flash:	A flashing beacon placed next to the crosswalk.
Overhead Flash:	A flashing beacon placed over the crosswalk.

Only 19 of the 2,000 sites (less than 1 percent) had any of these supplemental devices. Sites were selected to minimize the number of signs or beacons.

Condition of Crosswalk Markings

The condition of the marked crosswalk was recorded as excellent (E), good (G), fair (F), or poor (P). There was no way to determine the condition of the markings over the entire study period.

Area Type

Each crosswalk was in a central business district (CBD), fringe, or residential area.

CBD:	CBDs are downtown areas and are characterized by moderate to heavy pedestrian volumes, lower vehicle speeds, and dense commercial activity.
Fringe:	Fringe areas include suburban and commercial retail activity areas, and typically have moderate pedestrian volumes. These areas may also include high-rise apartments.
Residential:	Residential development would generally correspond to lower pedestrian volumes.

Of the 2,000 marked and unmarked crosswalks that were used in the analysis, 199 (10 percent) were in a CBD, 1,093 (54.7 percent) were in fringe areas, and 708 (35.4 percent) were in residential areas.

Estimated Pedestrian ADT

For each crosswalk and control site, the pedestrian ADT was based on expanding short-term pedestrian counts based on adjustment factors, as described below.

Pedestrians and motorists are out and about at all hours of the day and night. As a result, pedestrian crashes may happen at any hour. Therefore, to calculate crash rates, 24-hour daily pedestrian volumes are needed. It was not feasible to count pedestrians for every hour at each of the 1,000 marked crosswalks and 1,000 unmarked comparison sites. Instead, pedestrians were counted by 15-minute intervals for a total of 1 hour at each site. These counts were conducted on weekdays during daylight hours. The earliest count intervals started at 7 a.m., and the latest count intervals ended at 6 p.m.

Daily pedestrian volumes at each marked crosswalk and unmarked comparison site were then estimated from these 1-hour counts. If pedestrian activity were evenly distributed in each hour of the day, then each hour would comprise about 4.2 percent (100 percent ÷ 24 hours) of the daily total. The 1-hour count could simply be divided by an hourly adjustment factor of 4.2 percent (0.042) to get the all-day volume. In reality, though, hourly volumes vary throughout the day with greater pedestrian activity during certain peak periods. Suppose that 10 out of 100 (10 percent) of the day's pedestrians are counted between 5 p.m. and 6 p.m. If that hour's count were divided by 0.042, the true daily volume would be overestimated (10 / 4.2 percent = 238). Likewise, if 2 out of 100 (2 percent) are counted between 3 a.m. and 4 a.m., dividing that count by 4.2 percent would underestimate the true daily volume (2 / 0.042 = 48). Therefore, adjustment factors for each hour of the day are needed to obtain a more accurate estimate of the true daily volume.

The adjustment factors were derived from two data sets. First, all-day (8- to 12-hour) pedestrian counts were undertaken at 11 marked crosswalks and 11 unmarked comparison sites. Second, adjustments were calculated based on the method used by Zegeer et al. for 24-hour pedestrian counts in Seattle, WA.[39] They found that the 12-hour period from 7 a.m. to 7 p.m. represented 86 percent of the 24-hour daily pedestrian volume. Separate adjustment factors were used for each area type (CBD, fringe, and residential), because the area types have different patterns of hourly pedestrian volume. It was determined that crosswalks and comparison sites had similar pedestrian volume distributions by the time of day, so the same adjustment factor was used for a crosswalk and its matched comparison site.

The adjustment factors by time of day and area type appear in table 12. The 1-hour pedestrian counts at each crosswalk and comparison site were divided by the appropriate factor to obtain the 24-hour daily pedestrian volume. For example, suppose 100 pedestrians were counted between 9 a.m. and 10 a.m. at a CBD location. Then the daily pedestrian volume was estimated to be 100 / 4.9 percent = 2,041 pedestrians. At a fringe location, the daily volume would be 100 / 8.3 percent = 1,205 pedestrians. If the count interval was spread out over two periods, such as 9:30 a.m. to 10:30 a.m., then the adjustment factor for 9 a.m. to 10 a.m. was applied to the first part of the count, and the factor for 10 a.m. to 11 a.m. was applied to the second part of the count.

Table 12. Adjustment factors by time of day and area type used to obtain estimated pedestrian ADT.

Time of Day	Area Type		
	CBD (%)	Fringe (%)	Residential (%)
7 a.m. – 8 a.m.	2.4	6.9	4.8
8 a.m. – 9 a.m.	2.4	6.0	3.9
9 a.m. – 10 a.m.	4.9	8.3	5.7
10 a.m. – 11 a.m.	8.2	7.1	8.7
11 a.m. – 12 N	10.4	7.7	8.2
12 N – 1 p.m.	11.4	9.0	8.4
1 p.m. – 2 p.m.	11.6	6.3	6.9
2 p.m. – 3 p.m.	8.5	8.5	5.9
3 p.m. – 4 p.m.	16.2	8.1	7.4
4 p.m. – 5 p.m.	4.4	7.9	9.3
5 p.m. – 6 p.m.	3.5	8.1	11.4
Remaining 13 hours	16.0	16.0	19.5

At a few of the 2,000 sites, no pedestrians were observed during the crossing period. The pedestrian crash rate is computed as the number of pedestrian crashes divided by the pedestrian crossing volume. The pedestrian crossing volume is the product of the pedestrian ADT times the number of years times 365 days per year. Thus, assuming a zero hourly pedestrian volume is not only questionable, but also results in a pedestrian exposure of 0. Since it is not possible to use 0 as a value of exposure in computing pedestrian crash rates (i.e., since dividing by zero yields a rate of infinity), a count of 0.25 was substituted for 0 as the hourly pedestrian count for computing pedestrian ADT for use in computing pedestrian crash rates.

Unmarked crosswalks (the control sites) tended to have lower pedestrian volumes than marked crosswalks. This may be the result of pedestrians being drawn to marked crosswalks and/or due to crosswalks being marked at locations with more pedestrian activity.

Speed Limit

Speed limits were obtained from local traffic engineers, local data collectors in the field, and watching videotapes of the crosswalk inventory. The most common speed limits were 48.3 km/h (30 mi/h) (37.4 percent), 40.25 km/h (25 mi/h) (33.0 percent), and 56.35km/h (35 mi/h) (22.8 percent).

Traffic ADT

Traffic volumes were obtained from local traffic engineers. Figure 44 shows that marked crosswalks had similar traffic volumes to the unmarked crosswalks (the comparison sites). This was to be expected, because the comparison sites were chosen to be close to, and similar to, their matching marked crosswalks.

STEP 3—IDENTIFY SUITABLE CONTROL SITES

Each crosswalk was matched with a control site that was close to the crosswalk and had similar characteristics (such as number of lanes, area type, estimated traffic and pedestrian volumes, and one-way or two-way traffic flow), but which did not have crosswalk markings, stop sign, or traffic signal. This was done either by watching the video or in the field. For example, if a marked crosswalk was present on the east leg of an intersection but not on the west leg, then the west leg was often a good control site. If the east and west legs of an intersection had marked crosswalks, then the east and west legs of a nearby intersection along the same main road were often good control sites. The data items described in step 2 were recorded for the control sites.

Some marked crosswalks were excluded because suitable control sites could not be found, or they were school crossings. A total of 1,000 marked crosswalks, each matched with a control site (for a total of 1,000 control sites), was used in the analysis. The number of crosswalks by city is given in table 13.

STEP 4—COUNT PEDESTRIANS

Local data collectors were hired to count the number of pedestrians at the crosswalks and their corresponding control sites. Each location was counted in 15-minute intervals for one hour. At 11 crosswalks and 11 control sites, pedestrians were counted for 8 to 12 hours. These longer, all-day counts were used as the basis from which daily pedestrian volumes at each crosswalk and control site were estimated from the one-hour counts. All counts were done on weekdays.

STEP 5—OBTAIN CRASH DATA

Local city contacts provided crash data and hard-copy police reports for vehicle-pedestrian crashes that occurred at or near the crosswalks and comparison sites, for an average of about 5 years per site. Some cities had more than 5 years of crash data available, while other cities had 6 years of data that was available for use.

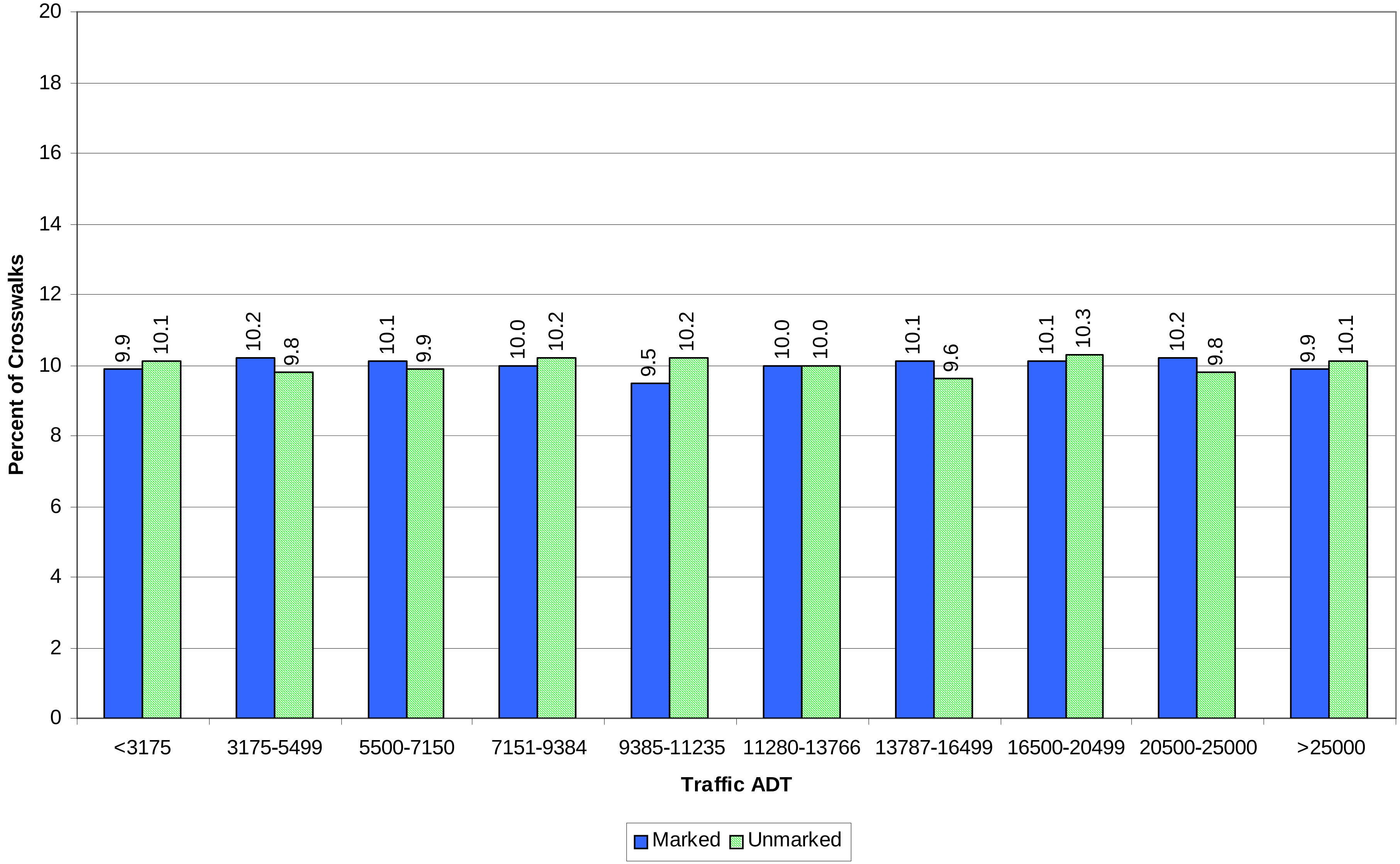


Figure 44. Marked and unmarked crosswalks had similar traffic ADT distributions.

Table 13. The number of marked crosswalks that were used in this study, by city or county.

City or County	Number of Crosswalks		City or County	Number of Crosswalks	
	Marked	Unmarked		Marked	Unmarked
Austin, TX	24	24	Orlando, FL	20	20
Baltimore, MD	30	30	Phoenix, AZ	36	36
Baltimore County, MD	11	11	Pittsburgh, PA	18	18
Cambridge, MA	46	46	Portland, OR	32	32
Cincinnati, OH	42	42	Raleigh, NC	14	14
Cleveland, OH	55	55	Salt Lake City, UT	18	18
Durham, NC	11	11	San Francisco, CA	91	91
Fort Worth, TX	28	28	Scottsdale, AZ	8	8
Gainesville, FL	45	45	Seattle, WA	102	102
Glendale, AZ	12	12	St. Louis, MO	15	15
Kansas City, MO	29	29	St. Louis County, MO	24	24
Madison, WI	29	29	Tempe, AZ	1	1
Milwaukee, WI	68	68	Topeka, KS	25	25
New Orleans, LA	80	80	Tucson, AZ	22	22
Oakland, CA	45	45	Winter Park, FL	19	19
			Totals (all cities)	**1,000**	**1,000**

Crash rates were normalized based on number of years of data. A total of 229 crashes (188 at marked crosswalks and 41 at control sites) occurred at the 2,000 sites and were used in the analysis.
Local traffic engineers and police departments provided crash data and hard-copy police crash reports for the marked and unmarked crosswalks. For each marked crosswalk and matching unmarked crosswalk, data and reports were obtained for the same 3- to 5- year period. The exact years varied from one city to another, depending on the data and reports that each city had available.

The crash reports were read to determine the crash type and to obtain information on other crash variables, such as pedestrian age, injury severity, and time of day. The crash type and other information were entered into a database for analysis.

Some crashes were eliminated because they did not occur at the crosswalks (or within 3 m (10 ft) of the crosswalk) of interest. For example, if a traffic engineer included Crash #1 among the crashes at Crosswalk #1, but it was later determined that Crash #1 actually occurred somewhere else, then Crash #1 would have been eliminated. The analysis resulted in the confirmation of 229 total pedestrian crashes. Of these, 188 occurred at marked crosswalks and 41 occurred at unmarked crosswalks.

APPENDIX B. STATISTICAL TESTING OF THE FINAL CRASH PREDICTION MODEL

To test the final crash prediction model in the terms of validity for the available database, several types of tests were conducted. These tests included:

- Goodness-of-fit.
- Test for functional form.
- Residuals.

GOODNESS-OF-FIT

Below is as excerpt from the PROC GENMOD output (table 14). In assessing the goodness-of-fit of the negative binomial regression model for crosswalks, we can see that the scaled deviance and the Pearson chi-square are small indicating that the model fits the data well.

Table 14. Criteria for assessing goodness-of-fit negative binomial regression model.

Criteria	DF	Value	Value/DF
Deviance	1990	609.5499	0.3063
Scaled Deviance	1990	609.5499	0.3063
Pearson chi-square	1990	2769.9029	1.3919
Scaled Pearson χ^2	1990	2769.9029	1.3919
Log Likelihood		−548.7469	

TEST FOR FUNCTIONAL FORM

We can test for overdispersion with a likelihood ratio test based on Poisson and negative binomial distributions. This test tests equality of the mean and the variance imposed by the Poisson distribution against the alternative that the variance exceeds the mean. For the negative binomial distribution, the variance = mean + k mean^2 (k> = 0, the negative binomial distribution reduces to Poisson when k = 0). The null hypothesis is: H_0: k = 0 and the alternative hypothesis is: H_a: k>0.

