Pedestrian Safety at Midblock Locations

Prepared by
Center for Urban Transportation Research

Prepared for
Florida Department of Transportation

September 2006

Contract Number: BD544-16

DISCLAIMER

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Pedestrian Safety at Midblock Locations		5. Report Date September 2006
		6. Performing Organization Code
7. Author(s) Xuehao Chu		8. Performing Organization Report No.
9. Performing Organization Name and Address Center for Urban Transportation Research (CUTR) University of South Florida 4202 E Fowler Av, CUT 100, Tampa, FL 33620-5375		10. Work Unit No.
		11. Contract or Grant No. BD544-16
12. Sponsoring Agency Name and Address Florida Department of Transportation 605 Suwannee Street, MS 30, Tallahassee, FL 32399		13. Type of Report and Period Covered
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report examines two aspects of pedestrian safety at midblock locations. In Part I, the report assesses the role of crossing locations and light conditions in pedestrian injury severity through a multivariate regression analysis to control for many other factors that also may influence pedestrian injury severity. Crossing locations include midblock and intersections, and light conditions include daylight, dark with street lighting, and dark without street lighting. The report formulates a theoretical framework on the determinants of pedestrian injury severity, and specifies an empirical model accordingly. The report applies the ordered probit model to the KABCO severity scale of pedestrian injuries which occurred while attempting street crossing from 1986 to 2003 in Florida. In Part II, the report proposes a set of guidelines for marking midblock crosswalks at uncontrolled locations along Florida's State Highway System through a comprehensive process. It describes the approach taken to developing these guidelines and a structure synthesized from guidelines from 28 localities. It summarizes the available evidence on the effect of crosswalk markings on pedestrian-vehicle collision risks. Before presenting the proposed guidelines, the report sets up a simple model of pedestrian-vehicle collision risks, uses this model to identify three mechanisms that help explain why crosswalk markings may lead to higher pedestrian-vehicle collision risks, and uses this model to identify engineering treatments to counter these mechanisms.

17. Key Words Pedestrian, midblock, lighting, crosswalk, treatments, guidelines	18. Distribution Statement		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 48 (without appendices)	22. Price

ACKNOWLEDGMENTS

Martin Guttenplan was the project manager for the Florida Department of Transportation.

Achilleas Kourtellis and Naved A. Siddiqui provided research assistance.

Staff from the following agencies served on the Steering Committee:

- FDOT Central Office – Planning
- FDOT Central Office – Safety
- FDOT Central Office – Design
- FDOT Central Office – Traffic Engineering and Operations
- FDOT District 7 – Pedestrian Coordinator
- FDOT District 7 – Project Development
- City of St Petersburg
- HARTline
- Alachua County

Input was gathered at the following professional meetings:

- Bicycle & Pedestrian Advisory Committee of the Hillsborough County MPO
- Florida Greenbook Advisory Committee
- Florida Probike & Prowalk Conference
- FDOT Senior Designers Team Meeting

Steve Polzin, Christine Williams, and Huaguo Zhou provided comments on an earlier version.

Patricia Ball was the editor of the report.

FOREWORD

The Florida Department of Transportation (FDOT) was alarmed in early 2004 by several trends in the safety of pedestrians while crossing roadways at midblock locations relative to intersections. These trends were derived from the Florida Department of Highway Safety and Motor Vehicles' annual *Traffic Crash Facts*, which has shown the number of pedestrian fatal and non-fatal injuries as a result of attempting to cross a roadway in Florida since 1986. The following summarizes these trends between the periods of 1986-1993 and 1994-2001:

- During these periods, the number of injuries increased over time from crossing at midblock locations, but decreased from crossing at intersections (Table 1). This differential trend between midblock and intersection crossings is true for both fatal and non-fatal injuries. Specifically, fatal injuries increased by 5.9 percent at midblock locations but decreased by 20.4 percent at intersections. At the same time, non-fatal injuries increased by 12.1 percent at midblock locations, but decreased by 4.8 percent at intersections. This differential trend does not necessarily mean that crossing at midblock locations is getting more dangerous relative to crossing at intersections. It could have resulted from the suburbanization of population and employment and a behavioral shift toward crossing more at midblock locations than at intersections.

Table 1. Florida Trends in Pedestrian Injuries from Street Crossing

Location	***Fatal Injuries***			***Non-Fatal Injuries***		
	1986-1993	***1994-2001***	***% Change***	***1986-1993***	***1994-2001***	***% Change***
Mid-block	1,992	2,109	5.9	20,966	23,511	12.1
Intersection	638	508	-20.4	9,006	8,573	-4.8
% Mid-block	76	81	N/A	70	73	N/A

Source: Derived from annual *Traffic Crash Facts*, Florida Department of Highway Safety and Motor Vehicles.

- Crossing at midblock locations represents most of the injuries from attempting to cross a road in Florida (Table 1). For the 1994-2001 period, 81 percent of all fatal injuries and 73 percent of non-fatal injuries from street crossing occurred at midblock locations. Furthermore, crossing at midblock locations represents an increasing share of pedestrian fatal and non-fatal injuries from street crossing over time. For fatal injuries, this share increased from 76 percent to 81 percent between the two periods, versus 70 percent to 73 percent for non-fatal injuries.

- Crossing at mid-block locations appears to be more deadly than at intersections (Table 2). Measured in terms of the number of deaths per 100 total injuries, the fatality rate during the 1994-2001 period is 8.2 for crossing at midblock locations versus 5.6 for crossing at intersections. The good news is that fatality rates appeared to be declining over time for crossing both at midblock and intersections. The fatality rate decreased from 8.7 to 8.2, versus a decrease from 6.6 to 5.6 at intersections. The bad news is that crossing at midblock locations appears to have become more deadly over time relative to crossing at intersections. The ratio of fatality rates between crossing at midblock locations and crossing at intersections is 1.31 during the 1986-1993 period and 1.47 during the 1994-2001 period. That is, the odds of a pedestrian sustaining a fatal injury from being hit by a motor vehicle while crossing at midblock locations are 31 percent higher than at intersections during the 1986-1993 period. During the later period, the odds of sustaining a fatal injury at midblock locations are almost 50 percent higher than at intersections.

Table 2. Relative Fatality Rates between Midblock and Intersection Locations

Measures	***1986-1993***	***1994-2001***
Mid-block fatality rate (fatal injuries per 100 total injuries)	8.7	8.2
Intersection fatality rate (fatal injuries per 100 total injuries)	6.6	5.6
Odds ratio (mid-block fatality rate over intersection fatality rate)	1.31	1.47

Source: Computed from Table 1.

Partly motivated by these trends, FDOT funded a research project in late 2004 on pedestrian safety at midblock locations. One focus area of the research was to examine the role of light conditions on pedestrian injury severity at midblock locations, and the other focus area was to develop a set of guidelines for placing midblock crosswalks at uncontrolled locations on the State Highway System. This report has two parts. Part I presents the results from the first focus area, while Part II presents the results from the second focus area.

EXECUTIVE SUMMARY

PROBLEM STATEMENT

Light Conditions

One serious problem with pedestrian safety in Florida relates to light conditions. Based on data from 1986 through 2003, about 37 percent of all pedestrian crashes occurred while the pedestrians were attempting to cross roadways under dark conditions versus daylight conditions. While dark conditions do not represent as large a share of pedestrian crashes as midblock locations, the differential risk across light conditions is significantly higher than that across crossing locations. Stated in the probability of a pedestrian getting killed once struck by a vehicle, the fatal injury risk, on average, is over 6 times as high under dark conditions as under daylight conditions.

Guidelines

Uncontrolled midblock locations with established pedestrian generators and attractors and adequate crossing demand along state roads rarely meet the current pedestrian signal warrant. Many of these locations are along multilane roads with high traffic volumes and speeds. Engineers are reluctant to mark uncontrolled midblock crosswalks without a good set of guidelines, and the existing guidelines need improvements for them to be useful for the practitioner. They are not structured and contain gaps that make implementation difficult. They are not always consistent with each other. They often discourage or even exclude uncontrolled midblock crosswalks from being considered under many conditions. These excluded conditions often include those locations along multilane roads with high traffic volumes and speeds that most need improvements for pedestrian crossings.

OBJECTIVES

Light Conditions

One objective was to assess the interactive roles of crossing locations and light conditions in pedestrian injury severity through a multivariate regression analysis to control for many other factors that also may influence pedestrian injury severity. One may not attribute the differential risks mentioned above simply to the differences in locations or light conditions. Many other factors are likely to have played a role in the observed differential average risks.

Guidelines

The second objective was to develop guidelines for uncontrolled midblock crosswalks on Florida’s State Highway System, including multilane roads with high traffic volumes and speeds.

FINDINGS AND CONCLUSIONS

Light Conditions

The study has estimated an ordered probit model with crash data from 1986 to 2003 in Florida. The empirical model is well behaved. It includes pedestrian attributes, driver attributes, road attributes, vehicle attributes, and weather conditions as control variables. All control variables that have specific expected directions of effects and are statistically significantly have the expected signs. More important, all five interactive variables on crossing locations and light conditions are statistically significant and have the expected direction of effects.

The results provide new insights on the roles of crossing locations and light conditions on pedestrian injury severity. In terms of crossing locations, the probability of a pedestrian dying when struck by a vehicle is higher at midblock locations than at intersections for any light condition. In fact, the odds of sustaining a fatal injury at intersections are 49 percent lower than at midblock locations under daylight conditions, 24 percent lower under dark conditions with street lighting, and 5 percent lower under dark conditions without street lighting. Relative to dark conditions without street lighting, daylight reduces the odds of a fatal injury by 75 percent at midblock locations and by 83 percent at intersections, while street lighting reduces the odds by 42 percent at midblock locations and by 54 percent at intersections.

Guidelines

The study has proposed a set of guidelines for marking midblock crosswalks at uncontrolled locations on Florida's State Highway System. The process used in developing these guidelines and the guidelines are common with similar efforts in other localities:

- The process is based on a review of actual guidelines from other localities.
- The process is based on a solicitation of practitioner inputs.
- The guidelines include a set of demand criteria.
- The guidelines include a set of basic safety criteria.
- The guidelines include a set of basic treatments and a set of enhanced treatments.
- The guidelines reflect all MUTCD guidance on marking crosswalks at uncontrolled midblock locations.

In addition to these common features, the process used and the resultant guidelines are unique in many ways:

- The process is more comprehensive and includes many forms of inputs.
- The process follows an inclusive philosophy toward marking crosswalks. Rather than excluding multilane roads, roads with high traffic volumes, or roads with high speeds from being considered for midblock crosswalks at uncontrolled locations, the focus is on selecting appropriate treatments for these environments when there is a well established crossing demand and adequate sight distance and lighting. The most serious problem of pedestrian crossing safety exists largely on those situations, doing nothing for well established demand is not a sound public policy.
- The guidelines are structured to avoid gaps that would make their implementation difficult.
- The guidelines include a spreadsheet tool that uses information on block characteristics, roadside characteristics, intersection characteristics, cross-sectional characteristics, and crossing patterns to estimate the likelihood of pedestrians who currently cross in the block using a new midblock crosswalk.
- The guidelines take into account available evidence that crosswalk markings appear to increase pedestrian-vehicle collision risks. The development process sets up a simple model of pedestrian-vehicle collision risks. This model is used to identify three

mechanisms through which pedestrian-vehicle collision risks may be higher in marked crosswalks. These mechanisms are multiple-threat collisions, pedestrians having a false sense of security, and lack of enhancements in addition to simple two-line markings. This model is further used to identify treatments to counter these mechanisms so that crosswalk markings do not lead to higher collision risks.

- The guidelines take into account the fact that the available evidence is uncertain. These guidelines are designed to be provisional and include a monitoring process for any new uncontrolled midblock crosswalks implemented under these guidelines.

BENEFITS

Adequate lighting has significant benefits in reducing pedestrian injury severity once the pedestrian is involved in a motor vehicle crash. This result has already been incorporated in the guidelines developed for placing midblock crosswalks at uncontrolled locations. Beyond being part of midblock crosswalk installations, providing adequate lighting should be a priority for FDOT in its continued efforts to improve pedestrian safety.

While existing evidence is still uncertain in whether placing midblock crosswalks at uncontrolled locations will improve pedestrian safety, the report has incorporated this uncertainty into the guidelines developed. The State Traffic Engineering and Operations Office is in the process of developing guidelines for placing midblock crosswalks at uncontrolled locations for the *Traffic Engineering Manual*. The results from this report could become an important source of information.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

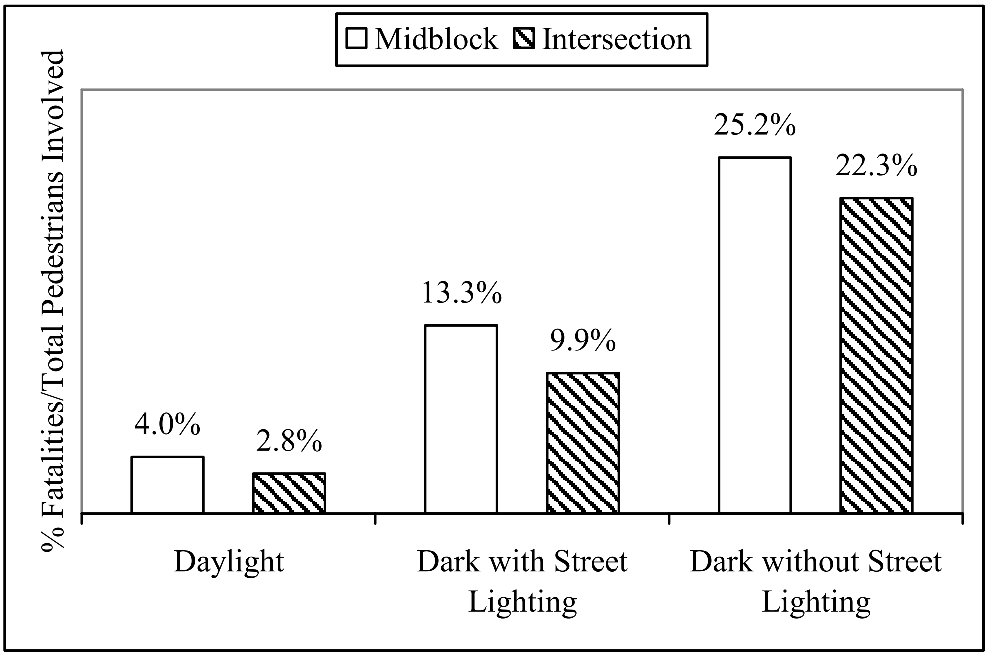
PART I: LIGHT CONDITIONS AND PEDESTRIAN INJURY SEVERITY

INTRODUCTION

In 2003, a total of 4,749 pedestrians were killed and 70,000 injured by motor vehicles in the United States (NHTSA 2005). The average pedestrian fatality rate in the United States in 2003 was 1.63 deaths per 100,000 population (NHTSA 2005). The situation is even more severe in Florida, which had the second highest rate in the country at 2.94 fatalities per 100,000 population.