To test the functional form, we used the likelihood ratio test, that is, compute LR statistic, -2 (LL (Poisson) – LL (negative binomial)). The asymptotic distribution of the LR statistic has probability mass of one half at zero and one half – chi-square distribution with 1 df.[40] To test the null hypothesis at the significance level α, use the critical value of chi-square distribution corresponding to significance level 2α, that is reject H_0 if LR statistic > $\chi^2_{(1-2\alpha,\ 1\ df)}$.

Table 15 is an excerpt from the PROC GENMOD output for a Poisson regression model with the same independent variables are is the final negative binomial model.

Table 15. Criteria for assessing goodness-of-fit Poisson regression model.

Criteria	DF	Value	Value/DF
Deviance	1990	881.5022	0.4430
Scaled Deviance	1990	881.5022	0.4430
Pearson Chi-Square	1990	3432.5818	1.7249
Scaled Pearson X2	1990	3432.5818	1.7249
Log Likelihood		−568.4558	

$$-2\,(LL\,(\text{Poisson}) - LL\,(\text{negative binomial})) =$$
$$-2*(-568.4558-(-548.7469)) =$$
$$2*(568.4558-548.7469) = 39.4178$$

Thus, the null hypothesis is rejected for $\alpha = 0.01$, and we conclude that the Poisson distribution is inadequate for this model.[40]

RESIDUALS

Because generalized estimating equations (GEE) were used, the interpretation of residuals is problematic and no residual analysis was undertaken.

MULTICOLLINEARITY

Certainly multicollinearity is an issue, because the marked crosswalk and the unmarked crosswalk were matched on geographic terms, thus the number of lanes, median type, and traffic ADT are distributed very similarly in the marked and the unmarked crosswalks.

Multicollinearity was explored using the regression diagnostics suggested by Belsley, Kuh, and Welsch.[41] They suggest two different measures: variance inflation factor (VIF) and the proportion of variation. VIF gauges the influence potential near dependencies may have on the estimation of the standard error of the estimate of the regression parameters. The proportion of variation is a diagnostic which permits the detection of morel complex dependencies. For the final model with predictor variables, the values were: an indicator for marked versus unmarked, pedestrian ADT, and traffic ADT; two indicators for number of lanes; two indicators for type of median; an interaction between the indicator for marked versus unmarked and pedestrian ADT; and an interaction between indicator for marked versus unmarked and traffic ADT. The largest VIF was 4.0; this is not high (VIF < 10), however, it is more than the suggested criterion of VIF > 1.55. Thus, the VIF for indicator for marked versus unmarked VIF = 3.5, traffic ADT, VIF = 2.5, and the interaction of these two predictor variables VIF = 4.0. There is some variance inflation in this model. Since none of the VIF are greater than 10, we can conclude that the model has not been degraded by collinearity. We should interpret the results with some care, because three predictors have VIFs greater than 1.55.

The proportion of variation suggested by Belsley, Kuh, and Welsch with a condition index of 9.4 suggests a weak dependency between the three predictors: indicator for marked versus unmarked, traffic ADT, and the interaction of these two predictor variables. It is not surprising that an interaction is correlated with the main factors.

In conclusion, the model does have a weak dependency among the predictor variables. This does not inflate the variance too much; thus, reasonable tests may be conducted. The mild nature of the collinearity does not present a threat to the interpretability of the model.[41]

APPENDIX C. PLOTS OF EXPECTED PEDESTRIAN CRASHES BASED ON THE FINAL NEGATIVE BINOMIAL PREDICTION MODEL

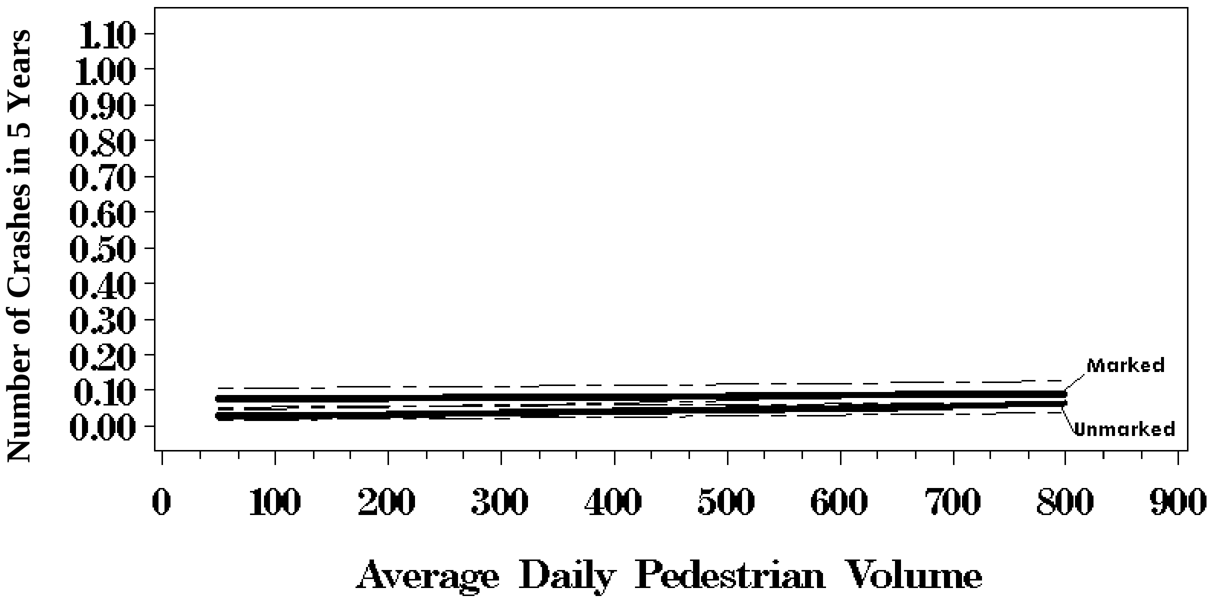


Figure 45. Response curves with 95 percent confidence intervals based on negative binomial regression model, two lanes with no median, average daily motor vehicle traffic = 10,000.

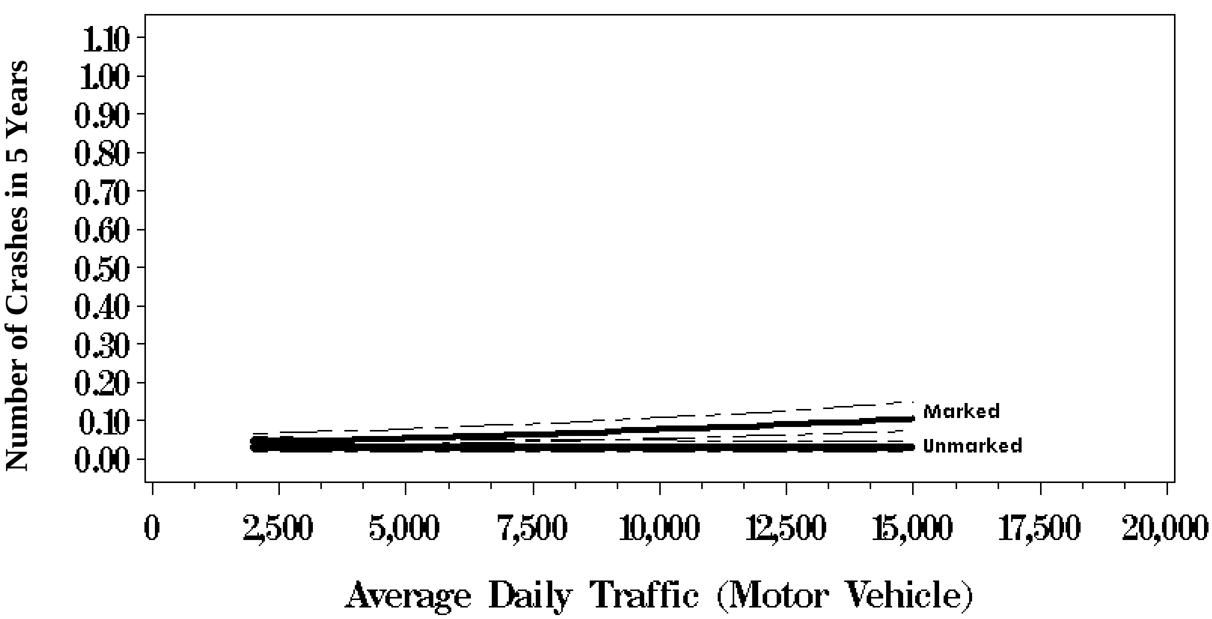


Figure 46. Response curves with 95 percent confidence intervals based on negative binomial regression model, two lanes with no median, average daily pedestrian volume = 100.

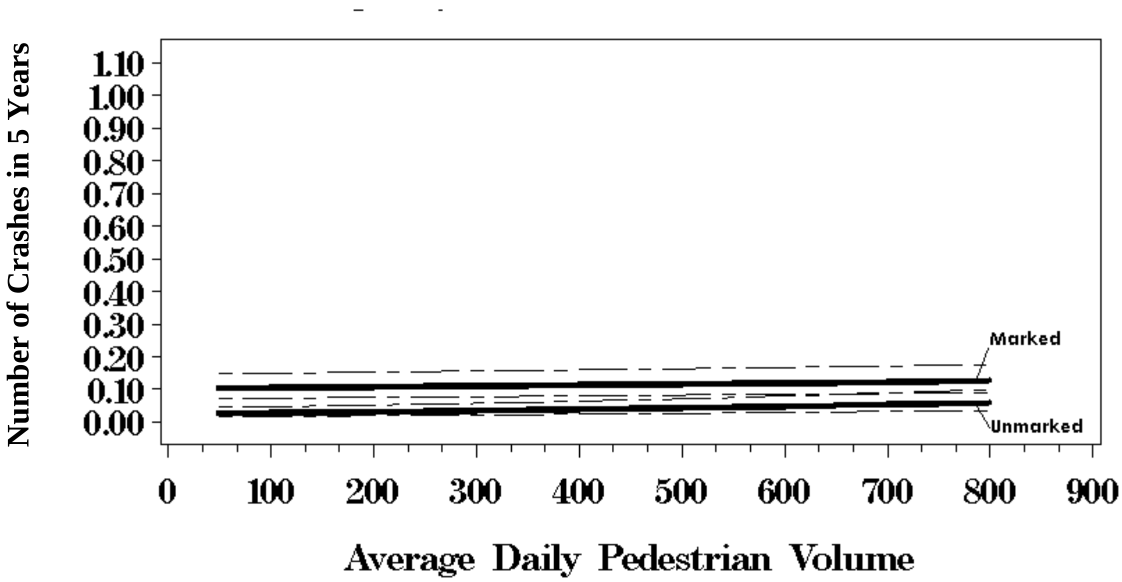


Figure 47. Response curves with 95 percent confidence intervals based on negative binomial regression model, two lanes with no median, average daily motor vehicle traffic = 15,000.

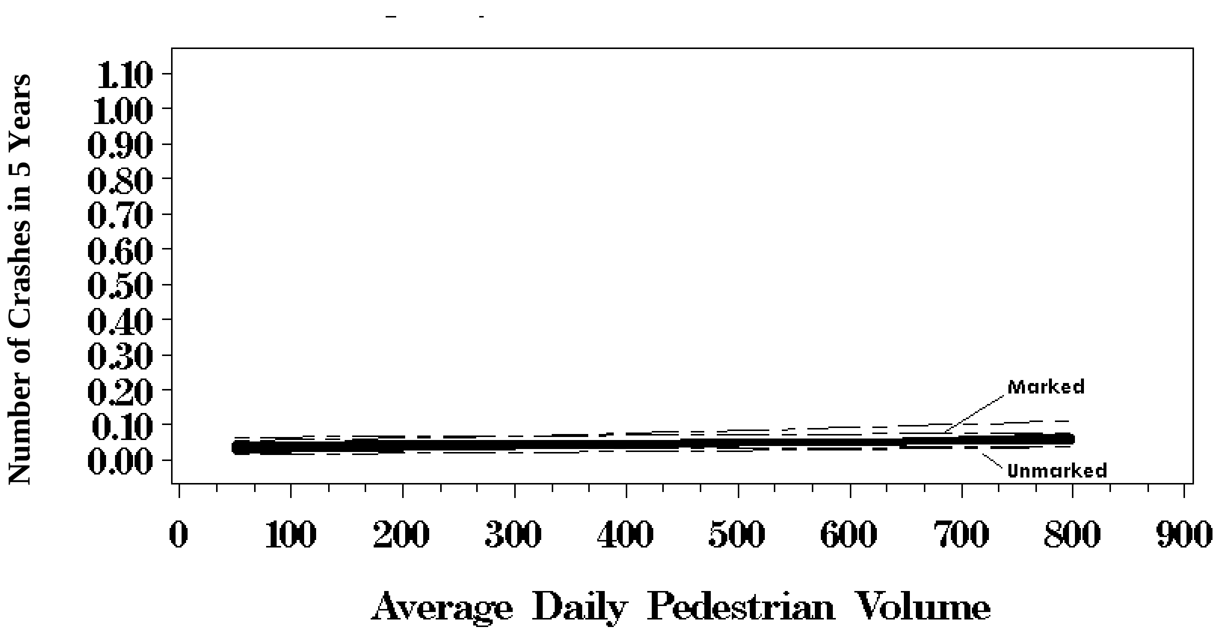


Figure 48. Response curves with 95 percent confidence intervals based on negative binomial regression model, two lanes with no median, average daily motor vehicle traffic = 2,000.

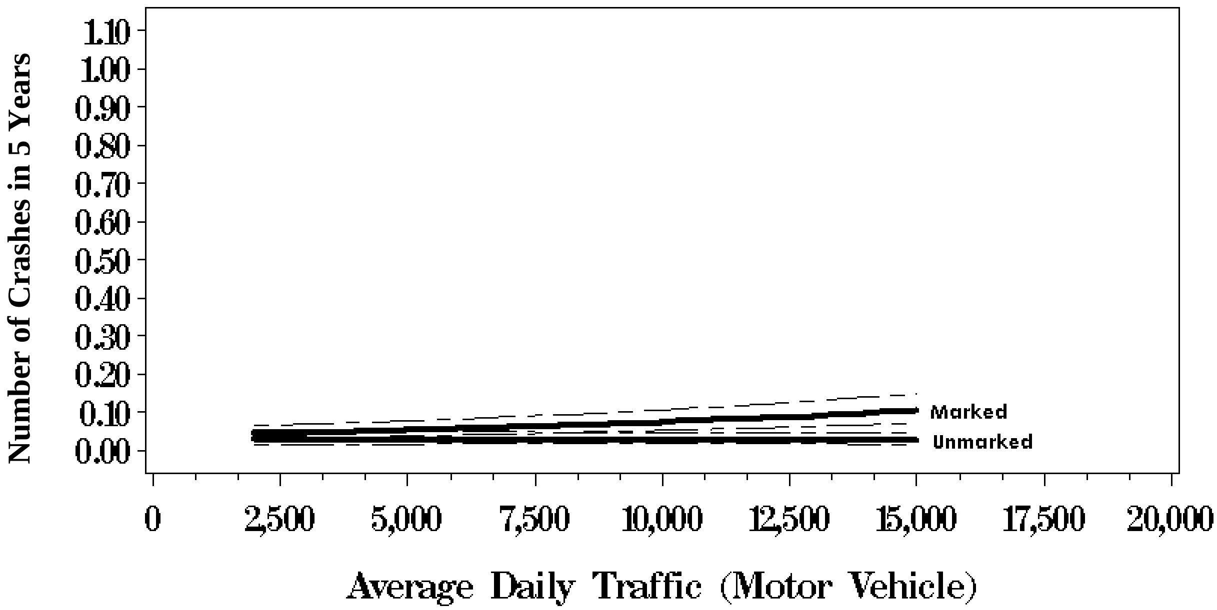


Figure 49 Response curves with 95 percent confidence intervals based on negative binomial regression model, two lanes with no median, average daily pedestrian volume = 50.