One serious problem with pedestrian safety in Florida relates to light conditions. Based on data from 1986 through 2003, about 37 percent of all pedestrian crashes occurred while the pedestrians were attempting to cross roads under dark conditions versus daylight conditions. While dark conditions do not represent as large a share of pedestrian crashes as midblock locations, the differential risk across light conditions is significantly higher than that across crossing locations. Stated in the probability of a pedestrian getting killed once struck by a vehicle, the fatal injury risk on average is many times higher under dark conditions than under daylight conditions (Figure 1).

Figure 1. Pedestrian Fatality Risk by Crossing Location and Light Condition



Earlier studies mention that fatal pedestrian crashes are more likely to occur during nighttime hours while non-fatal pedestrian crashes are more likely to occur during daytime hours (FHWA 2004). It has been found in previous studies that the probability of a pedestrian getting killed increases at least three times when involved in a nighttime crash compared to a daytime crash (Miles-Doan 1996; Sullivan and Flannagan 2002). A large body of research ascertains the reasons behind the high nighttime fatality risk (Allen 1970). However, previous work has not looked at light conditions and crossing locations in a joint approach.

This report assesses the interactive roles of crossing locations and light conditions in pedestrian injury severity through a multivariate regression analysis to control for many other factors that also may influence pedestrian injury severity. One may not attribute the differential risks in Figure 1 simply to the differences in locations or light conditions. Many other factors that differ across locations or light conditions are likely to have played a role in the observed differential average risks. This study contributes to the literature in a number of ways. One theoretical advantage of the study is the use of a reduced-form model of pedestrian injury severity to guide model specification, resulting in unbiased estimates of the effects of crossing locations and light conditions on pedestrian injury severity. One empirical advantage is the use of data for 17 years, resulting in reliable estimates of the effects of crossing locations and light conditions on pedestrian injury severity. This is important because of the relatively small number of pedestrian crashes reported each year and the need to estimate the effects of crossing locations and light conditions interactively.

THEORETICAL FRAMEWORK

Direct Determinants

Three sets of factors directly determine the injury severity of a pedestrian once struck by a motor vehicle:

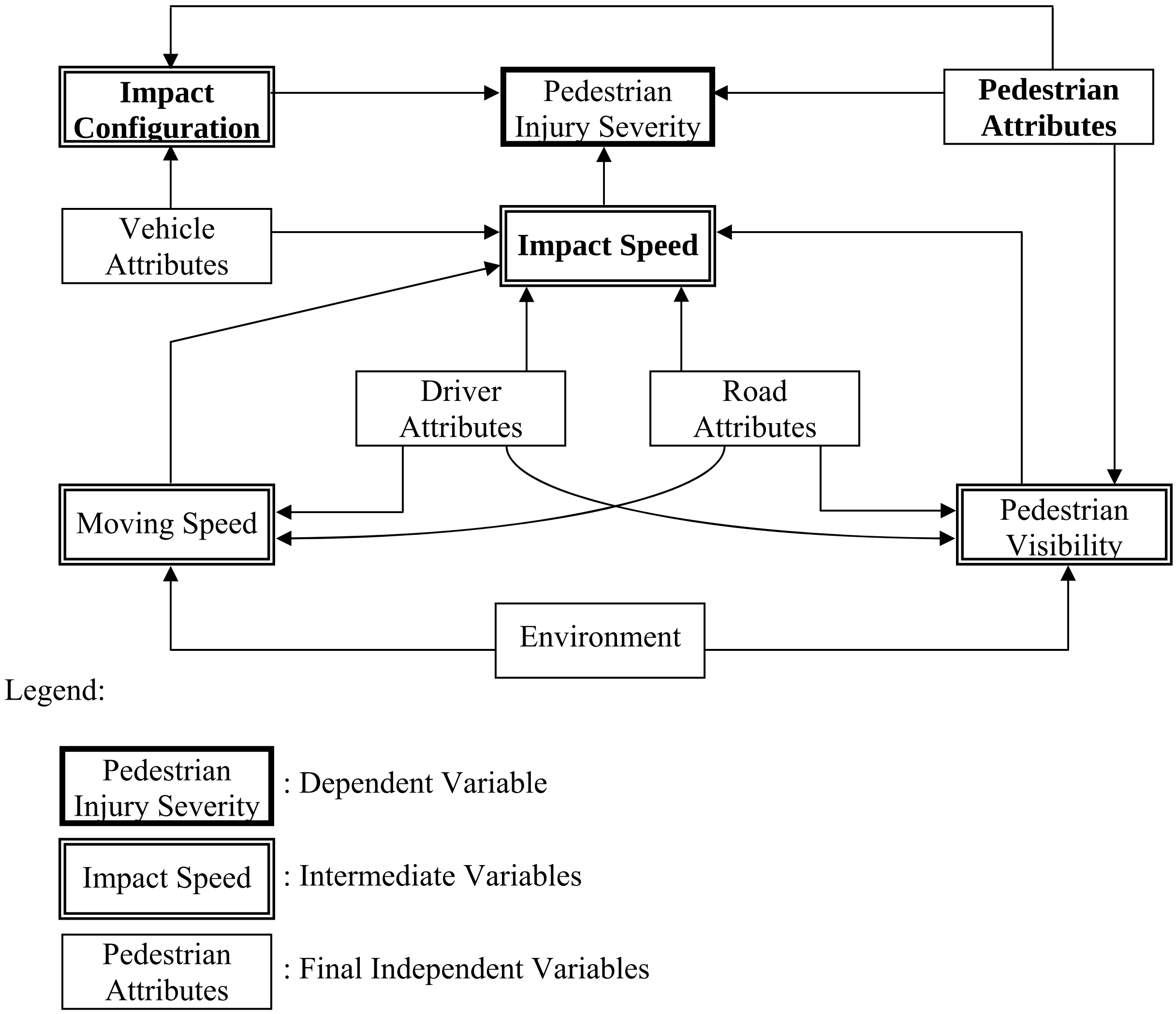
- **Impact Speed**—The most important factor is the impact speed, which is the speed of the vehicle upon striking the pedestrian (Lee and Abdel-Aty 2005; Sullivan and Flannagan 2002; Jensen 1999; Garder 2004; Pitt et al. 1990). The chance of survival by the pedestrian drops quickly between an impact speed of 20 mph and an impact speed of 40 mph (NHTSA 1999).
- **Impact Configuration**—Besides impact speed, one set of determinants relates to impact configuration between the pedestrian and the vehicle (Yang 2002). This impact configuration has several aspects, including the angle at which the vehicle strikes the pedestrian (e.g., frontal versus side), the angle at which the pedestrian is struck (i.e., front, back, side), and the height of the impact on the pedestrian.
- **Pedestrian Attributes**—The final set of determinants relate to the characteristics of the pedestrian. Two pedestrian age groups, the very young (Jensen 1999; Lascala et al. 2001; Al-Ghamdi 2002; Fontaine and Gourlet 1997) and the very old (Lee and Abdel-Aty 2005; Jensen 1999; Lascala et al. 2001; Al-Ghamdi 2002; Fontaine and Gourlet 1997; Zajac and Ivan 2003) are most vulnerable to suffering from severe injuries. Male pedestrians, being physically stronger and bigger on average than their female counterparts, may be less likely to sustain severe injuries.

These three sets of direct determinants are shown in bold in Figure 2. While the mass of an involved vehicle is an important determinant of injury severities to both its own occupants and the occupants of the other vehicles involved, the mass of the vehicle is unlikely to be a significant factor in determining the injury severity of a pedestrian.

Indirect Determinants

Policy analyses of pedestrian safety, however, often require an understanding of indirect determinants of pedestrian injury severity that go beyond the direct determinants. This study, for example, focuses on the role of crossing locations and light conditions on pedestrian injury severity. But crossing locations and light conditions do not directly affect pedestrian injury severity. These indirect determinants play a role in pedestrian injury severity through their effects on the direct determinants (Figure 2):

Figure 2. A Framework on the Determinants of Pedestrian Injury Severity



- Vehicle attributes may affect both impact configuration and impact speed. High profile vehicles, such as SUVs, are more likely to increase the height of the impact on a pedestrian. Holding other factors constant, on the other hand, heavy vehicles are harder to stop, resulting in a higher impact speed.
- In addition to vehicle attributes, several sets of other factors affect the impact speed of a vehicle. These include the moving speed of the vehicle, driver attributes, road attributes, and pedestrian visibility to the driver.
- Furthermore, both driver attributes and road attributes affect the moving speed and pedestrian visibility to the driver.

- Pedestrian attributes, such as whether they wear reflective clothing at night, affect pedestrian visibility to the driver.
- Finally, the environment in terms of weather and light conditions can affect both the moving speed of the vehicle and pedestrian visibility to the driver.

In this theoretical framework, crossing locations are part of road attributes, while light conditions are part of the environment. Crossing locations affect pedestrian injury severity most likely through their indirect effects on moving speeds, which in turn affect impact speed. Light conditions, on the other hand, affect pedestrian injury severity largely through their indirect effects on pedestrian visibility to drivers. The following discusses the link between light conditions and impact speed in more detail.

The constraints faced by drivers in recognizing pedestrians at night can be understood by discussing the two types of visual systems used by human eyes for observing and recognizing objects. One is focal vision controlled by the central retina, which helps in recognizing objects, and the other is ambient vision controlled by the peripheral retina, which helps in guiding movements. It has been researched that although focal vision degrades rapidly at night, ambient vision is relatively independent of any errors (Tyrell et al. 2004; Leibowitz and Owens 1986; Leibowitz and Owens 1977; Jeffrey and Owens 2001). Due to proper functioning of the guidance mode and rare appearance of pedestrians at night, drivers do not realize that their ability to react to an obstruction is adversely affected due to degradation of the recognition mode at night. Apart from that, the visible distance available to the driver at night is fixed due to the use of fixed headlights in the vehicles, which do not respond to changes in vehicle speeds or in the roadway environment. Also, drivers tend to use low beams at night, which reduces available sight distance further. Consequently, at night, often the distance available to drivers for successfully avoiding a crash when a pedestrian appears on road, is shorter than the total stopping sight distance required (Leibowitz et al. 1998; Tyrrell et al. 2003).

Visual degradation affects not only drivers but also pedestrians. The pedestrian's ability to find a proper gap for crossing roads at night is affected by the indistinctness of a vehicle's position, and the pedestrian's inability to judge the vehicle's actual approaching speed. Also, pedestrians do not realize the visual challenge experienced by drivers at night resulting in them overestimating drivers' observation abilities (Tyrrell et al. 2004; Tyrrell et al. 2003; Shinar 1984). Allen et al. (1970) found that the distances at which pedestrians thought they are visible to drivers are far greater than the distance at which they are actually visible to the drivers.

METHODOLOGY

Data

The study uses an electronic database of all 160,119 pedestrian crashes in Florida as reported on its Long Form Police Accident Reports (PARs) in the period from 1986 through 2003. It does not include pedestrian crashes reported on Florida's Short Form PARs. The only relevant change over this period is in what is considered a fatal injury. Before 1999, a fatality was considered to be a person who died within 90 days of a crash. Since then, a 30-day criterion has been used.

The database uses the KABCO scale for injury severity: possible injury, non-incapacitating injury, incapacitating injury, and fatal injury. The database also includes pedestrian crashes where the pedestrians involved were not injured. In addition to information on injury severity, the database includes a large number of characteristics about the crash, the vehicle, the driver, and the pedestrian. In particular, light conditions are described in five different categories: daylight, dusk, dawn, dark with street lighting, and dark without street lighting. Furthermore, a variable describing pedestrian action at the time of a crash provides information on whether the pedestrian was crossing a road, and where the pedestrian was crossing the road in terms of midblock locations versus intersections.

A total of 78,283 pedestrian crashes are excluded because they do not serve the purpose of the study. Among these, 77,297 are removed because they relate to pedestrian actions other than street crossing. The other 986 pedestrian crashes are removed because they occurred on freeways. In addition, a total of 23,634 pedestrian crashes are removed because of data problems. Among these, all 8,968 pedestrian crashes for 1990 are removed because data in that year have far more vehicles than drivers involved, indicating a general data problem. Another 9,419 crashes with inconsistent location information are also excluded. Besides the variable describing pedestrian action, the database has another variable that describes crash locations. The exclusion criterion in this case of location inconsistency is that these two variables show different locations for a given crash. Furthermore, all 2,817 crashes that occurred under dusk or dawn conditions are removed because the number of pedestrian crashes under these conditions is relatively small for reliable statistical analysis. Finally, 2,430 crashes are excluded due to other data problems, including crashes with unknown light conditions, injury severity, or locations. These exclusions result in a total of 58,202 pedestrian crashes for analysis.

Econometric Model

This study uses the ordered probit model. The dependant variable, injury severity, is an ordinal scale, where the relative difference between different injury severities is not well defined. For example, the distance between a possible injury and a non-incapacitating injury is different from that between an incapacitating injury and a fatal injury. Previous researchers have used the ordered probit model to analyze crash severity and injury severity of vehicle occupants (McCarthy 2002; Klop and Khatak 1999; O'Donnel and Connor 1996; Duncan et al. 1998; Yamamoto and Shankar 2004; Kockelman and Kweon 2002). More recently, researchers have also used the ordered probit model to model pedestrian injury severity (Lee and Abdel-Aty 2005; Zajac and Ivan 2003).

The ordered probit model is built around a latent regression as follows (Greene 1990):

$$y_i^* = x_i\beta + \varepsilon_i$$

where,

- y_i^* is the unobserved injury severity for observation i;
- x_i is a row vector of independent variables with 1 in the first column to denote the constant for observation i;
- β is a column vector of coefficients with the first row being the constant intercept; and

- ε_i is the error term that is normally distributed across observations with mean 0 and variance 1.

What the researcher observes is the pedestrian injury severity scale y as follows:

$$y = \begin{cases} 0, & \text{if} \quad y^* \le 0 & \text{(No Injury)} \\ 1, & \text{if} \quad 0 < y^* \le \mu_1 & \text{(Possible Injury)} \\ 2, & \text{if} \quad \mu_1 < y^* \le \mu_2 & \text{(Non-incapacitating Injury)} \\ 3, & \text{if} \quad \mu_2 < y^* \le \mu_3 & \text{(Incapacitating Injury)} \\ 4, & \text{if} \quad \mu_3 < y^* & \text{(Fatal Injury)} \end{cases}$$

where μ_i's are unknown thresholds to be estimated with β. Let $\Phi(\cdot)$ be the cumulative standard normal distribution and X be the matrix of independent variables with 1 in the first column, the probability of a pedestrian suffering each of the injury severities is given by the following:

$$\begin{aligned} &\Pr(y = 0) = \Phi(-X\beta), \\ &\Pr(y = 1) = \Phi(\mu_1 - X\beta) - \Phi(-X\beta), \\ &\Pr(y = 2) = \Phi(\mu_2 - X\beta) - \Phi(\mu_1 - X\beta), \\ &\Pr(y = 3) = \Phi(\mu_3 - X\beta) - \Phi(\mu_2 - X\beta), \\ &\Pr(y = 4) = 1 - \Phi(\mu_3 - X\beta). \end{aligned}$$

Unlike the commonly used linear regression model, the ordered probit model is non-linear, and its coefficients do not reflect the marginal effect on the dependant variable from one-unit change in any one independent variable. To help interpret the results of the ordered probit model, one common practice is to estimate the marginal effects of the independent variables, and to interpret the ordered probit model through these marginal effects. For a dummy variable, the marginal effect of an independent variable shows the difference in the probability with that variable taking the value of 1 versus 0. For a continuous independent variable X_k and fatal injuries, for example, the marginal effect at the mean of the sample $\overline{X}$ is computed as follows:

$$\frac{\partial \Pr\left(y = 4 \mid \overline{X}\right)}{\partial X_k} = \beta_k \left[\phi\left(\mu_3 - \overline{X}\beta\right)\right]$$

where $\phi(\cdot)$ is the standard normal density function.

Model Specification

The section describes what variables are included in the row vector of independent variables in the model stated above, and how they are included. The objective is to have a specification that would allow one to estimate the differential effects between crossing locations and between light conditions on the probability of pedestrians suffering specific injury severity levels once involved in a motor vehicle crash. The theoretical framework described earlier is used to guide the selection of control variables as well as the approach in which crossing locations and light conditions enter the model.

Guidance

The theoretical framework has important implications for model specification. If the objective were to determine the role of impact configuration, or any of the pedestrian characteristics, or impact speed on pedestrian injury severity, one would only need to consider the direct determinants in a model of pedestrian injury severity. However, both crossing locations and light conditions are indirect determinants. A focus on these two indirect determinants requires that the model of pedestrian injury severity exclude impact speed and other intermediate variables (vehicle configuration, moving speed, and pedestrian visibility) and include only final independent variables. In addition to pedestrian attributes, these final independent variables include driver attributes, vehicle attributes, road attributes (including crossing locations), and the environment (including light conditions). While impact speed needs to be excluded, posted speed limit as a part of road attributes needs to be included because it is an important determinant of moving speeds. In mathematical terms, the framework in Figure 1 represents a structural model of pedestrian injury severity, while the focus on the effects of crossing locations and light conditions requires the estimation of the reduced-form of the structural model.

Location and Light Conditions

To measure the effects of both crossing locations and light conditions on the probability of any injury severity, the study includes five interactive variables between the two locations (midblock and intersection) and the three light conditions (daylight, dark with street lighting, and dark without street lighting):

1. Intersection * Dark with Street Lighting
2. Intersection * Dark without Street Lighting
3. Midblock * Dayligh
4. Midblock * Dark with Street Lighting
5. Midblock * Dark without Street Lighting

This specification takes the interaction between intersections and daylight conditions as the base of comparison for all included interactions. Some descriptive statistics of these five interactive variables are shown at the bottom of Table 3 along with the expected sign of their coefficients.

Once the overall model is estimated and the marginal effects of individual variables are determined, one can determine the effects of crossing locations and light conditions on the probability of an injury severity. Assuming that α_i represents the marginal effect of a fatal injury with respect to the i-th interactive variable above, one can determine the effects of crossing locations and light conditions on the probability of a fatal injury. Holding other factors constant, for example, the probability of a fatal injury is expected to be lower at intersections by $-\alpha_3$ for daylight conditions, by $\alpha_1 - \alpha_4$ for dark conditions with street lighting, and by $\alpha_2 - \alpha_5$ for dark conditions without street lighting. Similarly, changes in the probability of a fatal injury at either midblock locations or intersections can also be determined between different light conditions. At midblock locations, daylight reduces the probability of a fatal injury by $\alpha_3 - \alpha_5$, and street lighting reduces the probability of a fatal injury by $\alpha_4 - \alpha_5$. At intersections, daylight reduces the probability by $-\alpha_2$, and street lighting reduces the probability by $\alpha_1 - \alpha_2$.

Table 3. Descriptive Statistics and Expected Direction of Effects

Variables	*Description*	*Mean*	*S.D.*	*Effect*
AGEGP1_P	1 if pedestrian is ≤ 10 years; 0 otherwise	0.2007	0.4005	+
AGEGP2_P	1 if 11 years ≤ pedestrian age ≤ 24 years; 0 otherwise	0.2397	0.4269	±
AGEGP5_P	1 pedestrian age ≥ 65 years; 0 otherwise	0.1477	0.3548	+
MALE_P	1 if pedestrian is male; 0 otherwise	0.6058	0.4887	-
BLACK_P	1 if pedestrian is Black; 0 otherwise	0.2949	0.4560	±
HISPNC_P	1 if pedestrian is Hispanic; 0 otherwise	0.0881	0.2834	±
DISABIL_P	1 if pedestrian has any physical disability; 0 otherwise	0.0422	0.2011	+
UI_P	1 if pedestrian was under influence; 0 otherwise	0.1629	0.3692	+
AGEGP1_D	1 if driver age ≤ 24; 0 otherwise	0.2502	0.4331	+
AGEGP4_D	1 if driver ≥ 65 years; 0 otherwise	0.1118	0.3151	+
MALE_D	1 if driver is male; 0 otherwise	0.6227	0.4847	+
BLACK_D	1 if driver is Black; 0 otherwise	0.2411	0.4278	±
HISPNC_D	1 if driver is Hispanic; 0 otherwise	0.0757	0.2645	±
DISABIL_D	1 if driver had any physical disability; 0 otherwise	0.0149	0.1210	+
UI_D	1 if driver was under influence; 0 otherwise	0.0319	0.1758	+
LANES	Number of lanes	3.4778	1.5657	+
UNDIV	1 if undivided road; 0 otherwise	0.6173	0.4861	+
US	1 if US owned; 0 otherwise	0.0659	0.2482	+
STATE	1 if state owned; 0 otherwise	0.3223	0.4674	+
COUNTY	1 if county owned; 0 otherwise	0.1908	0.3929	+
RURAL	1 if road in area with population ≤ 2,500; 0 otherwise	0.3443	0.4752	+
POST_SP	Posted speed limit in mph	35.2435	8.1990	+
RAINY	1 if it was raining; 0 otherwise	0.0577	0.2332	±
FOGGY	1 if it was foggy; 0 otherwise	0.0024	0.0491	±
BIG_VEH	1 if vehicle is truck or bus; 0 otherwise	0.1450	0.3521	+
YR92TO98	1 if occurred 1992 through 1998; 0 otherwise	0.4028	0.4905	±
YR99TO03	1 if occurred 1999 through 2003; 0 otherwise	0.2594	0.4383	±
MBDAY	1 if midblock and daylight; 0 otherwise	0.4452	0.4970	+
MBDRKSL	1 if midblock and dark with street lighting; 0 otherwise	0.1736	0.3788	+
MBDRKNSL	1 if midblock and dark without street lighting; 0 otherwise	0.0913	0.2881	+
ISDRKSL	1 if intersection an dark with street lighting; 0 otherwise	0.0656	0.2475	+
ISDRKNSL	1 if intersection and dark without street lighting; 0 otherwise	0.0166	0.1277	+

Notes: These statistics are for the population of 40,512 pedestrian crashes used in final model estimation, which is 17,690 crashes fewer than what were available after data exclusions described earlier. These crashes are not used in final model estimation due to missing data in at least one of the variables.

Once determined, these differences in the probability of a fatal injury can then be used along with the data from Figure 1 to show the percentage differences in the odds of a pedestrian fatal injury between locations as well as between light conditions. The odds of something happening is the ratio of the probability of that happening over the probability of that not happening. Figure 1, for example, shows the average probability of a fatal injury under daylight conditions is 4.0 percent at midblock locations and 2.8 percent at intersections. That is, the odds of a fatal injury under daylight conditions is 4.0/(100-4.0)=0.042 at midblock locations and 2.8/(100-2.8)=0.029 at intersections. Therefore, the odds of a fatal injury is 100(0.029-0.042)/0.042=-33 percent lower at intersections than at midblock locations. For intersections, the probability of a fatal injury for each light condition is assumed to be those shown in Figure 1. For midblock locations, the probability for each light condition is that for intersections plus the differences shown above. Percent differences in odds are just another useful way to look at the effects of crossing locations and light conditions on pedestrian injury severity.

Control Variables

Besides crossing locations and light conditions, all other final independent variables in the framework shown in Figure 1 are considered control variables. They would include all vehicle attributes, all driver attributes, and all pedestrian attributes. With the exception of crossing locations and light conditions, they also include all other road attributes and all weather attributes. The top portion of Table 3 shows some descriptive statistics of all control variables that are available from the original database and are included in the final model.

Pedestrian and Driver Attributes. Two pedestrian age groups, very young (Jense 1999; LaScala et al. 2001; Al-Ghamdi 2002; Fontaine and Gourlet 1997) and very old (Lee and Abdel-Aty 2005; Jensen 1999; LaScala et al. 2001; Al-Ghamdi 2002; Fontaine and Gourlet 1997; Zajac and Ivan 2003) are considered because they are most vulnerable to high severity crashes. Young and male drivers, being typically more aggressive, are likely to be involved in more severe pedestrian crashes. Male pedestrians, being physically stronger than their female counterparts, are less likely to sustain severe injury. Pedestrians having any physical disability may be more likely to be injured when struck by a vehicle. Drivers having any physical disability may take longer to react, resulting in a higher impact speed. Ethnicity of the pedestrian and the driver has also been included in the model as control variables to avoid any latent bias arising from their omission. One cannot help but notice in Table 3 that the unusually high involvement of blacks both as pedestrians and as drivers relative to the share of blacks in the general population. In fact, blacks represent over 29 percent of the involved pedestrians and over 24 percent of the involved drivers.

Consumption of alcohol by drivers and/or pedestrians is considered an important contributor to higher severity pedestrian crashes. It has been found in previous studies that alcohol consumption by pedestrians considerably increases the probability of getting injured severely or being killed once involved in the crash (Lee and Abdel-Aty 2005; Miles-Doan 1996; Zajac and Ivan 2003; LaScala et al. 2001; Fontaine and Gourlet 1997; Jehle and Cotinton 1988; Öström and Eriksson 2001). It is said that "pedestrians who drink have the judgment skills of a child and the mobility skills of a senior" (FDOT 1999) and are not only more likely to get involved in a crash, but also to sustain more severe injuries once involved. Based on the same reasoning, a drunk driver's ability to react to an obstacle (pedestrian) in the available time is affected adversely and contributes towards higher severity crashes (Zajac and Ivan 2003).

Road Attributes. Vehicular speeds are usually higher on wider roads. Rural roads are associated with higher vehicle speeds and emergency medical services are less accessible as they are in rural areas. It has also been found in earlier studies that rural roads are typically associated with more severe pedestrian crashes (Lee and Abdel-Aty 2005; Miles-Doan 1996). Functional classification of roads is unavailable in the data; instead the roadway system has been classified on the basis of ownership and has been used as a substitute. As pointed out already, posted speed limit is an important determinant of average vehicle moving speeds.

Environment. Rain and fog are included for weather conditions. Adverse weather conditions may force drivers to slow down, which is a positive effect on moving speeds. Adverse weather conditions may also make it harder to stop, which is a negative effect on impact speed, or to see pedestrians, which is a negative effect on their visibility of pedestrians.

Vehicle Attributes. The type of vehicles involved in the crash also is an important determinant of how severely a pedestrian is injured in a crash. Examples are the stiffness and shape of the vehicle front, such as the bumper height, hood height and length, and windshield frame (Yang 2002). Trucks of all sizes, all-terrain vehicles, and buses have been grouped into a category of "big" vehicles and the remainder into smaller vehicles. These "big" vehicles also are harder to stop, resulting in a higher impact speed.

Temporal Attributes. Two dummy variables are included to capture temporal effects on pedestrian injury severity. One covers the period from 1992 to 1998, and the other from 1999 to 2003, with the period from 1986 to 1991 as the basis of comparison. These variables are included to capture changes in the transportation system that help reduce pedestrian injury severity but are not controlled for through other control variables. They also are designed to capture any effect of the definitional change of a fatality made in 1999.

RESULTS

The results are presented in three forms: the estimated model, the derived marginal effects of individual variables for fatal injuries, and the location and light-condition effects on pedestrian injury severity in terms of both probabilities and odds for fatal injuries.

Estimated Model

Table 4 shows the maximum likelihood estimation of the ordered probit model. Repeated from Table 3 are the variable names and their descriptions. For each variable, the table shows the estimated coefficient and its t-statistic. In general, a positive coefficient indicates that an increase in the variable would lead to an increase in pedestrian injury severity. The model is well behaved in general. All variables that have specific expected directions of effects and are statistically significantly have the expected signs. More important, all five interactive variables on crossing locations and light conditions are statistically significant and have the expected direction of effects. Holding other factors constant, pedestrian injuries suffered under all other combinations of location and light conditions are more severe relative to injuries at intersection locations under daylight conditions.