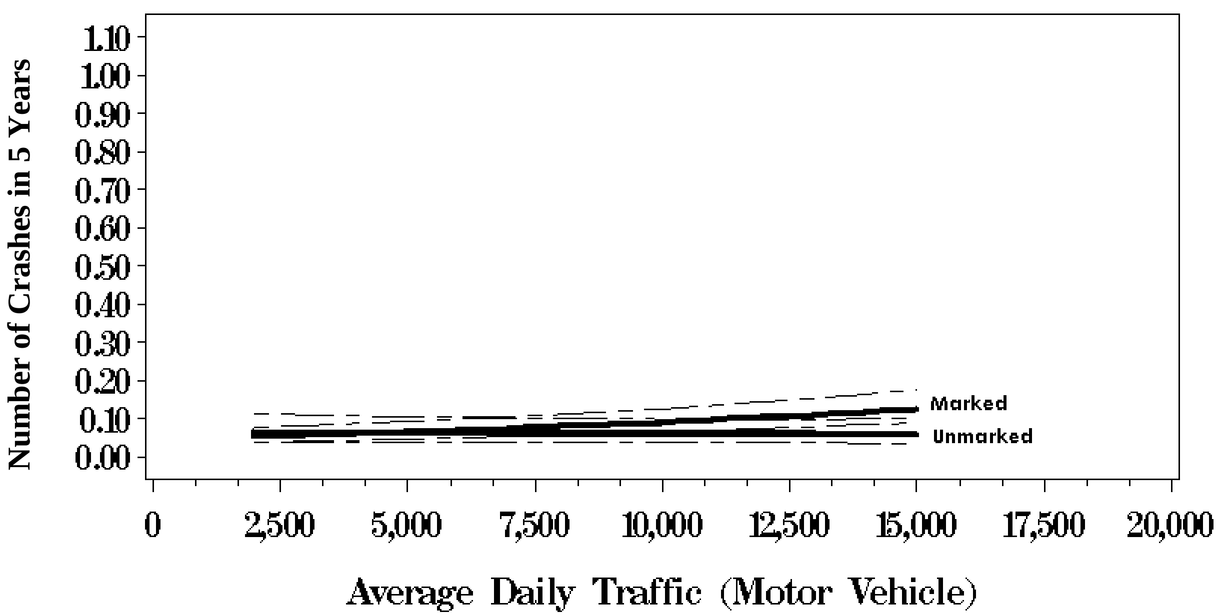


Figure 50. Response curves with 95 percent confidence intervals based on negative binomial regression model, two lanes with no median, average daily pedestrian volume = 800.

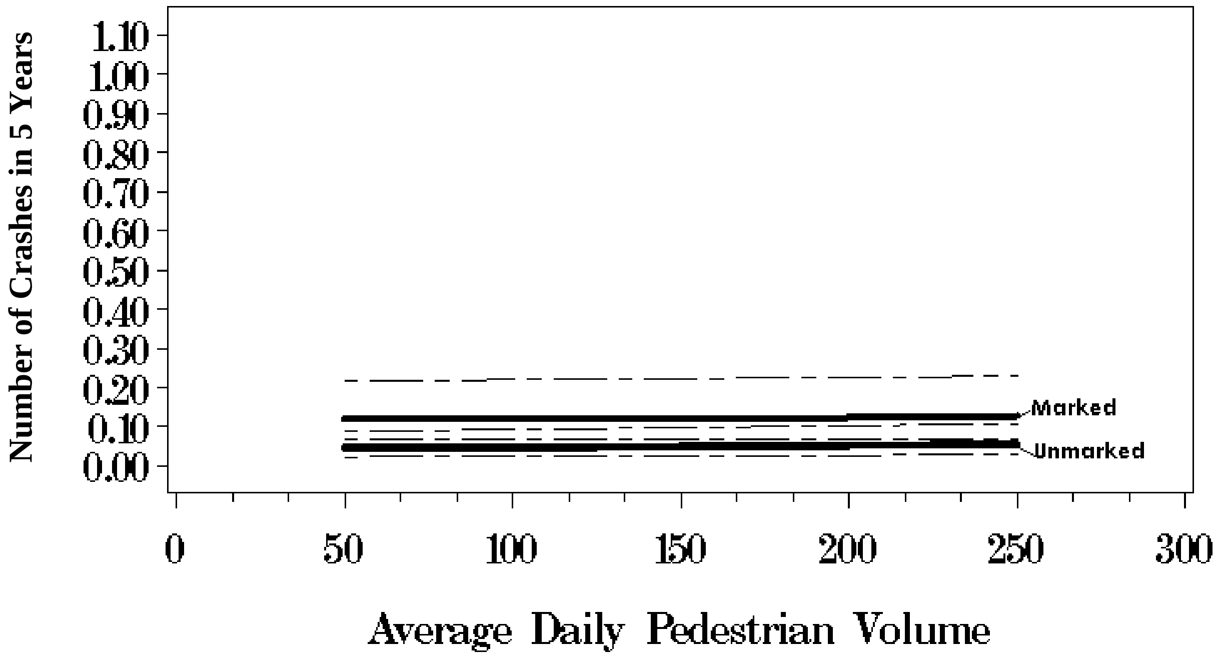


Figure 51. Response curves with 95 percent confidence intervals based on negative binomial regression model, five lanes with no median, average daily motor vehicle traffic = 10,000.

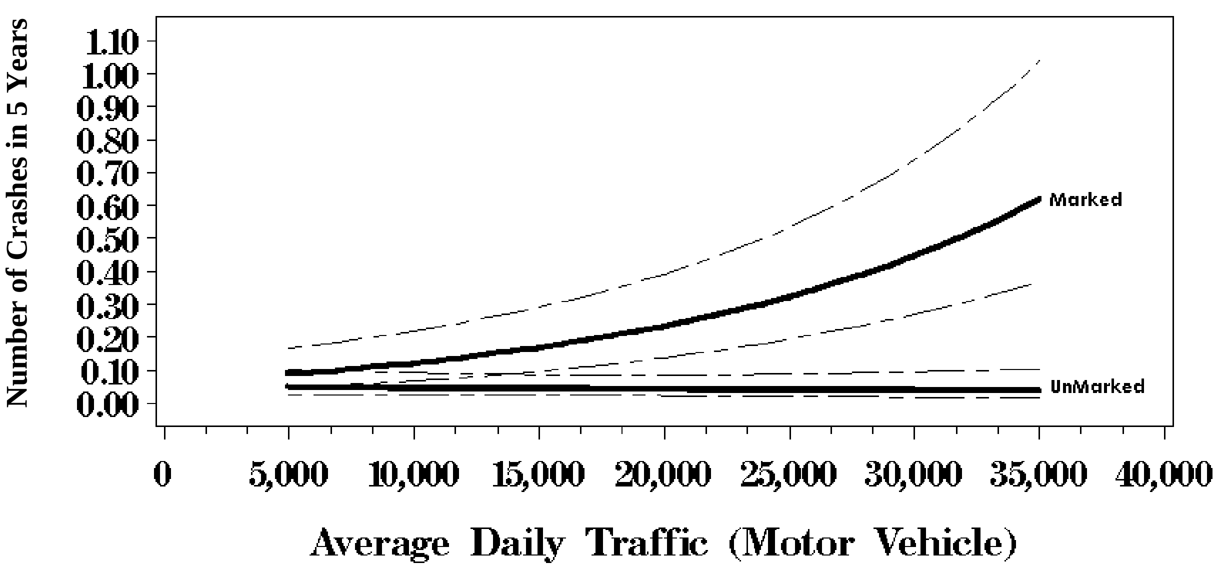


Figure 52. Response curves with 95 percent confidence intervals based on negative binomial regression model, five lanes with no median, average daily pedestrian volume = 100.

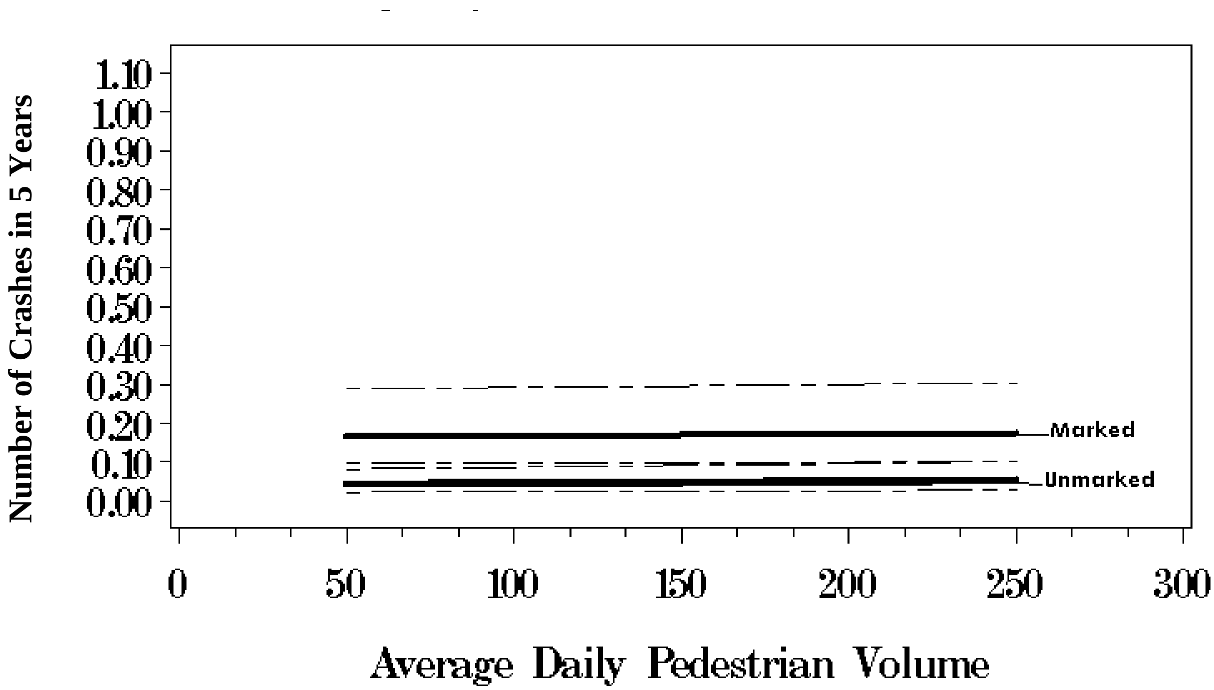


Figure 53. Response curves with 95 percent confidence intervals based on negative binomial regression model, five lanes with no median, average daily motor vehicle traffic = 15,000.

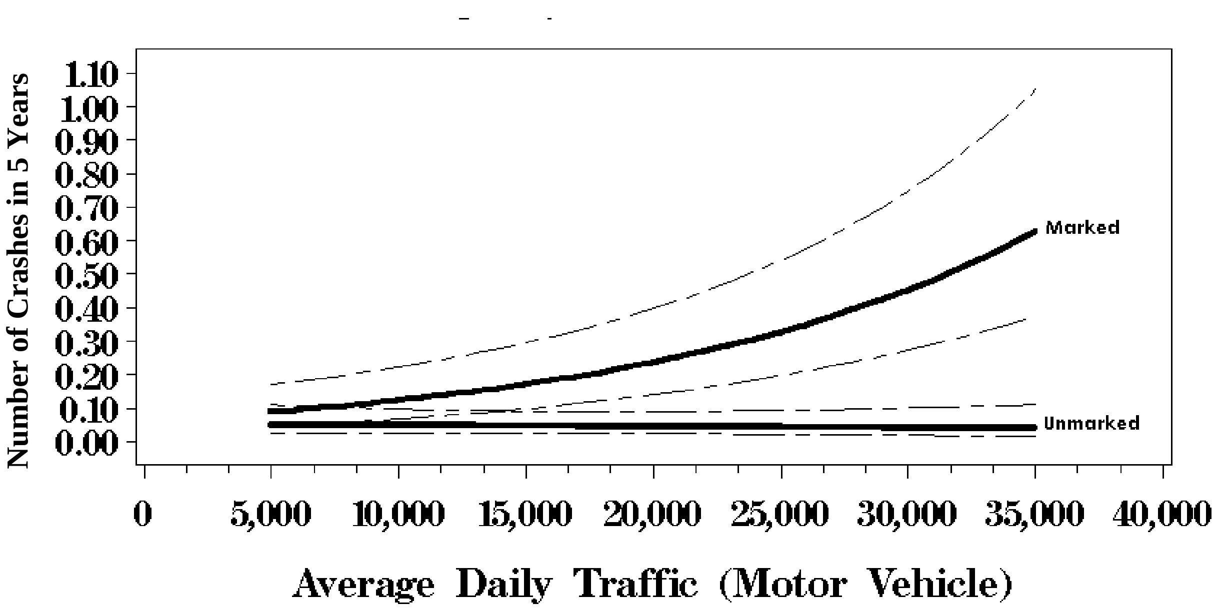


Figure 54. Response curves with 95 percent confidence intervals based on negative binomial regression model, five lanes with no median, average daily pedestrian volume = 150.

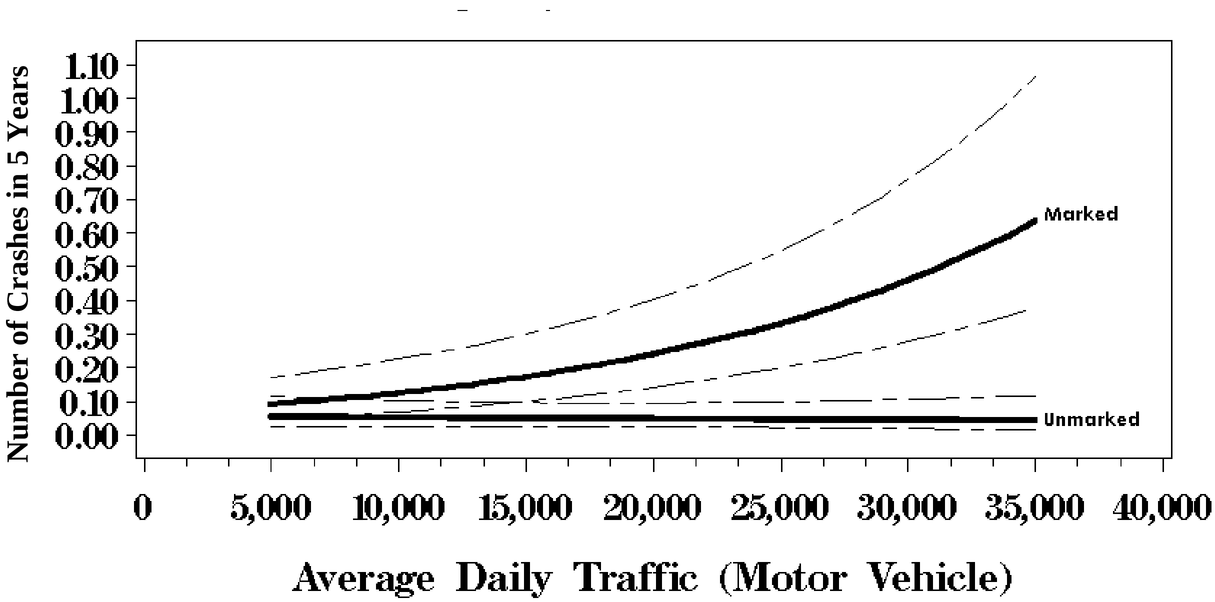


Figure 55. Response curves with 95 percent confidence intervals based on negative binomial regression model, five lanes with no median, average daily pedestrian volume = 200.