Table 4. Ordered Probit Model of Pedestrian Injury Severity

Variables	*Description*	*Coefficients*	*t-Statistic*
ONE	1	1.0032	27.64
AGEGP1_P	1 if pedestrian is under 10; 0 otherwise	0.0686	4.07
AGEGP2_P	1 if 11 years ≤ pedestrian age ≤ 24 years; 0 otherwise	-0.0705	-4.94
AGEGP5_P	1 if pedestrian is over 64; 0 otherwise	0.3793	22.34
MALE_P	1 if pedestrian is male; 0 otherwise	0.0146	1.31
BLACK_P	1 if pedestrian is Black; 0 otherwise	-0.1281	-9.54
HISPNC_P	1 if pedestrian is Hispanic; 0 otherwise	-0.0152	-0.72
DISABIL_P	1 if pedestrian has any physical disability; 0 otherwise	0.0631	2.36
UI_P	1 if pedestrian was under influence; 0 otherwise	0.1546	9.07
AGEGP1_D	1 if driver is under 25; 0 otherwise	0.0890	7.09
AGEGP4_D	1 if driver is over 64; 0 otherwise	0.0212	1.21
MALE_D	1 if driver is male; 0 otherwise	0.0211	1.88
BLACK_D	1 if driver is Black; 0 otherwise	-0.0008	-0.06
HISPNC_D	1 if driver is Hispanic; 0 otherwise	0.0526	2.35
DISABIL_D	1 if driver had any physical disability; 0 otherwise	0.1339	3.04
UI_D	1 if driver was under influence; 0 otherwise	0.2778	8.91
LANES	Number of lanes	0.0238	5.25
UNDIV	1 if undivided road; 0 otherwise	-0.0056	-0.43
US	1 if US owned; 0 otherwise	0.2520	10.17
STATE	1 if state owned; 0 otherwise	0.0695	4.73
COUNTY	1 if county owned; 0 otherwise	0.0902	5.38
RURAL	1 if road in area with population ≤ 2,500; 0 otherwise	0.0421	3.13
POST_SP	Posted speed limit in mph	0.0204	24.77
RAINY	1 if it was raining; 0 otherwise	-0.0134	-0.59
FOGGY	1 if it was foggy; 0 otherwise	0.2101	1.93
BIG_VEH	1 if vehicle is truck or bus; 0 otherwise	0.0984	6.35
YR92TO98	1 if occurred 1992 through 1998; 0 otherwise	-0.0608	-4.88
YR99TO03	1 if occurred 1999 through 2003; 0 otherwise	-0.1111	-7.85
MBDAY	1 if midblock and daylight; 0 otherwise	0.2036	14.05
MBDRKSL	1 if midblock and dark with street lighting; 0 otherwise	0.4623	24.93
MBDRKNSL	1 if midblock and dark without street lighting; 0 otherwise	0.6850	28.88
ISDRKSL	1 if intersection an dark with street lighting; 0 otherwise	0.2929	12.08
ISDRKNSL	1 if intersection and dark without street lighting; 0 otherwise	0.6183	14.05
Observations		40,512	
Restricted LL		-54,292	
Unrestricted LL		-51,451	

Marginal Effects of Control Variables

The marginal effects of the control variables on the probability of fatal injuries along with their standard errors are shown in the top portion of Table 5. The marginal effects of crossing locations and light conditions are discussed in the next sub-section. Only the marginal effects for fatal injuries are shown to save space.

Table 5. Marginal Effects on the Probability of a Fatal Injury

Variables	*Description*	*Marginal Effect*	*t-Statistic*
AGEGP1_P	1 if pedestrian is under 10; 0 otherwise	0.0088	8.03
AGEGP2_P	1 if 11 years ≤ pedestrian age ≤ 24 years; 0 otherwise	-0.0085	-6.18
AGEGP5_P	1 if pedestrian is over 64; 0 otherwise	0.0575	68.69
MALE_P	1 if pedestrian is male; 0 otherwise	0.0018	1.51
BLACK_P	1 if pedestrian is Black; 0 otherwise	-0.0153	-10.06
HISPNC_P	1 if pedestrian is Hispanic; 0 otherwise	-0.0019	-1.49
DISABIL_P	1 if pedestrian has any physical disability; 0 otherwise	0.0082	7.29
UI_P	1 if pedestrian was under influence; 0 otherwise	0.0208	21.70
AGEGP1_D	1 if driver is under 25; 0 otherwise	0.0114	10.89
AGEGP4_D	1 if driver is over 64; 0 otherwise	0.0027	2.24
MALE_D	1 if driver is male; 0 otherwise	0.0026	2.23
BLACK_D	1 if driver is Black; 0 otherwise	-0.0001	-0.08
HISPNC_D	1 if driver is Hispanic; 0 otherwise	0.0068	5.95
DISABIL_D	1 if driver had any physical disability; 0 otherwise	0.0183	17.94
UI_D	1 if driver was under influence; 0 otherwise	0.0418	47.47
LANES	Number of lanes	0.0029	5.15
UNDIV	1 if undivided road; 0 otherwise	-0.0007	-0.56
US	1 if US owned; 0 otherwise	0.0368	41.78
STATE	1 if state owned; 0 otherwise	0.0088	8.16
COUNTY	1 if county owned; 0 otherwise	0.0117	11.07
RURAL	1 if road in area with population ≤ 2,500; 0 otherwise	0.0053	4.65
POST_SP	Posted speed limit in mph	0.0025	19.58
RAINY	1 if it was raining; 0 otherwise	-0.0017	-1.32
FOGGY	1 if it was foggy; 0 otherwise	0.0305	32.51
BIG_VEH	1 if vehicle is truck or bus; 0 otherwise	0.0129	12.28
YR92TO98	1 if occurred 1992 through 1998; 0 otherwise	-0.0075	-5.43
YR99TO03	1 if occurred 1999 through 2003; 0 otherwise	-0.0132	-9.00
MBDAY	1 if midblock and daylight; 0 otherwise	0.0258	31.88
MBDRKSL	1 if midblock and dark with street lighting; 0 otherwise	0.0720	79.30
MBDRKNSL	1 if midblock and dark without street lighting; 0 otherwise	0.1267	91.76
ISDRKSL	1 if intersection an dark with street lighting; 0 otherwise	0.0439	50.97
ISDRKNSL	1 if intersection and dark without street lighting; 0 otherwise	0.1168	93.48

Among the control variables, the largest risk factors for fatal injuries facing pedestrians in a decreasing order are: being at least 65 years old, being hit by a driver who is driving under the influence, being involved in a crash on the U.S. road system, walking in foggy conditions, walking under the influence, being struck by a driver with physical disabilities, and being struck by large vehicles. Holding other factors constant, the probability of getting killed once involved in a crash is 5.8 percentage points higher for elderly pedestrians than pedestrians aged from 25 through 64. While not shown, this is equivalent to an increase of 68 percent in the odds of being killed when struck by a vehicle. Being under the influence by drivers is a greater fatality risk for pedestrians than being under the influence by pedestrians themselves. The probability of a pedestrian getting killed once involved in a crash is 4.5 percentage points higher when being hit by a driver under the influence than when hit by a sober driver. This is equivalent to an increase of 60 percent in the odds of being killed when struck by a vehicle. On the other hand, the probability is 2.1 percentage points higher between a pedestrian who is under the influence and a pedestrian who is sober. This is equivalent to an increase of 40 percent in the odds of being killed. Also, walking in foggy conditions increases the odds of being killed when struck by a vehicle by 42 percent than in non-foggy conditions. On the other hand, crossing in the rain or crossing undivided roads do not appear to be risk factors for pedestrians to be fatally injured once involved in a crash.

Location and Light Conditions

The marginal effects of the five interactive variables between crossing locations and light conditions on the probability of pedestrian fatal injuries are shown at the bottom of Table 5. To facilitate the discussion, these marginal effects have been translated into the location effects in Table 6 and the light-condition effects in Table 7. The determination of the information in Tables 6 and 7 has been explained in the subsection on model specification earlier.

Table 6. Location Effects: Differences in Probability and Odds of Dying from Crash Involvement between Intersections and Midblock Locations

Light Condition	***Probability (Percentage Points)***	***Odds (Percent)***
Daylight	-2.6%	-49%
Dark with Lighting	-2.8%	-24%
Dark without Lighting	-1.0%	-5%

The probability of a pedestrian dying from being hit by a vehicle is lower at intersections than at midblock locations for any light condition (Table 6). The difference is 2.6 percentage points under daylight conditions, 2.8 percentage points under dark conditions with street lighting, and 1.0 percentage point under dark conditions without street lighting. While the difference in probability of fatal injuries between locations is the largest under dark conditions with street lighting, the difference in the odds of sustaining a fatal injury between locations is the largest under daylight conditions by 49 percent, versus 24 percent under dark conditions with street lighting, and 5 percent under dark conditions without street lighting.

In terms of the probability of a fatal injury, light conditions have a larger effect than locations (Table 7). Daylight reduces the probability of a fatal injury by 10.1 percentage points at midblock locations and 11.7 percentage points at intersections, while street lighting reduces the probability of a fatal injury by 5.5 percentage points at midblock locations and 7.3 percentage points at intersections. In terms of the odds of a fatal injury, however, the difference is less clear cut. Daylight does have a larger effect on the odds of a fatal injury than the effect of locations under any light condition. The effect of street lighting is larger than the effect of locations under dark conditions but is comparable with the effect of locations under daylight conditions.

Table 7. Effects of Daylight and Street Lighting: Differences in Probability and Odds of Dying from Crash Involvement

Effects of	*Location*	*Probability (percentage points)*	*Odds (percent)*
Daylight	Midblock	-10.1%	-75%
	Intersection	-11.7%	-83%
Street Lighting	Midblock	-5.5%	-42%
	Intersection	-7.3%	-54%

Notes: The effect of daylight is calculated as the difference in marginal effects between daylight and dark without street lighting. The effect of street lighting is calculated as the difference in marginal effects between dark with street lighting and dark without street lighting.

The effect of street lighting is smaller than the effect of daylight (Table 7). Street lighting reduces the probability of a fatal injury by 5.5 percentage points at midblock locations and 7.3 percentage points at intersections. In comparison, the reductions from daylight are 10.1 percentage points at midblock locations, and 11.7 percentage points at intersections. Similarly, street lighting results in a reduction in the odds of a fatal injury around 50 percent, versus a reduction of around 80 percent from daylight.

The effect of light conditions is greater at intersections than at midblock locations (Table 7). Daylight reduces the probability of a fatal injury by 11.7 percentage points at intersections versus 10.1 percentage points at midblock locations. In terms of the odds of a fatal injury, the reductions are 83 percent at intersections and 75 percent at midblock locations. Similarly, street lighting reduces the probability of a fatal injury by 7.3 percentage points at intersections but 5.5 percentage points at midblock locations. The effect of street lighting in terms of the odds of a fatal injury is a reduction of 54 percent at intersections but 42 percent at midblock locations.

CONCLUSIONS

Applying the ordered probit model to crash data from 1986 to 2003 in Florida, the study assesses the interactive roles of crossing locations and light conditions on the injury severity of pedestrians once being struck by motor vehicles while crossing roads. The empirical model is well behaved. It includes pedestrian attributes, driver attributes, road attributes, vehicle attributes, and weather conditions as control variables. All control variables that have specific expected directions of effects and are statistically significantly have the expected signs. More important, all five interactive variables on crossing locations and light conditions are statistically significant and have the expected direction of effects.

The empirical model provides insights on the role of various control variables on pedestrian injury severity. The largest risk factors for fatal injuries facing pedestrians when struck by a vehicle in a decreasing order are: being at least 65 years old, being hit by a driver who is driving under the influence, being involved in a crash on the U.S. road system, walking in foggy conditions, walking under the influence, being hit by a driver with physical disabilities, and being hit by large vehicles. Holding other factors constant, for example, the odds of getting killed when struck by a vehicle is 68 percent higher for elder pedestrians than for 25-64 old pedestrians. Being under the influence by drivers is a greater fatality risk for pedestrians than being under the influence by pedestrians themselves. The odds of a pedestrian getting killed are

60 percent higher when struck by a driver under the influence than when struck by a sober driver. On the other hand, the odds are 40 percent higher between a pedestrian who is under the influence and a pedestrian who is sober. Also, walking in foggy conditions increases the odds of being killed when struck by a vehicle by 42 percent than in non-foggy conditions. However, crossing in the rain or crossing undivided roads does not appear to be risk factors for pedestrians to be fatally injured once involved in a crash.

More important, the results provide new insights on the role of crossing locations and light conditions on pedestrian injury severity. In terms of crossing locations, the probability of a pedestrian dying when struck by a vehicle is higher at midblock locations than at intersections for any light condition. In fact, the odds of sustaining a fatal injury at intersections are 49 percent lower than at midblock locations under daylight conditions, 24 percent lower under dark conditions with street lighting, and 5 percent lower under dark conditions without street lighting. Relative to dark conditions without street lighting, daylight reduces the odds of a fatal injury by 75 percent at midblock locations and by 83 percent at intersections, while street lighting reduces the odds by 42 percent at midblock locations and by 54 percent at intersections.

Like most previous work, this study also relies on electronic data from accident reports completed by investigating officers at the time of a crash. It is well established that traffic accident reports suffer from inconsistencies and inaccuracies due to judgmental and reporting discrepancies, including the injury severity of pedestrians involved (Agran et al. 1990). Lighting conditions from street lights under dark conditions do not reflect the quantity and quality of light. Additional errors may be introduced when information from the accident reports is entered into electronic databases. Furthermore, some pedestrian crashes are either un-reported or reported but not made electronically available.

Like most previous work, this study focuses on the resulting injury severity of the pedestrian after a crash has already occurred. To assess the overall roles of crossing locations and light conditions in pedestrian safety for street crossing, the relative probability of a pedestrian getting involved in crashes at different crossing locations and under different light conditions also needs to be considered. Such a broader consideration would require data on pedestrian exposure to vehicle traffic while crossing streets. One good measure would be pedestrian crossing volumes at the locations where pedestrian crashes occurred and at the times when these pedestrian crashes occurred. However, such exposure data are unavailable, and the probability of a pedestrian getting involved in a crash has not been incorporated in this study.

This study has several advantages over previous work, however. One theoretical advantage is the use of a reduced-form model of pedestrian injury severity to guide model specification, resulting in unbiased estimates of the effects of crossing locations and light conditions on pedestrian injury severity. One empirical advantage is the use of data for 17 years, resulting in reliable estimates of the effects of crossing locations and light conditions on pedestrian injury severity. This is important because of the relatively small number of pedestrian crashes reported each year, the potential errors in traffic accident reports, and the need to estimate the effects of crossing locations and light conditions interactively.

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PART II: DEVELOPING GUIDELINES FOR UNCONTROLLED MIDBLOCK CROSSWALKS

INTRODUCTION

Uncontrolled midblock locations with established pedestrian generators and attractors and adequate crossing demand along state roads rarely meet the current pedestrian signal warrant in the Manual on Uniform Traffic Control Devices (MUTCD) for Streets and Highways (FHWA 2003). This warrant requires that on an average day there must be at least 100 crossings during each of any four hours or at least 190 crossings during one hour; and no more than 60 gaps per hour. A new report from the Transportation Research Board (Fitzpatrick et al. 2006a) has proposed changes to this warrant. The consideration of gaps would be replaced by traffic volume, and discrete threshold values would be replaced by a non-linear relationship between pedestrian and traffic volumes. But the proposed warrant would still be difficult to meet. If traffic volume is at 1,200 vehicles per hour, there must be at least 107 crossings during each of any four hours, and at least 200 crossings during one hour. If traffic volume is at 900 per hour, on the other hand, there must be at least 160 crossings during each of any four hours, and 310 crossings during one hour.

Many of these locations with high pedestrian crossing activity which does not meet the current or proposed warrant are along multilane roads with high traffic volumes and speeds. These types of locations are described by the Orlando Sentinel below:

> Florida's most notorious roads are all high-speed, multilane highways breached by hundreds of driveways and side streets. All serve haphazardly developed urban areas. Frequently, as on Colonial and U.S. 19, long stretches have few crosswalks and no street lighting. Yet they are peppered with fast-food restaurants, carryouts, bus stops and other places that draw people on foot from nearby neighborhoods. (Powers 2004)

This second part of the report develops guidelines for uncontrolled midblock crosswalks on Florida’s State Highway System, including multilane roads with high traffic volumes and speeds.

Engineers are reluctant to mark uncontrolled midblock crosswalks without a good set of guidelines. The *Florida Greeenbook* does not deal with midblock crosswalks at uncontrolled locations (FDOT 2005). The *Traffic Engineering Manual* specifies guidelines on in-roadway warning lights but not on marking crosswalks at uncontrolled midblock locations in general (FDOT 1999a). The *Plans Preparation Manual* did not deal with the topic until the 2006 version (FDOT 2006a), which adopts AASHTO guidelines (2004). Released in 1999, the *Florida Pedestrian Planning and Design Handbook* has guidelines pulled from various national sources available at that time (FDOT 1999b). However limited, the guidelines on the books need improvements to be useful to the practitioner. They are not structured and contain gaps that make implementation difficult. They are not always consistent with each other. They often discourage or even exclude uncontrolled midblock crosswalks from being considered under many conditions. These excluded conditions often include those locations along multilane roads with high traffic volumes and speeds that most need improvements for pedestrian crossings.

At the national level, the 2003 Edition of the MUTCD, Section 3B.17 (FHWA 2003) has standards on the markings but not on the conditions under which unsignalized midblock crosswalks may be installed or what additional treatments may be used. It only has limited guidance on the conditions or additional treatments. Specifically, marked crosswalks should also be provided at midblock pedestrian crossings of pedestrian concentration; crosswalks should not be used indiscriminately; an engineering study should be performed before they are installed at unsignalized midblock locations; warning signs should be installed; and adequate visibility should be provided by parking prohibitions. Other national guidance often suffers from the same problems as the current guidelines in Florida (e.g., Cynecki 1998; AASHTO 2004).

Many localities have already developed their own midblock crosswalk guidelines, but this report differs from previous efforts in several important ways. First, the guidelines developed in this report are structured to avoid gaps that would make implementation difficult. Second, the guidelines developed in this report contain a spreadsheet tool for evaluating the likelihood of an uncontrolled midblock crosswalk being used once it is marked. An important part of midblock crosswalk guidelines is pedestrian volume criteria, which set the minimum level of crossing demand below which marking is not considered. Previous guidelines either do not define the spatial dimension of this volume or ignore the fact that some of this existing crossing volume may use alternatives when a new midblock crosswalk is marked. This report argues that the initial minimum demand should be measured at the block level and uses a previously developed discrete choice model to determine how much of this block-level demand may use the new midblock crosswalk.

More important, the report explicitly takes into account the safety effects of marked crosswalks. This explicit approach is reflected in the development of the guidelines by using a simple model of pedestrian-vehicle collision risks to identify mechanisms that help explain why collision risks may increase with marking, and to identify treatments to counter these mechanisms. In addition, the guidelines are designed to be provisional until the safety effects are known. This means that the guidelines explicitly acknowledge the absence or uncertainty of the safety effects. Furthermore, the guidelines require that a monitoring process be in place to study the safety effects of crosswalks marked under these guidelines.

The remainder of this second part is organized into six sections:

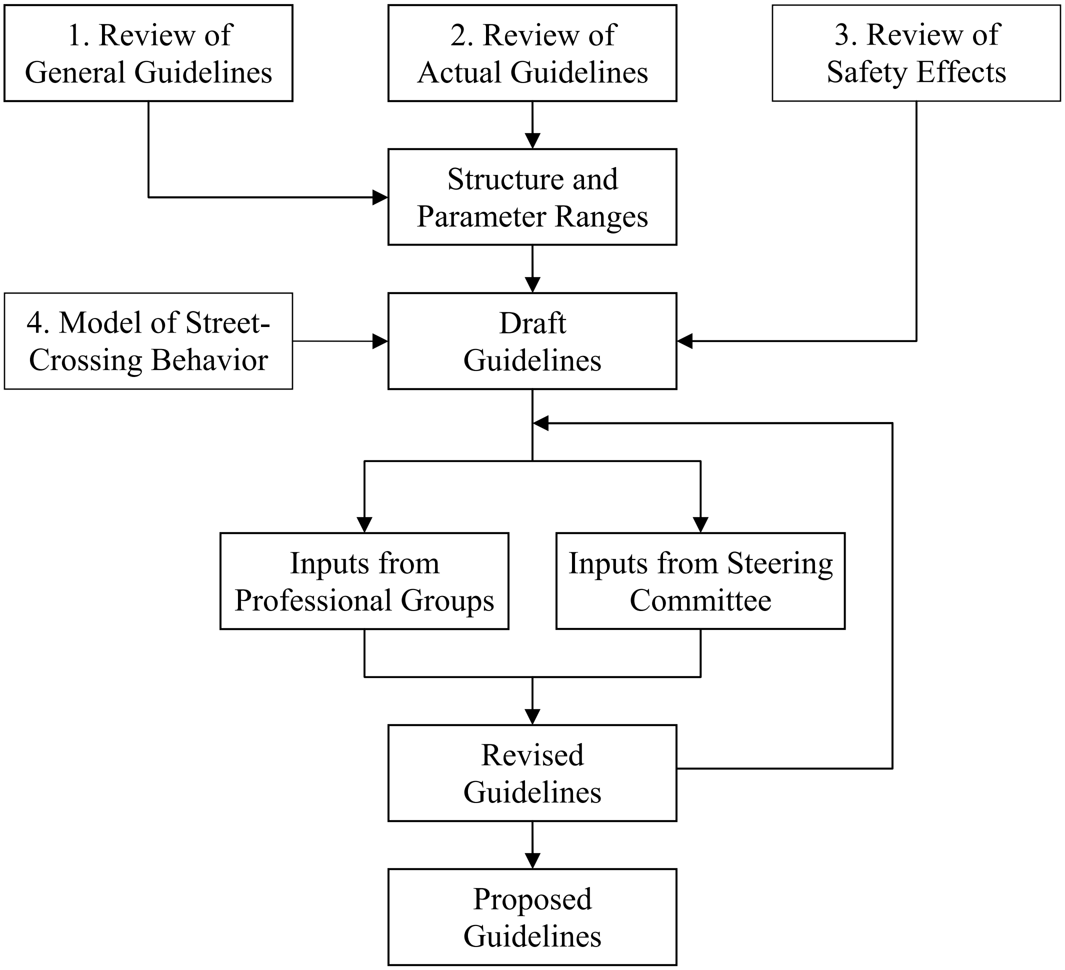
- Method of Guideline Development describes the method for developing the guidelines.
- Structure of Guidelines describes a structure synthesized from the actual midblock crosswalk guidelines reviewed.
- Evidence on Safety Effects summarizes what the empirical literature says about the safety effects of marking crosswalks at intersections and uncontrolled midblock locations. While there is uncertainty, the evidence indicates that crosswalk markings alone can lead to higher pedestrian-vehicle collision risks, particularly along multilane roads with high traffic volumes and speeds.
- Mechanisms sets up a simple model of pedestrian-vehicle collision risks and uses it to identify treatments for preventing collision risks from being higher in marked crosswalks.
- Proposed Guidelines presents the proposed guidelines.
- The last section concludes the report.

METHOD OF GUIDELINE DEVELOPMENT

Methods for developing actual midblock crosswalk guidelines vary. One method would simply be to take a set of general guidelines contained in an official document of a professional organization. One example of this is the Florida *Plans Preparation Manual* (FDOT 2006a) using AASHTO guidelines (2004). Another method would expand the first method by synthesizing multiple sets of general guidelines, an example of which is Turner and Carlson (2000) for Texas. A more general method, however, has three elements: 1) a review of general guidelines at the national level; 2) a review of actual guidelines from other localities; and 3) a solicitation of expert inputs from practitioners. The general guidelines by Smith and Knoblauch (1987) are based on this method. An example of actual guidelines based on this method is Dougald (2004).

This study uses a method that builds on these methods but also goes beyond them (Figure 3). This method uses four sources of information for developing a set of draft guidelines:

Figure 3. Method of Guideline Development



1. Considers two sets of general guidelines, one developed by Smith and Knoblauch (1987), and the other by Zegeer et al. (2005).
2. Reviews actual guidelines from 28 localities.
3. Reviews and takes into account the safety effects of marking crosswalks.
4. Uses a nested logit choice model of pedestrian street crossing behavior (Chu et al. 2004) to determine the likelihood of a new uncontrolled midblock crosswalk being used.

Using general and actual guidelines is similar to the existing methods in practice, but differs from them in that this study also synthesizes from these two sources a structure for midblock crosswalk guidelines. This structure is described in the next section. Using a model of pedestrian crossing behavior to estimate the likelihood of usage is new in the literature. Using evidence on the safety effects of crosswalk markings is new to a large degree. Many existing guidelines also consider the empirical evidence. In most cases, however, these guidelines simply exclude many crossing environments from being considered for midblock crosswalks. Some of the actual guidelines developed recently do take into account the results from Zegeer et al. (2005) in terms of the need to consider enhanced treatments under many situations. But these existing guidelines fail to account for the uncertainty in the available evidence.

Once they were developed, the draft guidelines were presented to practitioners in two forums for their inputs. One forum is a steering committee that consisted of planners and engineers who are involved in the planning and implementation of midblock crosswalks in Florida. The other forum is professional gatherings of planners and engineers. The inputs from the practitioners through these forums were used in revising the draft guidelines, and another round of solicitation of inputs took place. A set of guidelines were finally proposed after a second revision to consider the second set of inputs from the practitioners.

STRUCTURE OF GUIDELINES

A structure of midblock crosswalk guidelines is described. This structure is abstracted from a review of 13 state-level actual guidelines and 15 local-level actual guidelines from around the country. These guidelines are separately listed in the references section. A structure gives the development of guidelines a road map and ensures that the resulting guidelines do not contain gaps that would make implementation difficult. These localities are neither a random sample nor all of those with existing guidelines. The guidelines from these localities were located on the internet. Some of these have a long history, particularly those from the City of San Diego, California (1990). Some are new and have never been implemented. Others are new but have been applied, particularly those from the City of St. Petersburg, Florida (2001). While the exact format varies, these actual guidelines consist of one or more of the following components:

- Functions: Primary functions of crosswalk markings
- Philosophy: General attitudes toward midblock crosswalks at uncontrolled locations
- Demand Criteria: Minimum demand levels
- Basic Safety Criteria: Minimum safety level
- Basic Treatments: Minimum treatments for any uncontrolled midblock crosswalk
- Enhanced Treatments: Additional treatments for various road width, traffic volume, and traffic speed conditions

Functions

The literature identifies two functions of crosswalk markings at midblock locations (Harkey and Zegeer 2004). One is to channel pedestrians to a particular location to cross a road, and the other is to clarify to motorists that a legal crossing exists at a particular location. However, the 2003 MUTCD (FHWA 2003) identifies one function for crosswalk markings at controlled intersections: “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.” It identifies one function for crosswalk markings at uncontrolled intersections and midblock locations: “Crosswalk markings also serve to alert road users of a pedestrian crossing point across roadways not controlled by highway traffic signals or STOP signs.” Finally it identifies one function for crosswalk markings at midblock locations: “At nonintersection locations, crosswalk markings legally establish the crosswalk.” Based on the 2003 MUTCD, the channeling function is a function for crosswalk markings at intersections rather than at midblock locations. So, at midblock locations, a marked crosswalk is a warning device for drivers about a legal pedestrian crossing point.

The specific functions of crosswalk markings play an important role in the formulation of guidelines. If the sole function is to warn drivers about pedestrian crossings, the role of guidelines is to make sure that drivers will notice that they are approaching an uncontrolled crosswalk. If uncontrolled midblock crosswalks also serve to channel pedestrians, another role of guidelines would be to make sure that these crosswalks are attractive crossing points relative to other locations with or without a marked crosswalk.

Philosophy

The general attitudes toward mid-block crosswalks at uncontrolled locations are critical in developing guidelines for such crosswalks. A set of guidelines can play two opposite roles, depending on the general attitudes taken by the guidelines. The guidelines may be used as a tool to say “no” to midblock crosswalks or to help improve the safety and mobility of pedestrians in crossing streets. This report groups the different general attitudes into four categories: exclusion, discouragement, encouragement, and inclusion.

Exclusion

A few states and cities follow an exclusion philosophy. The city of Edina, Minnesota (undated) does not mark midblock crosswalks. Colorado (Colorado DOT undated) considers uncontrolled midblock crosswalks undesirable on state highways. Idaho (Idaho DOT 2006) does not recommend uncontrolled midblock crosswalks in urban areas.

Discouragement

The guidelines of a number of states discourage the installation of mid-block crosswalks at uncontrolled locations. For example, California (Caltran 2005) discourages midblock crosswalks unless, in the opinion of the engineer, there is strong justification in favor of such installation. Oregon (Oregon DOT, 2005) also discourages installing uncontrolled midblock crosswalks because of the concern that they may not improve safety and may, if inappropriate, put a pedestrian more at risk.

Encouragement

The guidelines of most localities have an encouragement philosophy. For example, the Mid-America Regional Council, Kansas (1998) believes that while some traffic engineers resist considering midblock crossings, the reality is that most pedestrians will not go far out of their way to cross a street, and that it makes more sense to provide a good crossing than to pretend there is no need. The City of Boulder, Colorado (2006) wants to encourage pedestrian travel by providing safe and efficient roadway crossing opportunities.