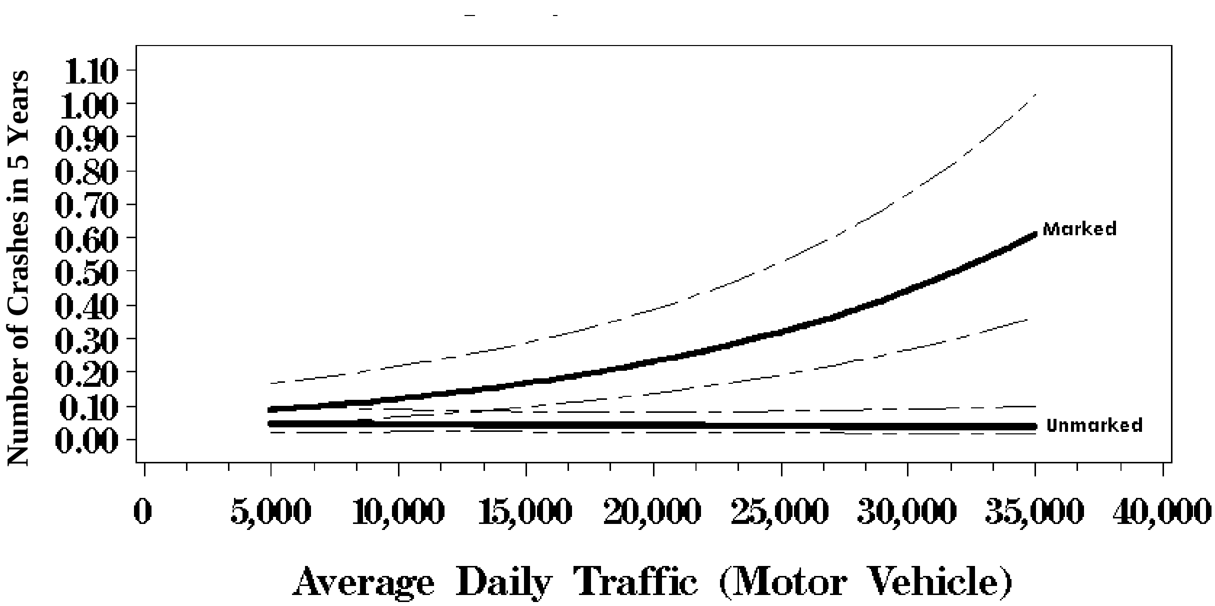


Figure 56. Response curves with 95 percent confidence intervals based on negative binomial regression model, five lanes with no median, average daily pedestrian volume = 50.

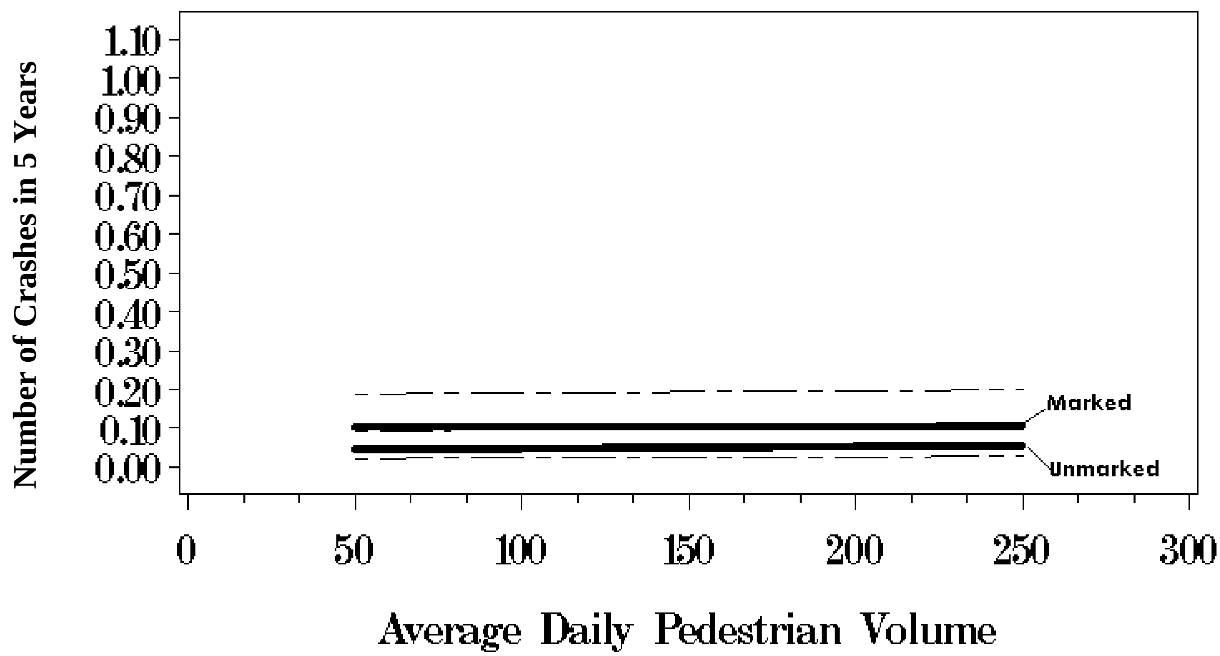


Figure 57. Response curves with 95 percent confidence intervals based on negative binomial regression model, five lanes with no median, average daily motor vehicle traffic = 7,500.

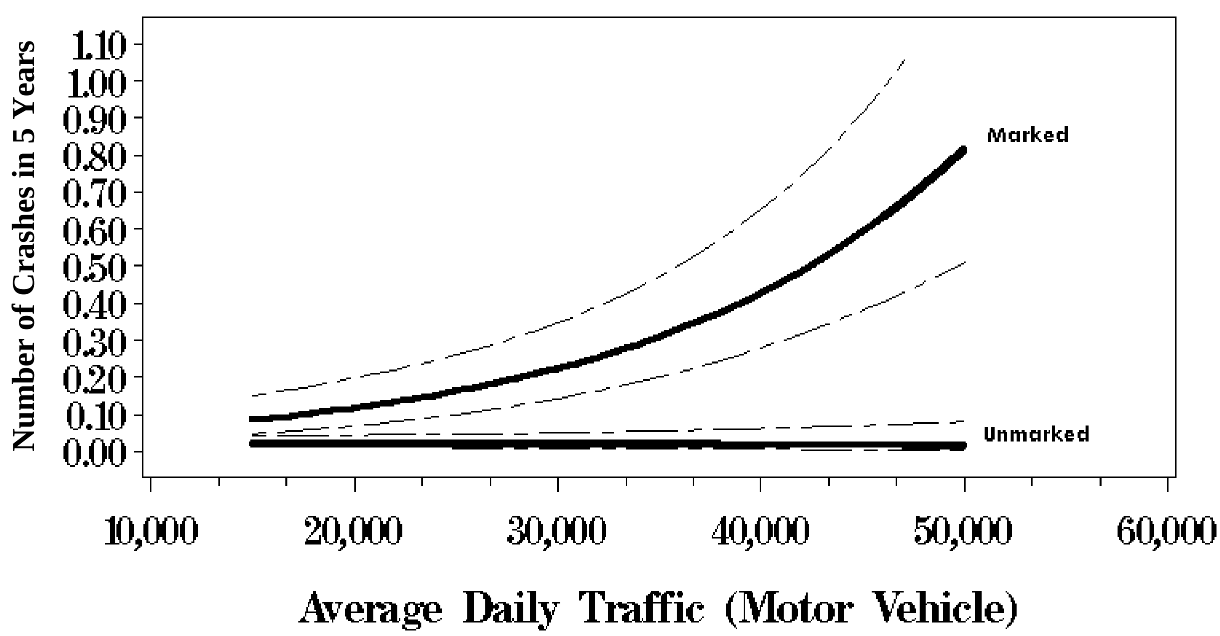


Figure 58. Response curves with 95 percent confidence intervals based on negative binomial regression model, five lanes with median, average daily pedestrian volume = 100.

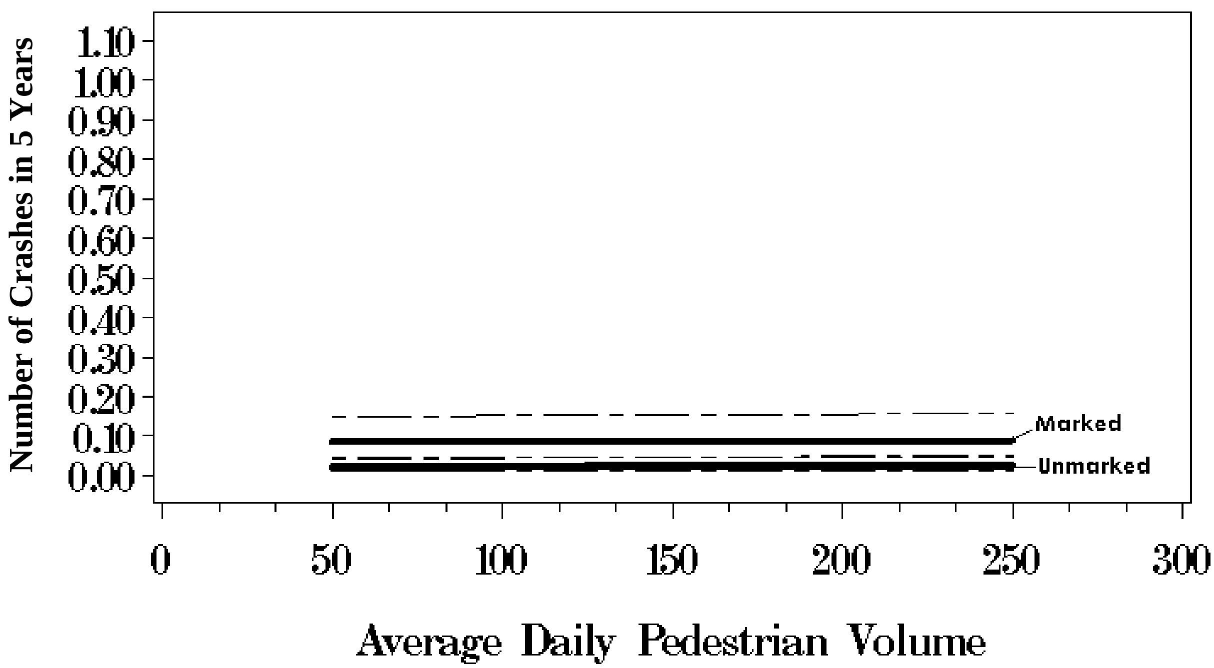


Figure 59. Response curves with 95 percent confidence intervals based on negative binomial regression model, five lanes with median, average daily motor vehicle traffic = 15,000.

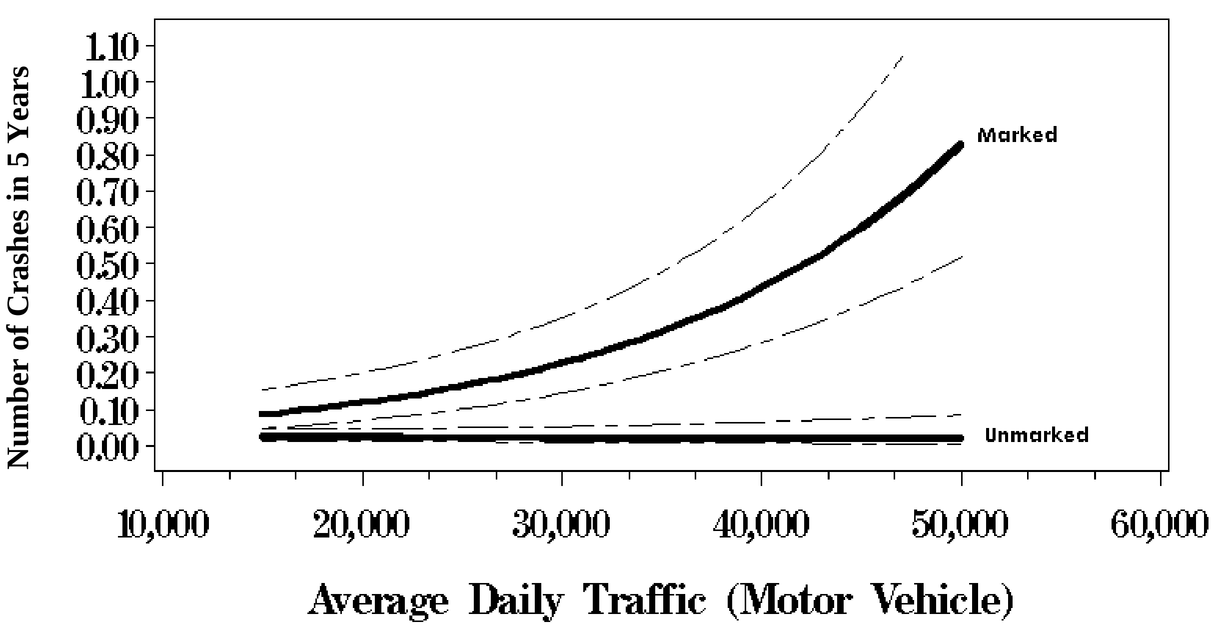


Figure 60. Response curves with 95 percent confidence intervals based on negative binomial regression model, five lanes with median, average daily pedestrian volume = 150.

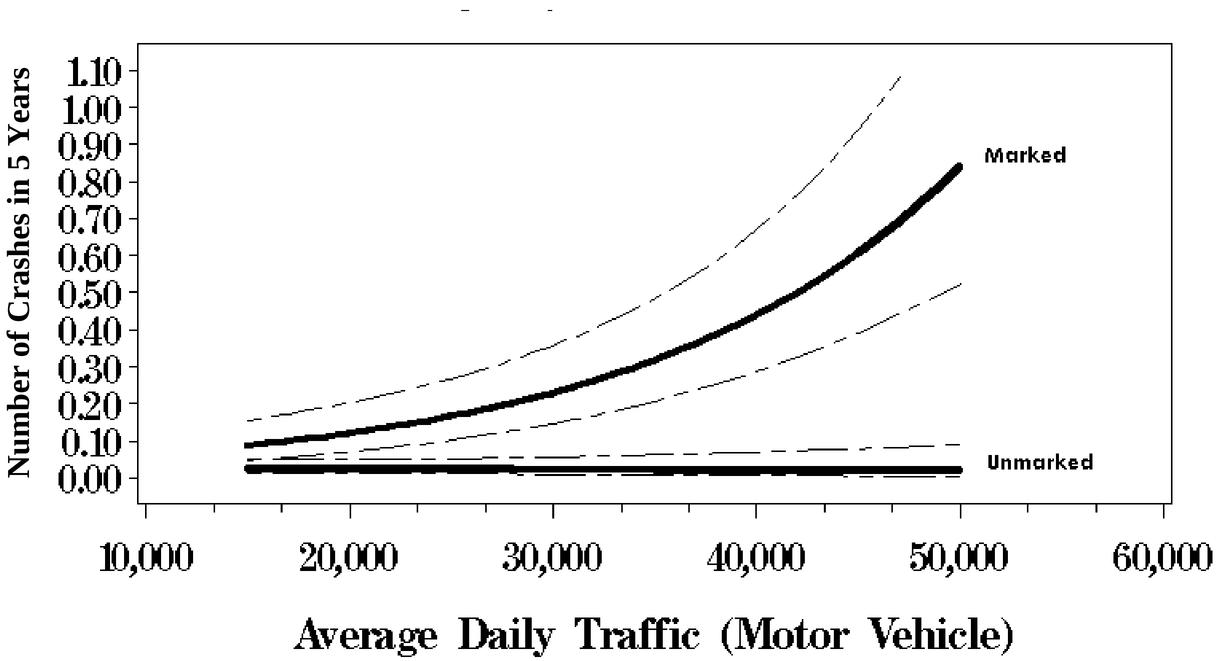


Figure 61. Response curves with 95 percent confidence intervals based on negative binomial regression model, five lanes with median, average daily pedestrian volume = 200.