Inclusion

Few localities have guidelines that are inclusive. For example, the City of Portland, Oregon (1998) marks midblock crosswalks with warning signs at locations where there is a demand for crossing, and there are no nearby marked crosswalks. The policy of the City of San Jose, California is that midblock crosswalks may be placed where there is a specific minimum level of demand, and enhancements may be required under certain conditions (2005).

Demand Criteria

Whether adequate demand exists has three dimensions. One is the level of demand, which in turn includes minimum pedestrian volume and the presence of pedestrian generators and attractors. In most cases, pedestrian volume and the presence of pedestrian generators are used as substitutes. In the three sets of guidelines that use the presence of pedestrian generators instead of pedestrian volume, two require generators to be within 300 feet of the crossing point under consideration. There are three sets of guidelines that use both criteria. Minimum pedestrian volume ranges widely from 10 to 50 during the peak hour. Furthermore, the spatial dimension of this threshold is not defined in many of the reviewed guidelines. A threshold of 25 pedestrians during the peak hour, for example, means different requirements between two spatial dimensions: 1) it is the point of crossing under consideration for marking a midblock crosswalk; or 2) it is the entire block where the point of crossing under consideration is located.

The second is the existence of alternatives, which in turn includes minimum block length and minimum distance to the nearest alternative. When used, minimum block length typically is 600 feet. Minimum distance to the nearest alternative ranges from 150 feet to 600 feet with a typical value of 300 feet. In most cases, an alternative is vaguely defined as any crossing point, which could be any marked or unmarked crosswalk or controlled or non-controlled. Other definitions of an alternative include any intersection, a signalized intersection, a non-signalized intersection, a marked crossing, and a protected crossing (either stop or signal controlled).

The third is the existence of crossing opportunities measured by either a minimum traffic volume or a maximum number of gaps available. Eight of the localities use a minimum traffic volume, with seven of them using average daily traffic volume ranging from 1,500 to 5,000 and with one using an hourly volume of 300. Only two localities use a maximum number of gaps.

Basic Safety Criteria

Five safety criteria are widely used in current guidelines, including sight distance, lighting, roadway width, traffic speed, and traffic volume. As with demand criteria, the reviewed guidelines vary widely in what specific safety criteria are used, whether thresholds are used, what threshold values are used for each criterion, and whether and how different criteria are jointly used. Almost all reviewed guidelines use sight distance and traffic speed as their safety criteria. But only one-third of the reviewed guidelines use lighting conditions as a safety criterion. The speed criterion is based on speed limit in most cases, and on the 85th percentile of the actual speed in the other cases.

When sight distance is a criterion, about one half use it as a qualitative one, i.e., adequate sight distance. Among the eight localities using sight distance as a quantitative criterion, three use a fixed threshold that is independent of speed limit (e.g., 250 feet), but the other five localities use a threshold that depends on speed limit. When the threshold depends on speed limit, different approaches are used in determining sight distance:

- Use a multiplicative factor of the speed limit, such as 8 or 10.
- Use the stopping sight distance formula at zero grade (Oregon DOT 2005).
- Use the signal timing formula at zero grade (City of St. Petersburg 2001).
- Use a table form linking the two variables, based on the stopping sight distance formula.

When a specific threshold is used for a quantitative criterion, in most cases that threshold acts as a disqualifying factor for installing midblock crosswalks at uncontrolled locations. In many other cases, however, these specific thresholds act as triggers for considering enhanced treatments to simple two-line marking of a midblock crosswalk. In some cases where thresholds are used as triggers for enhanced treatments, individual criteria are involved. In many other cases, however, more than one criterion is jointly used to consider enhanced treatments.

Basic Treatments

Basic treatments are what is required for all midblock crosswalks at uncontrolled locations. What constitutes basic treatments varies across the reviewed guidelines. Some are as simple as standard two-line marking, but others include high visibility markings, roadside advance warning signs, street lighting, or even special crosswalk lighting.

Enhanced Treatments

What additional treatments may be considered for any set of guidelines partially depends on what basic treatments are required. The guidelines vary in how enhanced treatments are linked to safety conditions as defined by traffic speed, traffic volume, and roadway width. In terms of this linkage, this report groups the reviewed guidelines into three categories: separate (no link), partial link, and full link.

Separate
Many of the reviewed guidelines do not link specific enhanced treatments to the safety criteria. Instead, they address the safety criteria and enhanced treatments separately. One example of this approach is the City of Palo Alto’s guidelines (2000).

Partial
Many reviewed guidelines partially link enhanced treatments to the safety criteria. By partial we mean that the link is defined for two or fewer criteria among traffic speed, traffic volume, and roadway width. One example is Oregon DOT’s guidelines (2005): “Traffic Volumes should be less than 10,000 ADT or if above 10,000 ADT raised median islands should be included.” The City of St. Petersburg is another example with a partial link between enhanced treatments and safety conditions (2001). But this link is more extensive than most other partial links. In addition to warrants for installing crosswalks at uncontrolled locations, including midblock locations, it has a separate set of warrants for installing ITS-based treatments:

An ITS enhanced crosswalk should be installed at sites that meet any of the following conditions:

1. Multiple lanes needed to be crossed in at least one direction of travel.
2. The mean vehicle speed is greater than 38 mph.
3. Hourly daytime two way traffic volumes exceed 800 vehicles per hour.
4. A history of events at a marked crosswalk.

Charlotte and Durham, North Carolina use traffic speed and volume to select enhanced treatments (City of Charlotte 2005; City of Durham 2006). In both cases, a table is used to link each enhanced treatment to a particular combination of traffic speed and volume. Refuge islands are recommended, for example, when operating speed is less than 40 mph and average annual daily traffic is between 12,000 and 30,000.

Full

A full link has been increasingly used after the set of general guidelines developed by Zegeer et al. (2005), using a combination of original data collection from 30 U.S. cities and a review of international guidelines. Part of the guidelines is a table showing conditions defined by average daily traffic volume, speed limit, roadway width, and presence of a raised median (Figure 4). The table is inclusive of all conditions in terms of speed limit, traffic volume, and roadway width. Speed limit has three levels: ≤30 mph, 35 mph, and ≥40 mph; traffic volume in ADT has four levels: ≤9000, >9000 and ≤12000, >12000 and ≤15000, and ≥15000; and roadway width has four levels: 2 lanes, 3 lanes, ≥4 lanes with a raised median, and ≥4 lanes without a raised median. The table groups these safety conditions into three categories: C = candidate sites for marking crosswalks; P = possible increase in pedestrian collision risk if no other enhancements are installed; and N = do not mark crosswalks without installing other enhancements. Among the 6 states and 4 cities that have adopted the work by Zegeer et al. (2005):

- California, Minnesota, and Texas have used the original table without any changes (Caltran 2005; Minnesota DOT 2005; Turner and Carlson 2000).
- Vermont has excluded midblock crosswalks at uncontrolled locations with a speed limit 40 mph or higher without any other changes (2004). Similarly, the University District excludes locations with an 85th percentile speed 35 mph or higher without any other changes (Champaign County Regional Planning Commission 2003).
- Sacramento, Stockton, and Virginia have matched treatments to each of the three categories of safety conditions without altering the structure of the original table (County of Sacramento DOT 2005; City of Stockton 2003; Virginia DOT 2004).
- Boulder and Washington have altered the structure of the original table (City of Boulder 2006; Washington State DOT 2003). The change by Washington State makes more locations qualify for the C category. The changes by Boulder are more dramatic: 1) Use a minimum level of traffic volume (1,500 ADT) for considering midblock crosswalks; 2) Exclude uncontrolled locations with a speed limit of 45 mph or higher from being considered for midblock crosswalks; 3) Exclude locations with 6 or more lanes from being considered for midblock crosswalks; and 4) Define the safety conditions into five categories. Both still match treatments to each of the new categories of safety conditions.

Figure 4. Table from Zegeer et al. (2005)*

Traffic Volume	Speed Limit** (mph)	2-Lanes	3-Lanes	4+ Lanes With Raised Median***	4+ Lanes Without Raised Median***
ADT ≤ 9,000	≤30	C	C	C	C
	35	C	C	C	P
	≥40	P	P	P	N
9000 <ADT≤ 12,000	≤30	C	C	C	P
	35	C	P	P	P
	≥40	P	P	N	N
12,000<ADT≤ 15,000	≤30	C	P	P	N
	35	C	P	P	N
	≥40	N	N	N	N
15,000<ADT	≤30	C	P	N	N
	35	P	N	N	N
	≥40	N	N	N	N

* These guidelines include intersection and midblock locations with no traffic signals or stop sign 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 which could present an increased safety risk to pedestrians, such as where there is poor sight distance, complex or confusing designs, substantial volumes 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 necessarily result in more vehicles stopping for pedestrians. Whether marked crosswalks are installed, it is important to consider other pedestrian facility enhancements, as needed, to improve the safety of the crossing (e.g., raised median, traffic signal, roadway narrowing, enhanced overhead lighting, traffic calming measures, curb extensions). These are general recommendations; good engineering judgment should be used in individual cases for deciding where to install crosswalks.

****** Where speed limit exceeds 40 mph, marked crosswalks alone should not be used at unsignalized locations.

******* The raised median or crossing island must be at least 4 ft wide and 6 ft long to adequately serve as a refuge area for pedestrians in accordance with MUTCD and 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 show 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 in-depth study of pedestrian volumes, vehicle speeds, sight distance, vehicle mix, etc. may be needed at other sites. It is recommended that a minimum of 20 pedestrian crossings per peak hour (or 15 or more elderly and/or child pedestrians) exist 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 not recommended, since pedestrian crash risk may be increased with marked crosswalks. Consider using other treatments, such as traffic signals with pedestrian signals to improve crossing safety for pedestrians.

EVIDENCE ON SAFETY EFFECTS

The existing evidence on the safety effects of midblock crosswalk markings is summarized. It is based on 13 studies conducted during a period of four decades from 1965 to 2002. Two of these have been published recently (Koepsell et al. 2002; Zegeer et al. 2005), and the other 11 studies (Ekman 1988; Ekman and Hyden 1999; Gibby et al. 1994; Gurnett 1974; Herms 1972; Jones and Tomcheck 2000; Knoblauch et al. 1986; Los Angeles County Road Department 1967; Machie and Older 1965; Tobey et al. 1983; Yagar 1985) have been reviewed recently by Koepsell et al. (2002) and Zegeer et al. (2005). These are listed separately in the reference section.

Intersections

These studies do not provide any evidence on the effects of crosswalk markings on injury severity to pedestrians at intersections. These studies do provide evidence on the effects of crosswalk markings on the risk of vehicle-pedestrian collisions at intersections. Two studies conclude that marking crosswalks at intersections reduces collision risks (Tobey et al. 1983; Knoblauch et al. 1986), but the other eleven studies conclude that marking crosswalks at intersections leads to higher collision risks for pedestrians. Three mechanisms have been hypothesized to explain why the collision risks would be higher with marked crosswalks. See more discussion on these mechanisms in a later section.

Unlike the earlier studies, the most recent two studies, Zegeer et al. (2005) and Koepsell et al. (2002), make their conclusions for uncontrolled locations only. Zegeer et al. (2005) find no difference in collision risks between marked and unmarked crosswalks along narrow or low traffic volume roads but collision risks to be several times higher in marked than in unmarked crosswalks along multilane roads with high traffic volumes and speeds. Focusing on elderly pedestrians, Koepsell et al. (2002) find no difference in collision risks between marked and unmarked crosswalks at controlled locations but find collision risks to be several times higher in marked than in unmarked crosswalks at uncontrolled locations.

Midblock Locations

Most of these studies focus exclusively on the safety effects of marking crosswalks at intersections. There are a few exceptions among them that also include midblock locations as study sites; however no separate results were presented for midblock locations. Zegeer et al. (2005) is one exception where 17.3 percent of the total 2000 study sites are midblock locations. While no separate pedestrian collision risks are presented separately for midblock locations, whether a pedestrian was crossing at an intersection or a midblock location does not statistically make a difference in their count-data regression models. That is, their results indirectly show that pedestrian collision risks are several times as higher in crosswalks as outside of crosswalks at uncontrolled midblock locations, particularly along multilane roads with high traffic volumes and speeds. Again, see more discussion in a later section on the mechanisms hypothesized to explain why pedestrian-vehicle collision risks would be higher in marked crosswalks.

Uncertainty

Uncertainty exists in the above evidence for intersections for a number of reasons. As already discussed, two of the 13 studies conclude that crosswalk markings lead to lower pedestrian-vehicle collision risks. In addition, the validity of the research results may be questioned. Because of the difficulty to control for the many other factors influencing collision risks, all 13 studies may suffer from biases in one form or another. Some biases result, for example, from the fact that crosswalks may be marked at locations with higher collision risks. Some biases may result from differences in who crosses in marked crosswalks versus unmarked crosswalks. Such biases may affect not only the magnitude but also the direction of the effects. These are just potential sources of biases; however, one cannot determine exactly what the sources of the biases are and how much bias each source contributes. In general, the most recent two studies, Zegeer et al. (2005) and Koepsell et al. (2002), are likely to have fewer biases. Both of these studies control for pedestrian crossing volumes and use control sites. Finally, cumulative observations over the years show pedestrian behavior to be generally better in marked crosswalks, and there is no indication of incautious or reckless pedestrian behavior while crossing in marked crosswalks (Zegeer et al. 2005).

How crosswalk marking affects pedestrian safety at uncontrolled midblock locations is even more uncertain. There is no evidence that crosswalk markings will reduce the collision risk of pedestrians at uncontrolled midblock locations. There is no direct evidence that crosswalk markings will increase the collision risk either. Indirectly, however, one of the most recent studies seems to indicate that the safety effect of crosswalk markings is the same between intersections and midblock locations. More generally, one may wonder if the evidence on the safety effects of crosswalk markings at uncontrolled intersections is transferable to uncontrolled midblock locations. The fact that the crossing task at midblock locations is not as complex as at intersections does not influence this transferability. The answer depends largely on gaining an understanding of why crosswalk markings would lead to higher pedestrian-vehicle collision risks. A good understanding of this also helps develop guidelines that prevent pedestrian-vehicle collision risks from being higher at marked crosswalks.