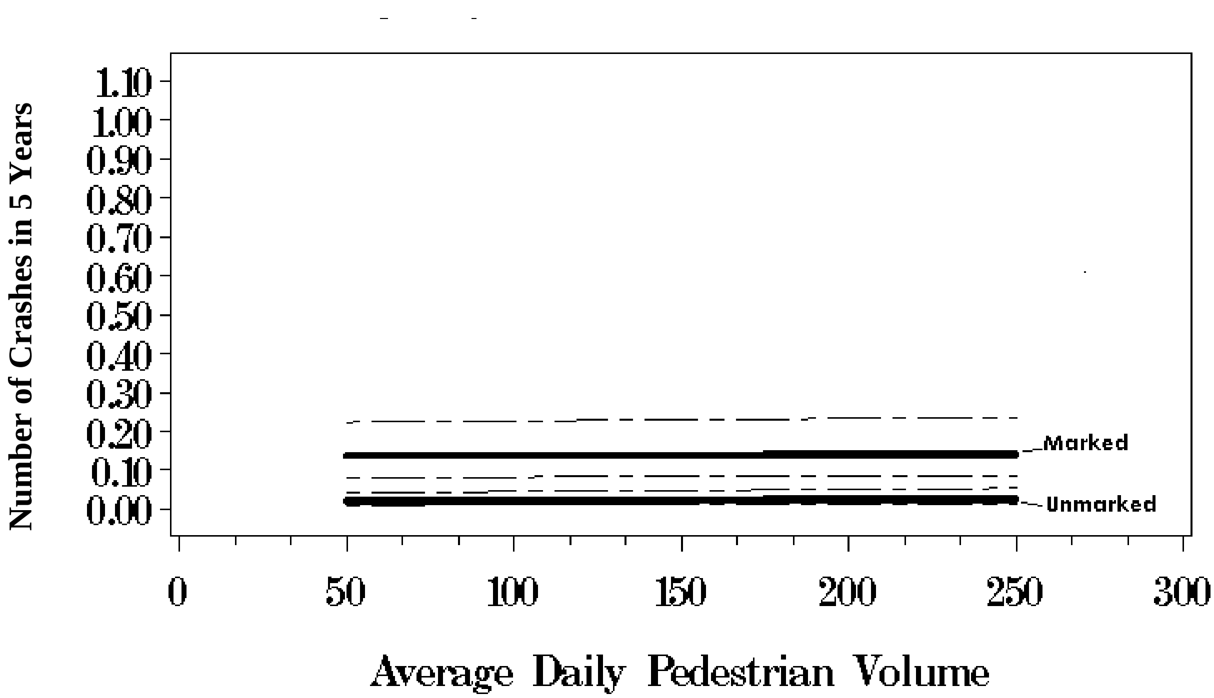


Figure 62. Response curves with 95 percent confidence intervals based on negative binomial regression model, five lanes with median, average daily motor vehicle traffic = 22,500.

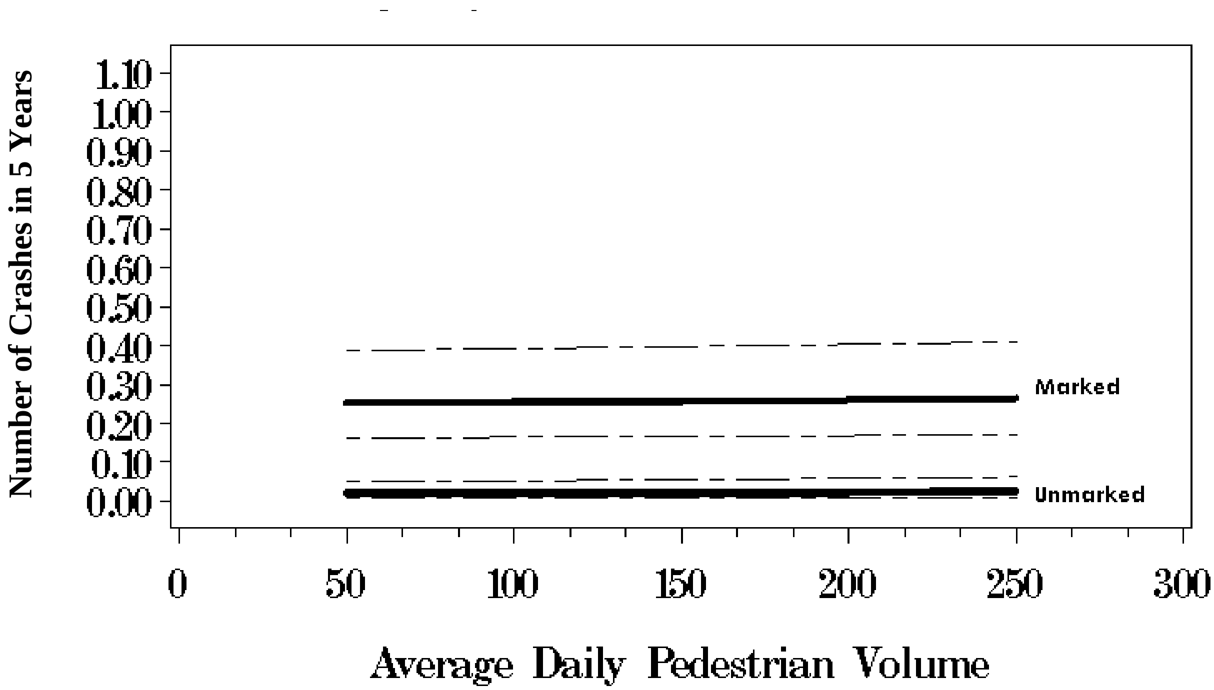


Figure 63. Response curves with 95 percent confidence intervals based on negative binomial regression model, five lanes with median, average daily motor vehicle traffic = 32,000.

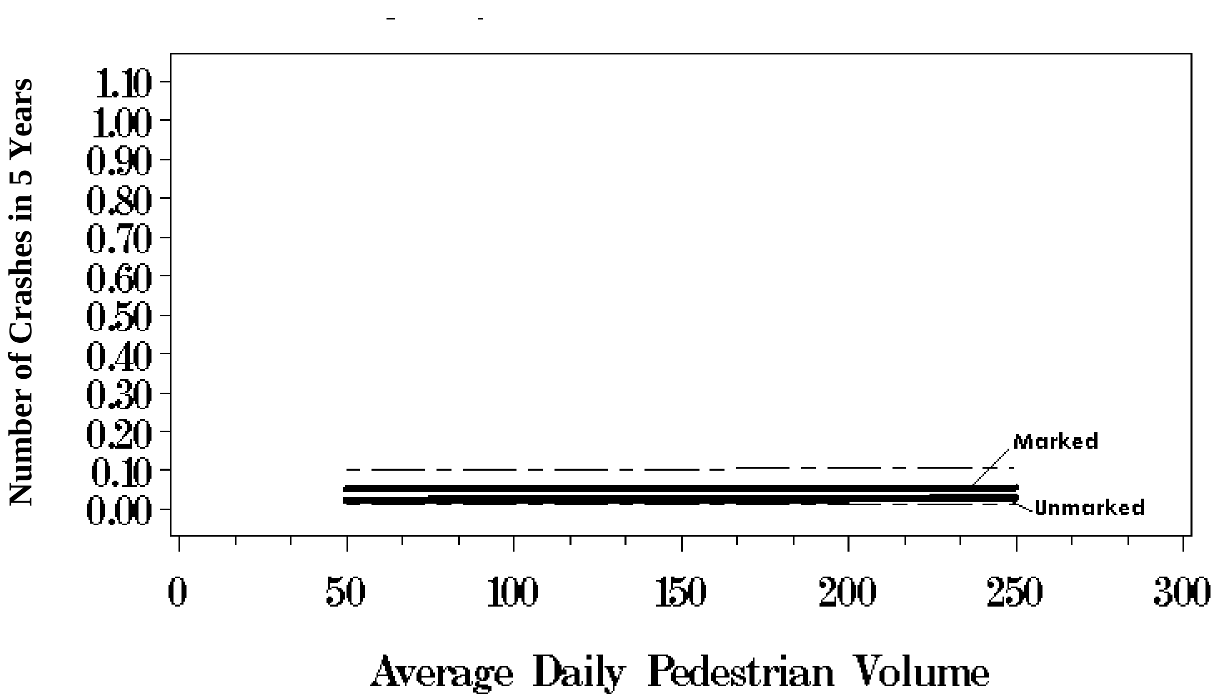


Figure 64. Response curves with 95 percent confidence intervals based on negative binomial regression model, five lanes with median, average daily motor vehicle traffic = 7,500.

APPENDIX D. ESTIMATED NUMBER OF PEDESTRIAN CRASHES (IN 5 YEARS) BASED ON THE FINAL NEGATIVE BINOMIAL PREDICTION MODEL

Estimated Number of Pedestrian Crashes in Five Years 1
Based on Negative Binominal Model
18:02 Tuesday, September 16, 2003
Two Lanes with No Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
50	2000	0.02	0.03	0.05	0.03	0.04	0.06
50	3000	0.02	0.03	0.05	0.03	0.05	0.07
50	4000	0.02	0.03	0.05	0.03	0.05	0.07
50	5000	0.02	0.03	0.05	0.04	0.05	0.08
50	6000	0.02	0.03	0.05	0.04	0.06	0.08
50	7000	0.02	0.03	0.05	0.04	0.06	0.09
50	8000	0.02	0.03	0.05	0.05	0.07	0.09
50	9000	0.02	0.03	0.05	0.05	0.07	0.10
50	10000	0.02	0.03	0.05	0.05	0.07	0.11
50	11000	0.02	0.03	0.05	0.06	0.08	0.11
50	12000	0.02	0.03	0.04	0.06	0.08	0.12
50	13000	0.02	0.03	0.04	0.06	0.09	0.13
50	14000	0.02	0.03	0.04	0.07	0.10	0.14
50	15000	0.02	0.03	0.04	0.07	0.10	0.15
100	2000	0.02	0.03	0.06	0.03	0.04	0.07
100	3000	0.02	0.03	0.06	0.03	0.05	0.07
100	4000	0.02	0.03	0.05	0.04	0.05	0.07
100	5000	0.02	0.03	0.05	0.04	0.05	0.08
100	6000	0.02	0.03	0.05	0.04	0.06	0.08
100	7000	0.02	0.03	0.05	0.04	0.06	0.09
100	8000	0.02	0.03	0.05	0.05	0.07	0.09
100	9000	0.02	0.03	0.05	0.05	0.07	0.10
100	10000	0.02	0.03	0.05	0.05	0.08	0.11
100	11000	0.02	0.03	0.05	0.06	0.08	0.11
100	12000	0.02	0.03	0.05	0.06	0.09	0.12
100	13000	0.02	0.03	0.05	0.06	0.09	0.13
100	14000	0.02	0.03	0.05	0.07	0.10	0.14
100	15000	0.02	0.03	0.05	0.07	0.10	0.15
150	2000	0.02	0.03	0.06	0.03	0.05	0.07
150	3000	0.02	0.03	0.06	0.03	0.05	0.07
150	4000	0.02	0.03	0.06	0.04	0.05	0.07
150	5000	0.02	0.03	0.06	0.04	0.06	0.08

Estimated Number of Pedestrian Crashes in Five Years
Based on Negative Binominal Model
18:02 Tuesday, September 16, 2003
Two Lanes with No Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
150	6000	0.02	0.03	0.05	0.04	0.06	0.08
150	7000	0.02	0.03	0.05	0.04	0.06	0.09
150	8000	0.02	0.03	0.05	0.05	0.07	0.10
150	9000	0.02	0.03	0.05	0.05	0.07	0.10
150	10000	0.02	0.03	0.05	0.05	0.08	0.11
150	11000	0.02	0.03	0.05	0.06	0.08	0.12
150	12000	0.02	0.03	0.05	0.06	0.09	0.12
150	13000	0.02	0.03	0.05	0.07	0.09	0.13
150	14000	0.02	0.03	0.05	0.07	0.10	0.14
150	15000	0.02	0.03	0.05	0.07	0.11	0.15
200	2000	0.02	0.03	0.06	0.03	0.05	0.07
200	3000	0.02	0.03	0.06	0.03	0.05	0.07
200	4000	0.02	0.03	0.06	0.04	0.05	0.08
200	5000	0.02	0.03	0.06	0.04	0.06	0.08
200	6000	0.02	0.03	0.06	0.04	0.06	0.08
200	7000	0.02	0.03	0.06	0.04	0.06	0.09
200	8000	0.02	0.03	0.05	0.05	0.07	0.10
200	9000	0.02	0.03	0.05	0.05	0.07	0.10
200	10000	0.02	0.03	0.05	0.05	0.08	0.11
200	11000	0.02	0.03	0.05	0.06	0.08	0.12
200	12000	0.02	0.03	0.05	0.06	0.09	0.12
200	13000	0.02	0.03	0.05	0.07	0.09	0.13
200	14000	0.02	0.03	0.05	0.07	0.10	0.14
200	15000	0.02	0.03	0.05	0.08	0.11	0.15
250	2000	0.02	0.04	0.07	0.03	0.05	0.07
250	3000	0.02	0.04	0.06	0.03	0.05	0.07
250	4000	0.02	0.04	0.06	0.04	0.05	0.08
250	5000	0.02	0.04	0.06	0.04	0.06	0.08
250	6000	0.02	0.04	0.06	0.04	0.06	0.09
250	7000	0.02	0.04	0.06	0.05	0.06	0.09
250	8000	0.02	0.03	0.06	0.05	0.07	0.10
250	9000	0.02	0.03	0.06	0.05	0.07	0.10

Based on Negative Binominal Model
18:02 Tuesday, September 16, 2003
Two Lanes with No Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
250	10000	0.02	0.03	0.06	0.06	0.08	0.11
250	11000	0.02	0.03	0.05	0.06	0.08	0.12
250	12000	0.02	0.03	0.05	0.06	0.09	0.13
250	13000	0.02	0.03	0.05	0.07	0.10	0.13
250	14000	0.02	0.03	0.05	0.07	0.10	0.14
250	15000	0.02	0.03	0.05	0.08	0.11	0.15
300	2000	0.02	0.04	0.07	0.03	0.05	0.07
300	3000	0.02	0.04	0.07	0.03	0.05	0.07
300	4000	0.02	0.04	0.06	0.04	0.05	0.08
300	5000	0.02	0.04	0.06	0.04	0.06	0.08
300	6000	0.02	0.04	0.06	0.04	0.06	0.09
300	7000	0.02	0.04	0.06	0.05	0.07	0.09
300	8000	0.02	0.04	0.06	0.05	0.07	0.10
300	9000	0.02	0.04	0.06	0.05	0.07	0.10
300	10000	0.02	0.04	0.06	0.06	0.08	0.11
300	11000	0.02	0.04	0.06	0.06	0.08	0.12
300	12000	0.02	0.04	0.06	0.06	0.09	0.13
300	13000	0.02	0.04	0.06	0.07	0.10	0.14
300	14000	0.02	0.04	0.06	0.07	0.10	0.15
300	15000	0.02	0.03	0.06	0.08	0.11	0.16
350	2000	0.02	0.04	0.07	0.03	0.05	0.07
350	3000	0.02	0.04	0.07	0.04	0.05	0.07
350	4000	0.02	0.04	0.07	0.04	0.05	0.08
350	5000	0.02	0.04	0.07	0.04	0.06	0.08
350	6000	0.02	0.04	0.06	0.04	0.06	0.09
350	7000	0.02	0.04	0.06	0.05	0.07	0.09
350	8000	0.02	0.04	0.06	0.05	0.07	0.10
350	9000	0.02	0.04	0.06	0.05	0.08	0.11
350	10000	0.02	0.04	0.06	0.06	0.08	0.11
350	11000	0.02	0.04	0.06	0.06	0.09	0.12
350	12000	0.02	0.04	0.06	0.07	0.09	0.13
350	13000	0.02	0.04	0.06	0.07	0.10	0.14

Estimated Number of Pedestrian Crashes in Five Years
Based on Negative Binominal Model
18:02 Tuesday, September 16, 2003
Two Lanes with No Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
350	14000	0.02	0.04	0.06	0.07	0.10	0.15
350	15000	0.02	0.04	0.06	0.08	0.11	0.16
400	2000	0.02	0.04	0.08	0.03	0.05	0.07
400	3000	0.02	0.04	0.07	0.04	0.05	0.07
400	4000	0.02	0.04	0.07	0.04	0.06	0.08
400	5000	0.02	0.04	0.07	0.04	0.06	0.08
400	6000	0.03	0.04	0.07	0.04	0.06	0.09
400	7000	0.03	0.04	0.07	0.05	0.07	0.09
400	8000	0.03	0.04	0.07	0.05	0.07	0.10
400	9000	0.03	0.04	0.06	0.05	0.08	0.11
400	10000	0.03	0.04	0.06	0.06	0.08	0.11
400	11000	0.03	0.04	0.06	0.06	0.09	0.12
400	12000	0.02	0.04	0.06	0.07	0.09	0.13
400	13000	0.02	0.04	0.06	0.07	0.10	0.14
400	14000	0.02	0.04	0.06	0.08	0.11	0.15
400	15000	0.02	0.04	0.06	0.08	0.11	0.16
450	2000	0.03	0.04	0.08	0.03	0.05	0.07
450	3000	0.03	0.04	0.08	0.04	0.05	0.08
450	4000	0.03	0.04	0.07	0.04	0.06	0.08
450	5000	0.03	0.04	0.07	0.04	0.06	0.08
450	6000	0.03	0.04	0.07	0.05	0.06	0.09
450	7000	0.03	0.04	0.07	0.05	0.07	0.10
450	8000	0.03	0.04	0.07	0.05	0.07	0.10
450	9000	0.03	0.04	0.07	0.06	0.08	0.11
450	10000	0.03	0.04	0.07	0.06	0.08	0.12
450	11000	0.03	0.04	0.07	0.06	0.09	0.12
450	12000	0.03	0.04	0.07	0.07	0.09	0.13
450	13000	0.03	0.04	0.07	0.07	0.10	0.14
450	14000	0.03	0.04	0.07	0.08	0.11	0.15
450	15000	0.03	0.04	0.07	0.08	0.11	0.16
500	2000	0.03	0.05	0.08	0.03	0.05	0.07
500	3000	0.03	0.05	0.08	0.04	0.05	0.08

Estimated Number of Pedestrian Crashes in Five Years
Based on Negative Binominal Model
18:02 Tuesday, September 16, 2003
Two Lanes with No Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
500	4000	0.03	0.05	0.08	0.04	0.06	0.08
500	5000	0.03	0.05	0.08	0.04	0.06	0.09
500	6000	0.03	0.05	0.08	0.05	0.06	0.09
500	7000	0.03	0.05	0.07	0.05	0.07	0.10
500	8000	0.03	0.05	0.07	0.05	0.07	0.10
500	9000	0.03	0.05	0.07	0.06	0.08	0.11
500	10000	0.03	0.04	0.07	0.06	0.08	0.12
500	11000	0.03	0.04	0.07	0.06	0.09	0.12
500	12000	0.03	0.04	0.07	0.07	0.10	0.13
500	13000	0.03	0.04	0.07	0.07	0.10	0.14
500	14000	0.03	0.04	0.07	0.08	0.11	0.15
500	15000	0.03	0.04	0.07	0.08	0.12	0.16
550	2000	0.03	0.05	0.09	0.03	0.05	0.07
550	3000	0.03	0.05	0.08	0.04	0.05	0.08
550	4000	0.03	0.05	0.08	0.04	0.06	0.08
550	5000	0.03	0.05	0.08	0.04	0.06	0.09
550	6000	0.03	0.05	0.08	0.05	0.07	0.09
550	7000	0.03	0.05	0.08	0.05	0.07	0.10
550	8000	0.03	0.05	0.08	0.05	0.07	0.10
550	9000	0.03	0.05	0.08	0.06	0.08	0.11
550	10000	0.03	0.05	0.07	0.06	0.08	0.12
550	11000	0.03	0.05	0.07	0.06	0.09	0.13
550	12000	0.03	0.05	0.07	0.07	0.10	0.13
550	13000	0.03	0.05	0.07	0.07	0.10	0.14
550	14000	0.03	0.05	0.07	0.08	0.11	0.15
550	15000	0.03	0.05	0.07	0.08	0.12	0.17
600	2000	0.03	0.05	0.09	0.04	0.05	0.07
600	3000	0.03	0.05	0.09	0.04	0.05	0.08
600	4000	0.03	0.05	0.09	0.04	0.06	0.08
600	5000	0.03	0.05	0.08	0.04	0.06	0.09
600	6000	0.03	0.05	0.08	0.05	0.07	0.09
600	7000	0.03	0.05	0.08	0.05	0.07	0.10

Two Lanes with No Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
600	8000	0.03	0.05	0.08	0.05	0.08	0.11
600	9000	0.03	0.05	0.08	0.06	0.08	0.11
600	10000	0.03	0.05	0.08	0.06	0.09	0.12
600	11000	0.03	0.05	0.08	0.07	0.09	0.13
600	12000	0.03	0.05	0.08	0.07	0.10	0.14
600	13000	0.03	0.05	0.08	0.07	0.10	0.15
600	14000	0.03	0.05	0.08	0.08	0.11	0.16
600	15000	0.03	0.05	0.08	0.08	0.12	0.17
650	2000	0.03	0.06	0.10	0.04	0.05	0.07
650	3000	0.03	0.05	0.09	0.04	0.06	0.08
650	4000	0.03	0.05	0.09	0.04	0.06	0.08
650	5000	0.03	0.05	0.09	0.04	0.06	0.09
650	6000	0.03	0.05	0.09	0.05	0.07	0.09
650	7000	0.03	0.05	0.09	0.05	0.07	0.10
650	8000	0.03	0.05	0.09	0.05	0.08	0.11
650	9000	0.03	0.05	0.08	0.06	0.08	0.11
650	10000	0.03	0.05	0.08	0.06	0.09	0.12
650	11000	0.03	0.05	0.08	0.07	0.09	0.13
650	12000	0.03	0.05	0.08	0.07	0.10	0.14
650	13000	0.03	0.05	0.08	0.08	0.11	0.15
650	14000	0.03	0.05	0.08	0.08	0.11	0.16
650	15000	0.03	0.05	0.08	0.09	0.12	0.17
700	2000	0.03	0.06	0.10	0.04	0.05	0.08
700	3000	0.03	0.06	0.10	0.04	0.06	0.08
700	4000	0.03	0.06	0.10	0.04	0.06	0.08
700	5000	0.03	0.06	0.09	0.05	0.06	0.09
700	6000	0.03	0.06	0.09	0.05	0.07	0.10
700	7000	0.03	0.06	0.09	0.05	0.07	0.10
700	8000	0.03	0.06	0.09	0.06	0.08	0.11
700	9000	0.03	0.06	0.09	0.06	0.08	0.12
700	10000	0.03	0.06	0.09	0.06	0.09	0.12
700	11000	0.03	0.05	0.09	0.07	0.09	0.13

Based on Negative Binominal Model
18:02 Tuesday, September 16, 2003
Two Lanes with No Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
700	12000	0.03	0.05	0.09	0.07	0.10	0.14
700	13000	0.03	0.05	0.09	0.08	0.11	0.15
700	14000	0.03	0.05	0.09	0.08	0.11	0.16
700	15000	0.03	0.05	0.09	0.09	0.12	0.17
750	2000	0.04	0.06	0.11	0.04	0.05	0.08
750	3000	0.04	0.06	0.10	0.04	0.06	0.08
750	4000	0.04	0.06	0.10	0.04	0.06	0.09
750	5000	0.04	0.06	0.10	0.05	0.06	0.09
750	6000	0.04	0.06	0.10	0.05	0.07	0.10
750	7000	0.04	0.06	0.10	0.05	0.07	0.10
750	8000	0.04	0.06	0.09	0.06	0.08	0.11
750	9000	0.04	0.06	0.09	0.06	0.08	0.12
750	10000	0.04	0.06	0.09	0.06	0.09	0.12
750	11000	0.04	0.06	0.09	0.07	0.10	0.13
750	12000	0.04	0.06	0.09	0.07	0.10	0.14
750	13000	0.03	0.06	0.09	0.08	0.11	0.15
750	14000	0.03	0.06	0.09	0.08	0.12	0.16
750	15000	0.03	0.06	0.09	0.09	0.12	0.17
800	2000	0.04	0.06	0.11	0.04	0.05	0.08
800	3000	0.04	0.06	0.11	0.04	0.06	0.08
800	4000	0.04	0.06	0.11	0.04	0.06	0.09
800	5000	0.04	0.06	0.10	0.05	0.07	0.09
800	6000	0.04	0.06	0.10	0.05	0.07	0.10
800	7000	0.04	0.06	0.10	0.05	0.07	0.10
800	8000	0.04	0.06	0.10	0.06	0.08	0.11
800	9000	0.04	0.06	0.10	0.06	0.08	0.12
800	10000	0.04	0.06	0.10	0.07	0.09	0.13
800	11000	0.04	0.06	0.10	0.07	0.10	0.13
800	12000	0.04	0.06	0.10	0.07	0.10	0.14
800	13000	0.04	0.06	0.10	0.08	0.11	0.15
800	14000	0.04	0.06	0.10	0.08	0.12	0.16
800	15000	0.04	0.06	0.10	0.09	0.13	0.18

Estimated Number of Pedestrian Crashes in Five Years
Based on Negative Binomial Model
18:02 Tuesday, September 16, 2003
Five Lanes with Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
50	5000	0.01	0.02	0.05	0.02	0.04	0.09
50	6000	0.01	0.02	0.05	0.02	0.05	0.09
50	7000	0.01	0.02	0.05	0.02	0.05	0.10
50	8000	0.01	0.02	0.05	0.03	0.05	0.10
50	9000	0.01	0.02	0.04	0.03	0.06	0.11
50	10000	0.01	0.02	0.04	0.03	0.06	0.11
50	11000	0.01	0.02	0.04	0.03	0.06	0.12
50	12000	0.01	0.02	0.04	0.04	0.07	0.13
50	13000	0.01	0.02	0.04	0.04	0.07	0.13
50	14000	0.01	0.02	0.04	0.04	0.08	0.14
50	15000	0.01	0.02	0.04	0.05	0.08	0.15
50	16000	0.01	0.02	0.04	0.05	0.09	0.16
50	17000	0.01	0.02	0.04	0.05	0.09	0.17
50	18000	0.01	0.02	0.04	0.06	0.10	0.17
50	19000	0.01	0.02	0.04	0.06	0.11	0.18
50	20000	0.01	0.02	0.04	0.07	0.11	0.19
50	21000	0.01	0.02	0.04	0.07	0.12	0.21
50	22000	0.01	0.02	0.04	0.08	0.13	0.22
50	23000	0.01	0.02	0.04	0.08	0.14	0.23
50	24000	0.01	0.02	0.04	0.09	0.15	0.24
50	25000	0.01	0.02	0.04	0.10	0.16	0.26
50	26000	0.01	0.02	0.04	0.11	0.17	0.27
50	27000	0.01	0.02	0.04	0.11	0.18	0.29
50	28000	0.01	0.02	0.05	0.12	0.19	0.31
50	29000	0.01	0.02	0.05	0.13	0.21	0.32
50	30000	0.01	0.02	0.05	0.14	0.22	0.34
50	31000	0.01	0.02	0.05	0.15	0.23	0.36
50	32000	0.01	0.02	0.05	0.16	0.25	0.39
50	33000	0.01	0.02	0.05	0.17	0.27	0.41
50	34000	0.01	0.02	0.05	0.19	0.28	0.44
50	35000	0.01	0.02	0.05	0.20	0.30	0.47
50	36000	0.01	0.02	0.05	0.21	0.32	0.50

Estimated Number of Pedestrian Crashes in Five Years
Based on Negative Binomial Model
18:02 Tuesday, September 16, 2003
Five Lanes with Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
50	37000	0.01	0.02	0.05	0.23	0.35	0.53
50	38000	0.01	0.02	0.06	0.24	0.37	0.56
50	39000	0.01	0.02	0.06	0.26	0.39	0.60
50	40000	0.01	0.02	0.06	0.28	0.42	0.64
50	41000	0.01	0.02	0.06	0.29	0.45	0.69
50	42000	0.01	0.02	0.06	0.31	0.48	0.74
50	43000	0.01	0.02	0.06	0.33	0.51	0.79
50	44000	0.00	0.02	0.06	0.35	0.55	0.84
50	45000	0.00	0.02	0.07	0.38	0.58	0.90
50	46000	0.00	0.02	0.07	0.40	0.62	0.97
50	47000	0.00	0.02	0.07	0.42	0.66	1.04
50	48000	0.00	0.02	0.07	0.45	0.71	1.12
50	49000	0.00	0.02	0.07	0.48	0.76	1.20
50	50000	0.00	0.02	0.07	0.50	0.81	1.29
100	5000	0.01	0.02	0.05	0.02	0.04	0.09
100	6000	0.01	0.02	0.05	0.02	0.05	0.09
100	7000	0.01	0.02	0.05	0.02	0.05	0.10
100	8000	0.01	0.02	0.05	0.03	0.05	0.10
100	9000	0.01	0.02	0.05	0.03	0.06	0.11
100	10000	0.01	0.02	0.05	0.03	0.06	0.12
100	11000	0.01	0.02	0.05	0.03	0.06	0.12
100	12000	0.01	0.02	0.05	0.04	0.07	0.13
100	13000	0.01	0.02	0.04	0.04	0.07	0.14
100	14000	0.01	0.02	0.04	0.04	0.08	0.14
100	15000	0.01	0.02	0.04	0.05	0.08	0.15
100	16000	0.01	0.02	0.04	0.05	0.09	0.16
100	17000	0.01	0.02	0.04	0.05	0.10	0.17
100	18000	0.01	0.02	0.04	0.06	0.10	0.18
100	19000	0.01	0.02	0.04	0.06	0.11	0.19
100	20000	0.01	0.02	0.04	0.07	0.12	0.20
100	21000	0.01	0.02	0.04	0.07	0.12	0.21
100	22000	0.01	0.02	0.04	0.08	0.13	0.22