MECHANISMS

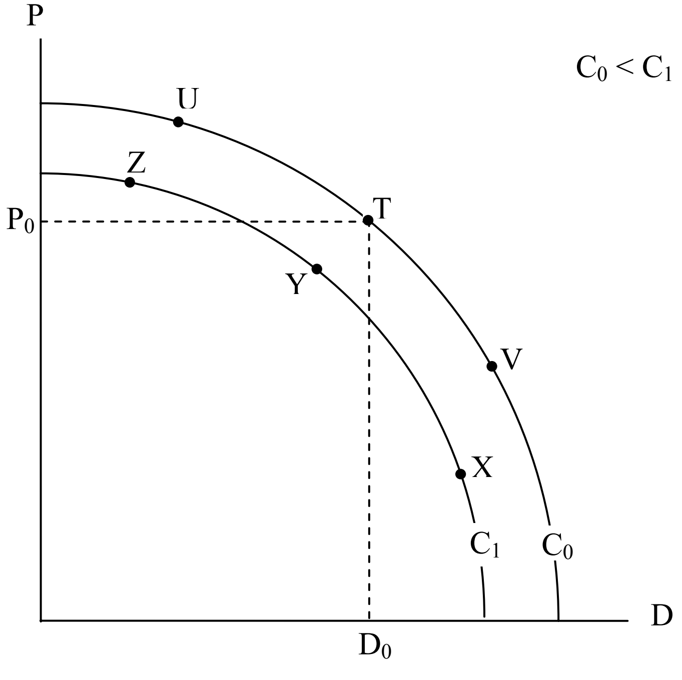
One may wonder if it is a sound strategy to develop guidelines when the prevailing evidence says that crosswalk markings may lead to higher pedestrian-vehicle collision risks and there is much uncertainty in this evidence. According to Fitzpatrick et al. (2006b), some traffic engineers and practitioners have interpreted this evidence to mean that marked crosswalks should not be provided on multilane roads with high traffic volumes and speeds. This exclusionary approach is based on a partial interpretation of this evidence: it is largely the result of simple markings without additional enhancements. In addition, this exclusionary approach is not sound public policy. Pedestrians at midblock locations along multilane roads with high traffic volumes and speeds with established crossing demand will continue to cross roads there. Finally, development of and compliance with guidelines serves many other purposes (Hauer 1999). They enable roadway users to behave legally; they provide a level playing field for all roadway users and avoid situations where a significant minority of roadway users has difficulties; and they provide protection against moral, professional, and legal liability for government agencies and roadway designers. They also reduce the need for ad hoc decisions on roadway design.

Developing guidelines but ignoring the prevailing evidence that marking crosswalks may increase pedestrian-vehicle collision risks at midblock locations is not a sound strategy either. The key is to understand why pedestrian-vehicle collision risks may be higher as a result of marking crosswalks and to design guidelines accordingly. To accomplish that, this section first sets up a simple model of pedestrian-vehicle collision risks. It then uses this model to identify three mechanisms that help explain why collision risks are higher with crosswalk markings. For each mechanism, it further identifies enhanced treatments to prevent pedestrian-vehicle collision risks from being higher in marked crosswalks.

A Model

Consider a particular crossing point along a road. This crossing point has a base level of risk for vehicle-pedestrian collisions under current conditions. To link this collision risk to the behaviors of both drivers and crossing pedestrians, the risk is modeled by the probability that neither the drivers nor the pedestrian see the other side early enough to avoid a collision between them in any particular crossing situation at this crossing point. For any crossing situation where a pedestrian is trying to cross at that point upon which vehicles are approaching, let D_0 be the probability that all drivers will notice the crossing pedestrian early enough to avoid a collision, independent of whether the pedestrian will notice all drivers in time. Similarly, let P_0 be the probability that the pedestrian will notice all drivers early enough to avoid a collision, independent of whether all drivers will notice the pedestrian in time. Then the base risk of vehicle-pedestrian collisions at this crossing point, C_0, is given by $(1-D_0)(1-P_0)$. The different combinations of D and P for a given collision risk form a frontier, as illustrated by the top curve labeled with C_0 in Figure 5, where D is on the horizontal axis and P on the vertical axis. Point T on this curve represents current conditions.

Figure 5. Graphical Illustration of Collision Risks



Changes in conditions (e.g., crosswalk markings, lighting, etc.) may not always lead to changes in the level of collision risks. If changes in conditions lead to changes in the probability of seeing the other side for both drivers and pedestrians but the new combination stays on the same frontier, collision risks stay the same (e.g., U, and V on C_0). If changes in the probability for drivers, pedestrians, or both move the new combination off the base frontier, collision risks change. The level of collision risks goes down if the new combination of D and P is above the base frontier, but goes up if the new combination is below the base frontier (e.g., X, Y, and Z on C_1).

It is useful to introduce two terms from the literature on the component effects of any engineering countermeasure (Elvik 2004). Independent of how the pedestrian may react, a change in the drivers' probability of seeing the crossing pedestrian as a result of a crosswalk marking is referred to as the engineering effect of the marking. A change in the pedestrian's probability of seeing the drivers as a result of a crosswalk marking is similarly referred to as the behavioral adaptation effect. The original expectation of marking a crosswalk is that it would lead to a decrease in the collision risk because the engineering effect would be positive and the behavioral adaptation effect would be zero. The problem is that we do not know if the engineering effect is positive or the behavioral adaptation effect is zero in real life. What we do know from the literature is that the net effect appears to be highly negative (i.e., higher collision risks), at least for multilane roads with high traffic volumes and speeds.

How the collision risk at a particular crossing point may change in response to marking a crosswalk there depends on the relative strengths of the engineering effect and the behavioral adaptation effect (Table 8). The engineering effect may be negative, zero, or positive while the behavioral adaptation effect may be negative or zero. Table 8 does not consider the case with positive behavioral adaptation effects because it is unlikely that pedestrians would be more likely to see approaching drivers early enough to avoid a collision as a result of marking. Based on this table, the following three sub-sections discuss three mechanisms through which marking may lead to higher collision risks.

Table 8. Possible Changes in Collision Risks from Marking

Engineering Effect	***Behavioral Adaptation Effect***	
	Negative	***Zero***
Negative	Higher	Higher
Zero	Higher	No Change
Positive	Higher/No Change/Lower	Lower

Prevent Negative Engineering Effects

Regardless of the behavioral adaptation effect, collision risks will go up if the engineering effect is negative. To avoid higher collision risks in marked crosswalks, negative engineering effects will have to be prevented. The engineering effect of marking a crosswalk can be negative if drivers become less likely to see crossing pedestrians after the marking than before the marking. It is possible that drivers may speed up to pass a crossing point before a crossing pedestrian reaches the travel lane. But it is highly unlikely that drivers would be less likely to see crossing pedestrians early enough to avoid a collision simply due to the presence of a marked crosswalk. In order for drivers to become less likely to see crossing pedestrians after marking, crosswalk markings would have to create new conditions that would make it more difficult for drivers to see crossing pedestrians. The only such condition identified in the literature is the so-called multiple threats to pedestrians crossing in a marked crosswalk along multilane roads (Zegeer et al. 2005). A yielding vehicle at a crosswalk blocks the views of both the crossing pedestrian and the driver in another lane. The notion of multiple threat collisions is one of three mechanisms that have been hypothesized in the literature to explain why crosswalk markings may lead to higher collision risks.

Multiple threats account for 17.6 percent of the 188 pedestrian crashes in marked crosswalks in the sample of study sites by Zegeer et al. (2005). It is 14.4 percent when all 229 pedestrian crashes are considered in both marked and unmarked crosswalks. If representative, multiple threats would be a significant source of pedestrian crashes. But it is hard to tell to what degree these multiple threat crashes contributed to the much higher crash rates in marked versus unmarked crosswalks in this study. On the other hand, the sample used by Zegeer et al. (2005) appears to show a much more serious problem of multiple threats than other samples. Among a much greater sample of close to 3,000 pedestrian crashes while attempting to cross roads from six states across the country, about 4.3 percent are multiple threat crashes (Stutts et al. 1996). If this is more representative of multiple threat crashes, they may account for a small degree of the dramatically higher collision risks in marked versus unmarked crosswalks.

The only treatments available in practice to counter multiple threats are a set of three: an advance yield bar, a Yield Here to Pedestrian sign, and a safety zone without any marking between the advance yield bar and the crosswalk. Lalani (2001) describes these treatments. Van Houten et al. (1998), Van Houten et al. (2001), and Huybers et al. (2004) evaluate the effect of the advance yield bar and the Yield Here to Pedestrian sign on driver behaviors. Fitzpatrick et al. (2006) review the results of these evaluations and many others at more than two dozen study sites, and find that these treatments are effective in reducing vehicle-pedestrian conflicts, increasing driver yielding to pedestrians at multilane crosswalks with an uncontrolled approach, and increasing the distance at which drivers yielded to pedestrians. In addition, the review shows that a combination of these treatments is more effective than a single treatment.

Table 9 lists these treatments in the second column, which is related to the objective of preventing negative engineering effects and the mechanism of multiple threats to pedestrians. The other two columns are for other two objectives and mechanisms discussed next. The row labeled B relates to the basic safety criteria described in the structure of guidelines. The letters C, P, and N refer to the three categories of safety conditions as defined in Figure 4. The difference between N-First and N-Second will be discussed in the proposed guidelines. The appendix illustrates most of these treatments with a field photo or a graphics.

Prevent Negative Behavioral Adaptation

Preventing negative engineering effects will help reduce the chance that marking may lead to higher collision risks, but will not fully prevent higher collision risks from happening. To fully prevent higher collision risks, we will have to prevent negative behavioral adaptation effects. The behavioral adaptation effect can be negative if a crossing pedestrian becomes less likely to see all approaching drivers early enough to avoid a collision. This can happen under multiple threat conditions described above. It also can happen without new conditions created by a marked crosswalk. It is not a surprise if pedestrians adapt their behavior to a marked crosswalk. It may be seen as one form of the behavior of risk compensation (Assum et al. 1999). While controversial, there is a general agreement in the literature that road users do adapt their behavior to certain risk-reducing countermeasures (Assum et al. 1999).

Table 9. Treatments to Prevent Higher Collision Risks from Marking

Mechanisms	***Multiple Threat***	***False Sense of Security***	***Markings Alone***
Objectives	***Prevent Negative Engineering Effects***	***Reduce Negative Behavioral Adaptation***	***Increase Positive Engineering Effects***
B		Sight Distance	Sight Distance Bulbouts Parking Restrictions Lighting
C	Yield Bar Yield Here for Pedestrian Sign Safety Zone	Pavement Legends Medians Refuge Islands	High Emphasis Marking Advance Warning Signs
P			Overhead Signs Flashing Beacons In-Roadway Lights
N-First			Traffic Signals Overpasses
N-Second			Electronic Signs Automated Detection HAWK

Behavioral adaptation by pedestrians in response to a marked crosswalk under regular conditions (rather than multiple threat conditions) is the second mechanism that has been suggested in the literature to explain why collision risks may be higher in marked crosswalks. It is frequently referred to as pedestrians having “a false sense of security” when crossing in a marked crosswalk (Herms 1972). One problem with this notion is that recent direct observations of pedestrian and driver behaviors through before-and-after studies contradict this notion (Zegeer et al. 2005). However, this contradiction does not prove that the notion is wrong. Much of the observational studies are done on low-speed, low-volume, and narrow roads, while the higher collision risk from crosswalk markings exists mostly along high speed, high volume, and multilane roads. In addition, there is no established link between pedestrian behaviors as observed to pedestrian collision risks.

Available treatments in practice are inadequate to counter negative behavioral adaptation at uncontrolled midblock locations. The only treatment in practice for reminding pedestrians to be alert is pavement legends. Word legends are placed on the pavement at each end of the crosswalk to be legible to pedestrians as they are waiting to cross (Lalani 2001). Another treatment designed for controlled locations is an animated eye display, which uses LED pedestrian signal head and adds animated eyes that scan from side to side (Lalani 2001). In addition, there are few engineering treatments designed not to keep pedestrians being alert but to reduce the complexity of a crossing environment at uncontrolled midblock locations so that pedestrians are more likely to see approaching drivers early enough to avoid a collision. One is raised medians, and the other is refuge islands when raised medians are not present.

Evaluations of these treatments are limited, especially for midblock locations. In their comprehensive review of pedestrian crossing treatments, Fitzpatrick et al. (2006) describe one study by Retting et al. (1996), who evaluate the effects of the warning signs and pavement markings prompting pedestrians to look for potential vehicle conflicts. The message "PEDESTRIANS: LOOK FOR TURNING VEHICLES" was used at 2 intersections in Canada and 1 intersection in U.S. The results indicate that the percent of pedestrians looking for threats increased from about 15% to about one-third at all three sites, and that the number of vehicle-pedestrian conflicts per 100 pedestrians reduced from 3 to 0 at all three sites.

On the other hand, median refuge islands are considered to be effective for pedestrian crossings on multilane roads. In fact, Zegeer et al. (2005) show that the pedestrian crash rates per unit of exposure along multilane roads are two to four times lower with median refuge islands than without them.

Increase Positive Engineering Effects

It may be possible to fully prevent negative engineering effects, but it may not be easy to fully prevent negative behavioral adaptation by pedestrians. When negative behavioral adaptation cannot be fully prevented from using the limited treatments available in Table 9 under "Reduce Negative Behavioral Adaptation," other treatments targeting drivers would need to be implemented to reach a level of positive engineering effects that is high enough to more than offset the remaining negative behavioral adaptation. This relates to the third mechanism that has been suggested in the literature to explain why pedestrian-vehicle collision risks may be higher in marked crosswalks. Zegeer et al. (2005) hypothesize that simple markings without any enhancements lead to higher collision risks because the vast majority of the marked crosswalks included in their study have nothing but simple markings.

The last column of Table 9 lists such treatments targeted at drivers under the heading "Increase Positive Engineering Effects." Lalani (2001), Zegeer et al. (2002), Harkey and Zegeer (2004), and Fitzpatrick et al. (2006) describe many of these treatments. What is not included in Table 9 but has become popular in many localities in the U.S. are crosswalk flags and in-street pedestrian crossing signs (Lalani 2001). Little orange flags are available in holders on a pole at both ends of a crosswalk. Pedestrians pick up a flag and flag traffic to let drivers know they wish to cross. Once on the other side, pedestrians return the flag to a holder. Signs are posted on the poles describing the use of the flags. In-street pedestrian crossing signs are regulatory signs placed in the street (on lane edge lines, road centerlines, or in medians), and are used to remind drivers of state laws regarding right of way in crosswalks. These treatments do not appear to be suitable for state highways in most cases.