Based on Negative Binomial Model
18:02 Tuesday, September 16, 2003
Five Lanes with Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
100	23000	0.01	0.02	0.05	0.09	0.14	0.23
100	24000	0.01	0.02	0.05	0.09	0.15	0.25
100	25000	0.01	0.02	0.05	0.10	0.16	0.26
100	26000	0.01	0.02	0.05	0.11	0.17	0.28
100	27000	0.01	0.02	0.05	0.11	0.18	0.29
100	28000	0.01	0.02	0.05	0.12	0.20	0.31
100	29000	0.01	0.02	0.05	0.13	0.21	0.33
100	30000	0.01	0.02	0.05	0.14	0.22	0.35
100	31000	0.01	0.02	0.05	0.15	0.24	0.37
100	32000	0.01	0.02	0.05	0.16	0.25	0.39
100	33000	0.01	0.02	0.05	0.18	0.27	0.42
100	34000	0.01	0.02	0.05	0.19	0.29	0.44
100	35000	0.01	0.02	0.05	0.20	0.31	0.47
100	36000	0.01	0.02	0.06	0.22	0.33	0.50
100	37000	0.01	0.02	0.06	0.23	0.35	0.54
100	38000	0.01	0.02	0.06	0.25	0.37	0.57
100	39000	0.01	0.02	0.06	0.26	0.40	0.61
100	40000	0.01	0.02	0.06	0.28	0.43	0.65
100	41000	0.01	0.02	0.06	0.30	0.46	0.70
100	42000	0.01	0.02	0.06	0.32	0.49	0.74
100	43000	0.01	0.02	0.07	0.34	0.52	0.80
100	44000	0.01	0.02	0.07	0.36	0.55	0.85
100	45000	0.00	0.02	0.07	0.38	0.59	0.92
100	46000	0.00	0.02	0.07	0.40	0.63	0.98
100	47000	0.00	0.02	0.07	0.43	0.67	1.05
100	48000	0.00	0.02	0.07	0.46	0.72	1.13
100	49000	0.00	0.02	0.08	0.48	0.77	1.22
100	50000	0.00	0.02	0.08	0.51	0.82	1.31
150	5000	0.01	0.03	0.05	0.02	0.04	0.09
150	6000	0.01	0.03	0.05	0.02	0.05	0.10
150	7000	0.01	0.03	0.05	0.03	0.05	0.10
150	8000	0.01	0.03	0.05	0.03	0.05	0.11

Estimated Number of Pedestrian Crashes in Five Years
Based on Negative Binomial Model
18:02 Tuesday, September 16, 2003
Five Lanes with Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
150	9000	0.01	0.03	0.05	0.03	0.06	0.11
150	10000	0.01	0.02	0.05	0.03	0.06	0.12
150	11000	0.01	0.02	0.05	0.03	0.07	0.12
150	12000	0.01	0.02	0.05	0.04	0.07	0.13
150	13000	0.01	0.02	0.05	0.04	0.07	0.14
150	14000	0.01	0.02	0.05	0.04	0.08	0.15
150	15000	0.01	0.02	0.05	0.05	0.08	0.15
150	16000	0.01	0.02	0.05	0.05	0.09	0.16
150	17000	0.01	0.02	0.05	0.06	0.10	0.17
150	18000	0.01	0.02	0.05	0.06	0.10	0.18
150	19000	0.01	0.02	0.05	0.06	0.11	0.19
150	20000	0.01	0.02	0.05	0.07	0.12	0.20
150	21000	0.01	0.02	0.05	0.07	0.13	0.21
150	22000	0.01	0.02	0.05	0.08	0.13	0.22
150	23000	0.01	0.02	0.05	0.09	0.14	0.24
150	24000	0.01	0.02	0.05	0.09	0.15	0.25
150	25000	0.01	0.02	0.05	0.10	0.16	0.26
150	26000	0.01	0.02	0.05	0.11	0.17	0.28
150	27000	0.01	0.02	0.05	0.12	0.19	0.30
150	28000	0.01	0.02	0.05	0.13	0.20	0.31
150	29000	0.01	0.02	0.05	0.13	0.21	0.33
150	30000	0.01	0.02	0.05	0.14	0.23	0.35
150	31000	0.01	0.02	0.05	0.15	0.24	0.37
150	32000	0.01	0.02	0.05	0.17	0.26	0.40
150	33000	0.01	0.02	0.06	0.18	0.27	0.42
150	34000	0.01	0.02	0.06	0.19	0.29	0.45
150	35000	0.01	0.02	0.06	0.20	0.31	0.48
150	36000	0.01	0.02	0.06	0.22	0.33	0.51
150	37000	0.01	0.02	0.06	0.23	0.36	0.54
150	38000	0.01	0.02	0.06	0.25	0.38	0.58
150	39000	0.01	0.02	0.06	0.27	0.40	0.62
150	40000	0.01	0.02	0.07	0.28	0.43	0.66

Five Lanes with Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
150	41000	0.01	0.02	0.07	0.30	0.46	0.71
150	42000	0.01	0.02	0.07	0.32	0.49	0.75
150	43000	0.01	0.02	0.07	0.34	0.53	0.81
150	44000	0.01	0.02	0.07	0.36	0.56	0.87
150	45000	0.01	0.02	0.07	0.39	0.60	0.93
150	46000	0.00	0.02	0.08	0.41	0.64	1.00
150	47000	0.00	0.02	0.08	0.43	0.68	1.07
150	48000	0.00	0.02	0.08	0.46	0.73	1.15
150	49000	0.00	0.02	0.08	0.49	0.78	1.23
150	50000	0.00	0.02	0.08	0.52	0.83	1.33
200	5000	0.01	0.03	0.06	0.02	0.04	0.09
200	6000	0.01	0.03	0.06	0.02	0.05	0.10
200	7000	0.01	0.03	0.05	0.03	0.05	0.10
200	8000	0.01	0.03	0.05	0.03	0.05	0.11
200	9000	0.01	0.03	0.05	0.03	0.06	0.11
200	10000	0.01	0.03	0.05	0.03	0.06	0.12
200	11000	0.01	0.03	0.05	0.04	0.07	0.13
200	12000	0.01	0.03	0.05	0.04	0.07	0.13
200	13000	0.01	0.03	0.05	0.04	0.08	0.14
200	14000	0.01	0.03	0.05	0.04	0.08	0.15
200	15000	0.01	0.03	0.05	0.05	0.09	0.16
200	16000	0.01	0.03	0.05	0.05	0.09	0.16
200	17000	0.01	0.02	0.05	0.06	0.10	0.17
200	18000	0.01	0.02	0.05	0.06	0.10	0.18
200	19000	0.01	0.02	0.05	0.06	0.11	0.19
200	20000	0.01	0.02	0.05	0.07	0.12	0.20
200	21000	0.01	0.02	0.05	0.08	0.13	0.21
200	22000	0.01	0.02	0.05	0.08	0.14	0.23
200	23000	0.01	0.02	0.05	0.09	0.14	0.24
200	24000	0.01	0.02	0.05	0.09	0.15	0.25
200	25000	0.01	0.02	0.05	0.10	0.17	0.27
200	26000	0.01	0.02	0.05	0.11	0.18	0.28

Five Lanes with Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
200	27000	0.01	0.02	0.05	0.12	0.19	0.30
200	28000	0.01	0.02	0.05	0.13	0.20	0.32
200	29000	0.01	0.02	0.05	0.14	0.21	0.34
200	30000	0.01	0.02	0.06	0.15	0.23	0.36
200	31000	0.01	0.02	0.06	0.16	0.24	0.38
200	32000	0.01	0.02	0.06	0.17	0.26	0.40
200	33000	0.01	0.02	0.06	0.18	0.28	0.43
200	34000	0.01	0.02	0.06	0.19	0.30	0.46
200	35000	0.01	0.02	0.06	0.21	0.32	0.48
200	36000	0.01	0.02	0.06	0.22	0.34	0.52
200	37000	0.01	0.02	0.06	0.24	0.36	0.55
200	38000	0.01	0.02	0.07	0.25	0.38	0.59
200	39000	0.01	0.02	0.07	0.27	0.41	0.63
200	40000	0.01	0.02	0.07	0.29	0.44	0.67
200	41000	0.01	0.02	0.07	0.31	0.47	0.71
200	42000	0.01	0.02	0.07	0.33	0.50	0.76
200	43000	0.01	0.02	0.07	0.35	0.53	0.82
200	44000	0.01	0.02	0.08	0.37	0.57	0.88
200	45000	0.01	0.02	0.08	0.39	0.61	0.94
200	46000	0.01	0.02	0.08	0.42	0.65	1.01
200	47000	0.00	0.02	0.08	0.44	0.69	1.08
200	48000	0.00	0.02	0.08	0.47	0.74	1.16
200	49000	0.00	0.02	0.09	0.50	0.79	1.25
200	50000	0.00	0.02	0.09	0.52	0.84	1.34
250	5000	0.01	0.03	0.06	0.02	0.05	0.09
250	6000	0.01	0.03	0.06	0.02	0.05	0.10
250	7000	0.01	0.03	0.06	0.03	0.05	0.10
250	8000	0.01	0.03	0.06	0.03	0.06	0.11
250	9000	0.01	0.03	0.06	0.03	0.06	0.11
250	10000	0.01	0.03	0.05	0.03	0.06	0.12
250	11000	0.01	0.03	0.05	0.04	0.07	0.13
250	12000	0.01	0.03	0.05	0.04	0.07	0.13

Five Lanes with Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
250	13000	0.01	0.03	0.05	0.04	0.08	0.14
250	14000	0.01	0.03	0.05	0.04	0.08	0.15
250	15000	0.01	0.03	0.05	0.05	0.09	0.16
250	16000	0.01	0.03	0.05	0.05	0.09	0.17
250	17000	0.01	0.03	0.05	0.06	0.10	0.17
250	18000	0.01	0.03	0.05	0.06	0.11	0.18
250	19000	0.01	0.03	0.05	0.07	0.11	0.19
250	20000	0.01	0.03	0.05	0.07	0.12	0.21
250	21000	0.01	0.03	0.05	0.08	0.13	0.22
250	22000	0.01	0.03	0.05	0.08	0.14	0.23
250	23000	0.01	0.03	0.05	0.09	0.15	0.24
250	24000	0.01	0.03	0.05	0.10	0.16	0.26
250	25000	0.01	0.02	0.05	0.10	0.17	0.27
250	26000	0.01	0.02	0.06	0.11	0.18	0.29
250	27000	0.01	0.02	0.06	0.12	0.19	0.30
250	28000	0.01	0.02	0.06	0.13	0.20	0.32
250	29000	0.01	0.02	0.06	0.14	0.22	0.34
250	30000	0.01	0.02	0.06	0.15	0.23	0.36
250	31000	0.01	0.02	0.06	0.16	0.25	0.38
250	32000	0.01	0.02	0.06	0.17	0.26	0.41
250	33000	0.01	0.02	0.06	0.18	0.28	0.43
250	34000	0.01	0.02	0.06	0.20	0.30	0.46
250	35000	0.01	0.02	0.07	0.21	0.32	0.49
250	36000	0.01	0.02	0.07	0.22	0.34	0.52
250	37000	0.01	0.02	0.07	0.24	0.37	0.56
250	38000	0.01	0.02	0.07	0.26	0.39	0.59
250	39000	0.01	0.02	0.07	0.27	0.42	0.63
250	40000	0.01	0.02	0.07	0.29	0.44	0.68
250	41000	0.01	0.02	0.08	0.31	0.47	0.72
250	42000	0.01	0.02	0.08	0.33	0.51	0.78
250	43000	0.01	0.02	0.08	0.35	0.54	0.83
250	44000	0.01	0.02	0.08	0.37	0.58	0.89

Based on Negative Binomial Model
18:02 Tuesday, September 16, 2003
Five Lanes with Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
250	45000	0.01	0.02	0.08	0.40	0.61	0.95
250	46000	0.01	0.02	0.09	0.42	0.66	1.02
250	47000	0.01	0.02	0.09	0.45	0.70	1.10
250	48000	0.01	0.02	0.09	0.47	0.75	1.18
250	49000	0.00	0.02	0.09	0.50	0.80	1.27
250	50000	0.00	0.02	0.09	0.53	0.85	1.36

Estimated Number of Pedestrian Crashes in Five Years
Based on Negative Binominal Model
17:25 Tuesday, September 16, 2003
Five Lanes with No Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
50	5000	0.02	0.05	0.10	0.05	0.09	0.16
50	6000	0.02	0.05	0.10	0.05	0.09	0.17
50	7000	0.02	0.05	0.09	0.05	0.10	0.18
50	8000	0.02	0.05	0.09	0.06	0.11	0.19
50	9000	0.02	0.05	0.09	0.06	0.11	0.20
50	10000	0.02	0.04	0.09	0.07	0.12	0.22
50	11000	0.02	0.04	0.09	0.07	0.13	0.23
50	12000	0.02	0.04	0.09	0.08	0.14	0.24
50	13000	0.02	0.04	0.08	0.08	0.15	0.26
50	14000	0.02	0.04	0.08	0.09	0.16	0.27
50	15000	0.02	0.04	0.08	0.10	0.17	0.29
50	16000	0.02	0.04	0.08	0.10	0.18	0.31
50	17000	0.02	0.04	0.08	0.11	0.19	0.32
50	18000	0.02	0.04	0.08	0.12	0.20	0.34
50	19000	0.02	0.04	0.08	0.13	0.22	0.36
50	20000	0.02	0.04	0.08	0.14	0.23	0.39
50	21000	0.02	0.04	0.08	0.15	0.25	0.41
50	22000	0.02	0.04	0.08	0.16	0.26	0.44
50	23000	0.02	0.04	0.08	0.17	0.28	0.47
50	24000	0.02	0.04	0.08	0.18	0.30	0.50
50	25000	0.02	0.04	0.08	0.19	0.32	0.53
50	26000	0.02	0.04	0.08	0.20	0.34	0.56
50	27000	0.02	0.04	0.09	0.22	0.36	0.60
50	28000	0.02	0.04	0.09	0.23	0.39	0.64
50	29000	0.02	0.04	0.09	0.25	0.41	0.68
50	30000	0.02	0.04	0.09	0.27	0.44	0.73
50	31000	0.02	0.04	0.09	0.28	0.47	0.78
50	32000	0.02	0.04	0.09	0.30	0.50	0.83
50	33000	0.02	0.04	0.09	0.32	0.54	0.89
50	34000	0.01	0.04	0.10	0.34	0.57	0.96
50	35000	0.01	0.04	0.10	0.36	0.61	1.02
100	5000	0.02	0.05	0.10	0.05	0.09	0.17

Estimated Number of Pedestrian Crashes in Five Years
Based on Negative Binominal Model
17:25 Tuesday, September 16, 2003
Five Lanes with No Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
100	6000	0.02	0.05	0.10	0.05	0.09	0.18
100	7000	0.02	0.05	0.10	0.05	0.10	0.19
100	8000	0.02	0.05	0.10	0.06	0.11	0.20
100	9000	0.02	0.05	0.09	0.06	0.11	0.21
100	10000	0.02	0.05	0.09	0.07	0.12	0.22
100	11000	0.02	0.05	0.09	0.07	0.13	0.23
100	12000	0.02	0.05	0.09	0.08	0.14	0.25
100	13000	0.02	0.05	0.09	0.08	0.15	0.26
100	14000	0.02	0.05	0.09	0.09	0.16	0.28
100	15000	0.02	0.05	0.09	0.10	0.17	0.29
100	16000	0.02	0.05	0.09	0.10	0.18	0.31
100	17000	0.02	0.04	0.09	0.11	0.19	0.33
100	18000	0.02	0.04	0.09	0.12	0.20	0.35
100	19000	0.02	0.04	0.09	0.13	0.22	0.37
100	20000	0.02	0.04	0.09	0.14	0.23	0.39
100	21000	0.02	0.04	0.09	0.15	0.25	0.42
100	22000	0.02	0.04	0.09	0.16	0.27	0.44
100	23000	0.02	0.04	0.09	0.17	0.28	0.47
100	24000	0.02	0.04	0.09	0.18	0.30	0.50
100	25000	0.02	0.04	0.09	0.19	0.32	0.53
100	26000	0.02	0.04	0.09	0.21	0.34	0.57
100	27000	0.02	0.04	0.09	0.22	0.37	0.61
100	28000	0.02	0.04	0.09	0.24	0.39	0.65
100	29000	0.02	0.04	0.09	0.25	0.42	0.69
100	30000	0.02	0.04	0.09	0.27	0.45	0.74
100	31000	0.02	0.04	0.10	0.29	0.48	0.79
100	32000	0.02	0.04	0.10	0.31	0.51	0.84
100	33000	0.02	0.04	0.10	0.33	0.54	0.90
100	34000	0.02	0.04	0.10	0.35	0.58	0.97
100	35000	0.02	0.04	0.10	0.37	0.62	1.04
150	5000	0.02	0.05	0.11	0.05	0.09	0.17
150	6000	0.02	0.05	0.11	0.05	0.09	0.18

Estimated Number of Pedestrian Crashes in Five Years
Based on Negative Binominal Model
17:25 Tuesday, September 16, 2003
Five Lanes with No Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
150	7000	0.02	0.05	0.10	0.05	0.10	0.19
150	8000	0.03	0.05	0.10	0.06	0.11	0.20
150	9000	0.03	0.05	0.10	0.06	0.12	0.21
150	10000	0.03	0.05	0.10	0.07	0.12	0.22
150	11000	0.03	0.05	0.10	0.07	0.13	0.24
150	12000	0.03	0.05	0.09	0.08	0.14	0.25
150	13000	0.03	0.05	0.09	0.08	0.15	0.26
150	14000	0.03	0.05	0.09	0.09	0.16	0.28
150	15000	0.03	0.05	0.09	0.10	0.17	0.30
150	16000	0.03	0.05	0.09	0.11	0.18	0.31
150	17000	0.02	0.05	0.09	0.11	0.19	0.33
150	18000	0.02	0.05	0.09	0.12	0.21	0.35
150	19000	0.02	0.05	0.09	0.13	0.22	0.37
150	20000	0.02	0.05	0.09	0.14	0.24	0.40
150	21000	0.02	0.05	0.09	0.15	0.25	0.42
150	22000	0.02	0.05	0.09	0.16	0.27	0.45
150	23000	0.02	0.05	0.09	0.17	0.29	0.48
150	24000	0.02	0.05	0.09	0.18	0.31	0.51
150	25000	0.02	0.04	0.09	0.20	0.33	0.54
150	26000	0.02	0.04	0.09	0.21	0.35	0.58
150	27000	0.02	0.04	0.10	0.22	0.37	0.61
150	28000	0.02	0.04	0.10	0.24	0.40	0.66
150	29000	0.02	0.04	0.10	0.26	0.42	0.70
150	30000	0.02	0.04	0.10	0.27	0.45	0.75
150	31000	0.02	0.04	0.10	0.29	0.48	0.80
150	32000	0.02	0.04	0.10	0.31	0.51	0.86
150	33000	0.02	0.04	0.11	0.33	0.55	0.92
150	34000	0.02	0.04	0.11	0.35	0.59	0.98
150	35000	0.02	0.04	0.11	0.37	0.63	1.05
200	5000	0.03	0.05	0.11	0.05	0.09	0.17
200	6000	0.03	0.05	0.11	0.05	0.10	0.18
200	7000	0.03	0.05	0.11	0.06	0.10	0.19

Estimated Number of Pedestrian Crashes in Five Years
Based on Negative Binominal Model
17:25 Tuesday, September 16, 2003
Five Lanes with No Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
200	8000	0.03	0.05	0.11	0.06	0.11	0.20
200	9000	0.03	0.05	0.10	0.06	0.12	0.21
200	10000	0.03	0.05	0.10	0.07	0.12	0.23
200	11000	0.03	0.05	0.10	0.07	0.13	0.24
200	12000	0.03	0.05	0.10	0.08	0.14	0.25
200	13000	0.03	0.05	0.10	0.09	0.15	0.27
200	14000	0.03	0.05	0.10	0.09	0.16	0.28
200	15000	0.03	0.05	0.10	0.10	0.17	0.30
200	16000	0.03	0.05	0.10	0.11	0.18	0.32
200	17000	0.03	0.05	0.10	0.11	0.20	0.34
200	18000	0.03	0.05	0.10	0.12	0.21	0.36
200	19000	0.03	0.05	0.10	0.13	0.22	0.38
200	20000	0.03	0.05	0.10	0.14	0.24	0.40
200	21000	0.02	0.05	0.10	0.15	0.26	0.43
200	22000	0.02	0.05	0.10	0.16	0.27	0.45
200	23000	0.02	0.05	0.10	0.17	0.29	0.48
200	24000	0.02	0.05	0.10	0.19	0.31	0.51
200	25000	0.02	0.05	0.10	0.20	0.33	0.55
200	26000	0.02	0.05	0.10	0.21	0.35	0.58
200	27000	0.02	0.05	0.10	0.23	0.38	0.62
200	28000	0.02	0.05	0.10	0.24	0.40	0.66
200	29000	0.02	0.05	0.10	0.26	0.43	0.71
200	30000	0.02	0.05	0.11	0.28	0.46	0.76
200	31000	0.02	0.05	0.11	0.29	0.49	0.81
200	32000	0.02	0.05	0.11	0.31	0.52	0.87
200	33000	0.02	0.04	0.11	0.33	0.56	0.93
200	34000	0.02	0.04	0.11	0.36	0.59	0.99
200	35000	0.02	0.04	0.12	0.38	0.63	1.06
250	5000	0.03	0.06	0.12	0.05	0.09	0.17
250	6000	0.03	0.06	0.12	0.05	0.10	0.18
250	7000	0.03	0.06	0.11	0.06	0.10	0.19
250	8000	0.03	0.06	0.11	0.06	0.11	0.20

Estimated Number of Pedestrian Crashes in Five Years

5

Based on Negative Binominal Model
17:25 Tuesday, September 16, 2003
Five Lanes with No Median

Average Daily Pedestrian Volume	Average Daily Traffic (Motor Vehicle)	Unmarked Lower 95%	Unmarked Predicted	Unmarked Upper 95%	Marked Lower 95%	Marked Predicted	Marked Upper 95%
250	9000	0.03	0.06	0.11	0.06	0.12	0.22
250	10000	0.03	0.06	0.11	0.07	0.13	0.23
250	11000	0.03	0.05	0.11	0.08	0.13	0.24
250	12000	0.03	0.05	0.10	0.08	0.14	0.26
250	13000	0.03	0.05	0.10	0.09	0.15	0.27
250	14000	0.03	0.05	0.10	0.09	0.16	0.29
250	15000	0.03	0.05	0.10	0.10	0.17	0.30
250	16000	0.03	0.05	0.10	0.11	0.19	0.32
250	17000	0.03	0.05	0.10	0.12	0.20	0.34
250	18000	0.03	0.05	0.10	0.12	0.21	0.36
250	19000	0.03	0.05	0.10	0.13	0.23	0.38
250	20000	0.03	0.05	0.10	0.14	0.24	0.41
250	21000	0.03	0.05	0.10	0.15	0.26	0.43
250	22000	0.03	0.05	0.10	0.17	0.28	0.46
250	23000	0.02	0.05	0.10	0.18	0.29	0.49
250	24000	0.02	0.05	0.10	0.19	0.31	0.52
250	25000	0.02	0.05	0.10	0.20	0.34	0.56
250	26000	0.02	0.05	0.11	0.22	0.36	0.59
250	27000	0.02	0.05	0.11	0.23	0.38	0.63
250	28000	0.02	0.05	0.11	0.25	0.41	0.67
250	29000	0.02	0.05	0.11	0.26	0.43	0.72
250	30000	0.02	0.05	0.11	0.28	0.46	0.77
250	31000	0.02	0.05	0.11	0.30	0.50	0.82
250	32000	0.02	0.05	0.12	0.32	0.53	0.88
250	33000	0.02	0.05	0.12	0.34	0.56	0.94
250	34000	0.02	0.05	0.12	0.36	0.60	1.01
250	35000	0.02	0.05	0.12	0.38	0.64	1.08

REFERENCES

1. *Uniform Vehicle Code and Model Traffic Ordinance*, Millennium Edition, National Committee on Uniform Traffic Laws and Ordinances, Evanston, IL, 2000.
2. *Manual on Uniform Traffic Control Devices—Millennium Edition*, Federal Highway Administration, Washington, DC, 2000.
3. Herms, B., "Pedestrian Crosswalk Study: Crashes in Painted and Unpainted Crosswalks," *Record No. 406*, Transportation Research Board, Washington, DC, 1972.
4. Zegeer, C., Stewart, J., and Huang, H., *Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Executive Summary and Recommended Guidelines,* Report No. FHWA–RD–01–075, Federal Highway Administration, Washington, DC, March 2002.
5. Gibby, A.R., Stites, J.L., Thurgood, G.S., and Ferrara, T.C., "*Evaluation of Marked and Unmarked Crosswalks at Intersections in California*," Chico State University, Report No. FHWA/CA/TO–94/1, June 1994.
6. Gurnett, G., *Marked Crosswalk Removal Before and After Study*, Los Angeles County Road Department, Los Angeles, CA, November 1974.
7. Los Angeles County Road Department, *Marked Crosswalks at Non-Signalized Intersections*, Traffic and Lighting Division, Los Angeles, CA, July 1967.
8. Toby, H.N., Shunamen, E.M., and Knoblauch, R.L., *Pedestrian Trip Making Characteristics and Exposure Measures*, DTFH61–81–C–00020, Federal Highway Administration, Washington, DC, 1983.
9. Ekman, L., *On the Treatment of Flow in Traffic Safety Analysis*, Bulletin 136, University of Lund, Lund, Sweden, 1996.
10. Ekman, L. and Hyden, C., *Pedestrian Safety in Sweden*, Report No. FHWA–RD–99–091, Federal Highway Administration, Washington, DC, December 1999.
11. Yagar, S., "Safety Impacts of Installing Pedestrian Crosswalks," Proceedings of the Effectiveness of Highway Safety Improvements Conference, American Society of Civil Engineers, New York, NY, March 1985.
12. Katz, A., Zaidel, D., and Elgrishi, A., "An Experimental Study of Driver and Pedestrian Interaction During the Crossing Conflict," *Human Factors*, Vol. 17, No. 5, 1975, pp. 514–527.
13. Knoblauch, R.L., Nitzburg, M., and Seifert, R.F., *Pedestrian Crosswalk Case Studies: Richmond, Virginia; Buffalo, New York; Stillwater, Minnesota*, Report No. FHWA–RD–00–103, Federal Highway Administration, Washington, DC, August 2001.
14. Knoblauch, R.L. and Raymond, P.D., *The Effect of Crosswalk Markings on Vehicle Speeds in Maryland, Virginia, and Arizona*, Report No. FHWA–RD–00–101, Federal Highway Administration, Washington, DC, August 2000.
15. Van Houten, R., "The Influence of Signs Prompting Motorists to Yield Before Marked Crosswalks on Motor Vehicle-Pedestrian Conflicts at Crosswalks with Flashing Amber," *Accident Analysis and Prevention*, Vol. 24, No. 3, 1992, pp. 217–225.
16. Campbell, B.J., Zegeer, C.V., Cynecki, M.J., and Huang H., *A Review of Pedestrian Safety Research in the United States and Abroad,* Report No. FHWA–RD–03–042, Federal Highway Administration, Washington, DC, January 2004.
17. Ekman, L., *Pedestrian Safety in Sweden*, Report No. FHWA–RD–99–091, Federal Highway Administration, Washington, DC, December 1999.
18. Davies, D., *Research, Development, and Implementation of Pedestrian Safety Facilities in the United Kingdom*, Report No. FHWA–RD–99–089, Federal Highway Administration, Washington, DC, December 1999.
19. Van Houten, R., *Canadian Research on Pedestrian Safety*, Report No. FHWA–RD–99–090, Federal Highway Administration, Washington, DC, December 1999.
20. Cairney, P., *Pedestrian Safety in Australia*, Report No. FHWA–RD–99–093, Federal Highway Administration, Washington, DC, December 1999.

21. Hummel, T., *Dutch Pedestrian Safety Research Review*, Report No. FHWA–RD–99–092, Federal Highway Administration, Washington, DC, December 1999.
22. Zegeer, C.V., Seiderman, C., Lagerwey, P., and Cynecki, M., *Pedestrian Facilities User's Guide: Providing Safety and Mobility*, Report No. FHWA–RD–01–102, Federal Highway Administration, Washington, DC, 1999.
23. Lalani, N., *Alternative Treatments for At-Grade Pedestrian Crossings*, Institute of Transportation Engineers, Pedestrian and Bicycle Task Force, Washington, DC, 2001.
24. Ewing, R., *Traffic Calming: State of the Practice*, ITE/FHWA Report No. FHWA–RD–99–135, Federal Highway Administration, Washington, DC, August 1999, available online at http://www.ite.org/traffic/tcstate.htm, accessed July 30, 2004.
25. Huang, H.F., C.V. Zegeer, R. Nassi, and B. Fairfax, *The Effects of Innovative Pedestrian Signs at Unsignalized Locations: A Tale of Three Treatments*, Report No. FHWA–RD–00–098, Federal Highway Administration, Washington, DC, August 2000, available online at http://www.walkinginfo.org/task_orders/to_11/3signs00.pdf, accessed July 30, 2004.
26. McCullagh, P. and Nelder, J.A., *Generalized Linear Models*, Second Edition, Chapman and Hall, London, UK, 1989.
27. Hilbe, J., "Log Negative Binomial Regression Using the GENMOD Procedure," Proceedings of the Nineteenth Annual SAS User's Group International Conference, Vol. 14, 1994, pp. 1199–1204.
28. Lawless, J.E., "Negative Binomial and Mixed Poisson Regression," *The Canadian Journal of Statistics*, Vol. 15, 1987, pp. 209–225.
29. SAS Institute Inc., SAS OnlineDoc®, Version 8, SAS Institute Inc., Cary, NC, 1999.
30. Garder, P., Personal correspondence, October 7, 1999 and March 2000.
31. Bowman, B. and Vecellio, R., "Effects of Urban and Suburban Median Types on Both Vehicular and Pedestrian Safety," *Record No. 1445*, Transportation Research Board, Washington, DC, 1994.
32. Garder, P., "Pedestrian Safety at Traffic Signals: A Study Carried Out With the Help of a Traffic Conflicts Technique," *Accident Analysis & Prevention*, Vol. 21, October 1989, pp. 435–444.
33. *Safety of Vulnerable Road Users*, Organisation for Economic Co-operation and Development (OECD), August 1998.
34. Van Houten, R., "The Effects of Advance Stop Lines and Sign Prompts on Pedestrian Safety in Crosswalks on a Multilane Highway," *Journal of Applied Behavior Analysis*, Vol.21, 1988.
35. *Design and Safety of Pedestrian Facilities: A Recommended Practice*, Institute for Transportation Engineers, March 1998.
36. Zegeer, C. and Seiderman, C., Chapter 19, "Designing for Pedestrians," *The Traffic Safety Toolbox*, Institute for Transportation Engineers, 1999.
37. *Pedestrian Safety: Analyses and Safety Measures*, Danish Road Directorate, Division of Traffic Safety and Environment, Copenhagen, Denmark, June 1998.
38. *Making Streets That Work—Neighborhood Planning Tool*, City of Seattle, WA, May 1996.
39. Zegeer, C.V., Opiela, K.S., and Cynecki, M.J., *Pedestrian Signalization Alternatives*, Report No. FHWA–RD–83–102, Federal Highway Administration, Washington, DC, July 1985.
40. Cameron, A.C. and Trivedi, P.K., *Regression Analysis of Count Data*, Cambridge University Press, Cambridge, MA, 1998.
41. Belsley, D.A., Kuh, E., and Welsch, R.E., *Regression Diagnostics*, John Wiley & Sons, Inc., New York, NY, 1980.