Most of these treatments have been evaluated for their effects on driver behaviors in terms of approaching speed, yielding, etc. Many have recently reviewed the results of these evaluations (SRF Consulting Group 2003; Retting et al. 2003; Bechtel et al. 2003; Campbell et al. 2004; Cottrell et al. 2004; Martin 2005; Zegeer et al. 2005; Fitzpatrick et al. 2006). Fitzpatrick et al. (2006) is unique in that they both review existing evaluations and present results from their own evaluations for many treatments. They group these treatments into traffic signal and red beacon displays, flashing beacons, in-roadway lights, and driver warning signs and pavement markings. The following summaries are based on their review:

- The group of traffic signal and red beacon displays includes the HAWK and is highly effective in encouraging drivers to yield to pedestrians along multilane roads with high volumes and speeds. The rate of drivers yielding to pedestrians falls in the 90-100 percent range.
- The group of flashing beacons is widely used in the U.S. and varies both in design and operations. The basic design is either overhead or side mounted. The basic operation is continuous or activation by manual pushbuttons or automatic detection. The evaluations show that activation-based flashing beacons are more effective than continuously flashing beacons. In addition, overhead flashing beacons have the best visibility to drivers. The general effectiveness of flashing beacons, however, appears to be limited on multilane roads with high traffic volumes and speeds. The rate of drivers yielding to pedestrians falls in the 25-76 percent range with an average rate around 58 percent.
- In-roadway lights are a special design of flashing beacons and have been increasingly installed in the U.S. in the last 10 years. For most of the cases, they have increased driver yielding to the 50-90 percent range. In addition, in-roadway lights typically increase the distance at which drivers first brake. These results are more dramatic at night than during daytime.
- The group of driver warning signs and pavement markings include overhead signs and electronic signs (e.g., animated eyes). The experience with these has generally been modest, especially on multilane roads with high traffic volumes and speeds.
- In addition to these groups, Fitzpatrick et al. (2006) also review a study on the effects of automated pedestrian detection on standard pedestrian signals at three intersections in three different states by Hughes et al. (2001). The use of automated detection reduced vehicle-pedestrian conflicts by 89 percent for the first half of the crossing, and 42 percent for the second half of the crossing.

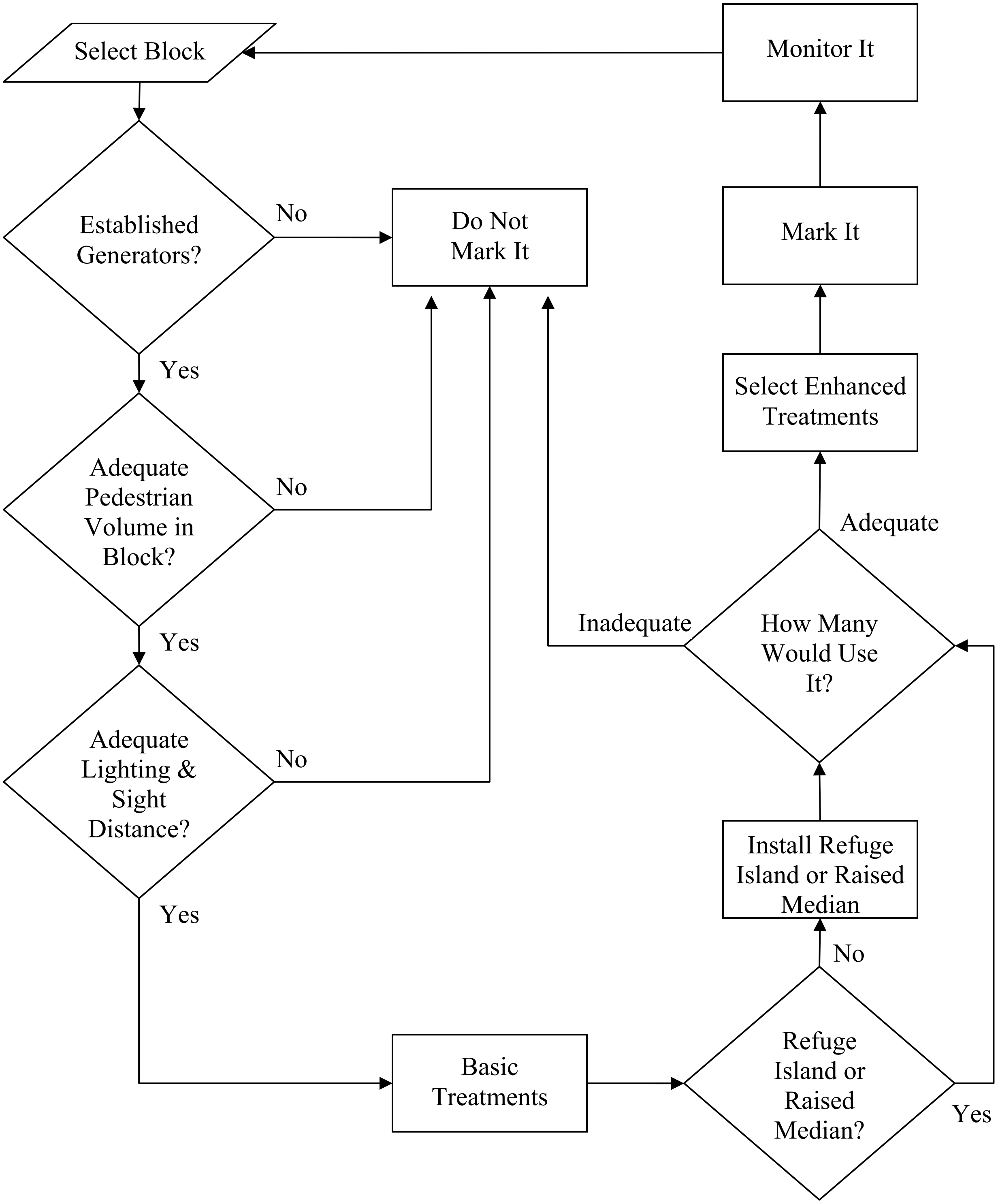
But these treatments have not been seriously evaluated for their effects on pedestrian-vehicle collision risks. There are two related reasons for this lack of evaluations on their safety effects. It is infeasible to evaluate their safety effects through localized before-and-after studies because it takes many years to observe actual collisions. It is infeasible either to evaluate their safety effects through large-scale cross-sectional studies because these treatments have not been widely implemented in any single metropolitan area.

PROPOSED GUIDELINES

This section proposes a set of guidelines for uncontrolled midblock crosswalks for state highways in Florida. The proposed guidelines are stated in the structure described earlier. In addition to the six components synthesized from the actual guidelines, three additional components are added toward the end. These include a component on the likelihood of usage, a component on the responsibility of conducting an engineering study, and a component on continuous monitoring.

Figure 6 shows the different components, their relationships, how they affect whether a midblock crosswalk should be marked, and what treatments should be applied if marked. Several of the components are not explicitly shown in this framework. Some of these are not a particular step in the decision process, including functions and philosophy, and are reflected throughout the guidelines. Others are not one single step, including conducting an engineering study, which includes gathering the necessary information for other components and using the spreadsheet tool for estimating the likelihood of usage.

Figure 6. Guideline Flowchart



Function

Marking an uncontrolled midblock crosswalk serves as a warning device to motorists and pedestrians at locations where there is adequate sight distance and lighting and where a high volume of pedestrians are already crossing between major pedestrian generators and attractors. This function is consistent with MUTCD guidance. Given this function, one objective of the proposed guidelines is to make sure that motorists will see this warning device when approaching a crosswalk. Equally important, another objective of the proposed guidelines is to make sure that pedestrians will be as alert as without the markings and will not assume that approaching drivers will always yield to them when crossing in the crosswalk.

Philosophy

The Florida Department of Transportation should follow an inclusive approach to marking crosswalks at uncontrolled midblock locations. For locations with established crossing demand and adequate sight distance and lighting (see the next two components for specifics), treatments should be selected (including pedestrian signals) to ensure reasonable safety even at high speed and volume locations. This inclusive approach is consistent with MUTCD guidance that marked crosswalks should be provided at uncontrolled midblock crossings of pedestrian concentration.

Demand Criteria

Making sure that adequate demand exists is critical for a particular set of guidelines to avoid midblock crosswalks being overused at uncontrolled locations. A combination of three criteria should be used to determine whether adequate demand exists for an uncontrolled midblock crosswalk. These include the level of demand (pedestrian volume, presence of pedestrian generators), the existence of alternatives (block length, distance to the nearest alternative), and the existence of crossing opportunities (minimum traffic volume).

Level of Demand

- Any block under consideration for a possible midblock crosswalk should show a well defined spatial pattern of pedestrian generators, pedestrian attractors, and pedestrian flow between them.
- Sufficient demand should exist: a minimum of 25 pedestrians during the peak hour of pedestrian crossing traffic or a minimum of 75 pedestrians during the peak four hours of pedestrian crossing traffic.
- The measurement of pedestrian volume should be between the established generator and attractor within the entire block under consideration.
- Crosswalks should be considered at any midblock location that is an integral part of a designated multi-use path.

Existence of Alternatives

- An alternative is defined as any protected crossing with the protection provided by stop signs, traffic signals, or pedestrian overpasses or underpasses.
- The minimum distance to the nearest alternative is 300 feet.
- The minimum block length is 660 feet.

Crossing Opportunities

- For county and municipal roads, a minimum threshold for average daily vehicle traffic should be considered. A threshold typically falls in the range of 1,500 to 3,000 ADT. It is rare that this range of minimum average daily vehicle traffic is not satisfied for state highways.

These criteria are consistent with MUTCD guidance that marked crosswalks should be provided at uncontrolled midblock crossings of pedestrian concentration and that uncontrolled midblock crosswalks should not be used indiscriminately.

Basic Safety

The candidate block under consideration should meet the following basic safety criteria:

- Use the stopping sight distance in Table 10 to determine minimum sight distance. This table is adopted from FDOT's *Plans Preparation Manual*, Table 2.7.1 (2006a). The original table links minimum sight distance to design speed. Speed limit is added with the assumption that speed limit is 5 mph lower than the corresponding design speed. The table may be applied in terms of either design speed or speed limit.
- The consideration of sight distance needs to take into account the presence of street parking. When street parking prevents a location from meeting the minimum sight distance threshold, use a bulbout (Figure A1) or restrict parking within a sufficient range of the proposed midblock crosswalk (Figure A2).
- A minimum illumination level of 2.5 horizontal foot candles shall be used for both approaches (Figure A3). When regular street lighting is not present or inadequate to reach this minimum illumination level, separate crosswalk lighting shall be installed. If it is economically infeasible to install regular lighting, solar-based lighting may be used.

Table 10. Stopping Sight Distance for Grades 2% or Less

Design Speed (mph)	Speed Limit (mph)	Stopping Sight Distance (feet)
20	15	155
25	20	200
30	25	250
35	30	305
40	35	360
45	40	425
50	45	495
55	50	570
60	55	645

These basic safety criteria are consistent with MUTCD guidance that uncontrolled midblock crosswalks should not be installed indiscriminately and that parking may be restricted to ensure sight distance. These basic safety criteria also help achieve the objective of increasing positive engineering effects of marked crosswalks, and the objective of reducing negative behavioral adaptation (Table 9).

Basic Treatments

Any uncontrolled midblock crosswalk shall include ALL of the following treatments:

- A Special Emphasis Crosswalk (Figure A4) in FDOT's *Design Standards*, Index No. 17346, should be used (2006b).
- Pavement legends should be included at both ends of the crosswalk directing pedestrians to look for approaching vehicles (Figure A5).
- An advance warning sign (Figure A6) that consists of A PEDESTRIAN CROSSING (W11-2) sign along with the AHEAD (W16-9P) supplemental panel should be included. This is consistent with MUTCD guidance that advance warning signs should be installed. The Department's *Design Standards*, Index No. 17346 shall be used for mounting locations as related to approach speeds (FDOT 2006b).
- A yield bar with a safety zone between the yield bar and the crosswalk (Figure A6) should be included. In addition, a YIELD HERE TO PEDESTRIAN sign shall be installed (Figure A7). The 2003 MUTCD, Sections 7C.04 and 2B.11 shall be used for specifications (FHWA 2003).
- If not already present, a raised median (Figure A8) or a raised median (Figure A9) should be installed. On two-lane roads, only refuge islands should be considered.
- Sidewalks should connect the mid-block crosswalk to and from an established pedestrian generator and attractor. The Department's *Plans Preparation Manual*, Section 8.3.1 shall be used for sidewalk design considerations (FDOT 2006a).

This set of basic treatments is far more comprehensive than what is specified in any set of actual guidelines reviewed. They are designed to help achieve the three objectives described in the last section: 1) preventing negative engineering effects; 2) reducing negative behavioral adaptation; and 3) increasing positive engineering effects so that pedestrian-vehicle collision risks would not be higher in marked crosswalks (Table 9).

Enhanced Treatments

Use the table in Figure 4 to select appropriate enhanced treatments for specific safety conditions defined by traffic volume, speed limit, and roadway width.

C = Basic treatments.

P = In addition to the C-level enhanced treatments, overhead signs (Figure A10), pedestrian-actuated flashing beacons (Figure 11), and pedestrian-actuated in-roadway lights (Figure A12) should be considered for installation. The 2003 MUTCD, Section 4K.03 shall be used for specifications on warning beacons (FHWA 2003). With revisions to be consistent with these proposed guidelines for marking crosswalks, the Department's *Traffic Engineering Manual*, Section 3.8 should be followed for implementing pedestrian-actuated in-roadway lights (FDOT 1999a).

N = In addition to C-level treatments, consider pedestrian-actuated signals or pedestrian overpasses first. The 2003 MUTCD should be followed for considering pedestrian-actuated signals (FHWA 2003). FDOT's *Plans Preparation Manual*, Section 8.7 shall be used for considering pedestrian overpasses (2006a). In the event that such control device does not meet current warrants or is infeasible in the short term due to financial considerations, electronic signs (Figure A13), automated detection (Figure A14) combined with the P-level enhanced treatments, or HAWK signal (Figure A15) should be considered.

These enhanced treatments are designed to make sure that the engineering effect of marking an uncontrolled midblock crosswalk is positive enough to more than offset any negative behavioral adaptation by pedestrians (Table 9).

The consideration of pedestrian-actuated signals or pedestrian overpasses first for the N-level conditions is consistent with the current thinking of the traffic engineering profession. The recent TRB report (Fitzpatrick et al. 2006) has proposed that if the proposed new pedestrian signal warrant is not met in a future version of the MUTCD, less restrictive devices may be considered. Specifically, it has proposed to include pedestrian beacons as a less restrictive alternative to the traditional pedestrian signal.

Using the table in Figure 4 as a basis for considering treatments also is consistent with the current thinking of the traffic engineering profession. The same TRB report (Fitzpatrick et al 2006) has suggested that this table along with other findings of the original study (Zegeer et al. 2005) be the basis for developing midblock crosswalk warrants for the MUTCD.

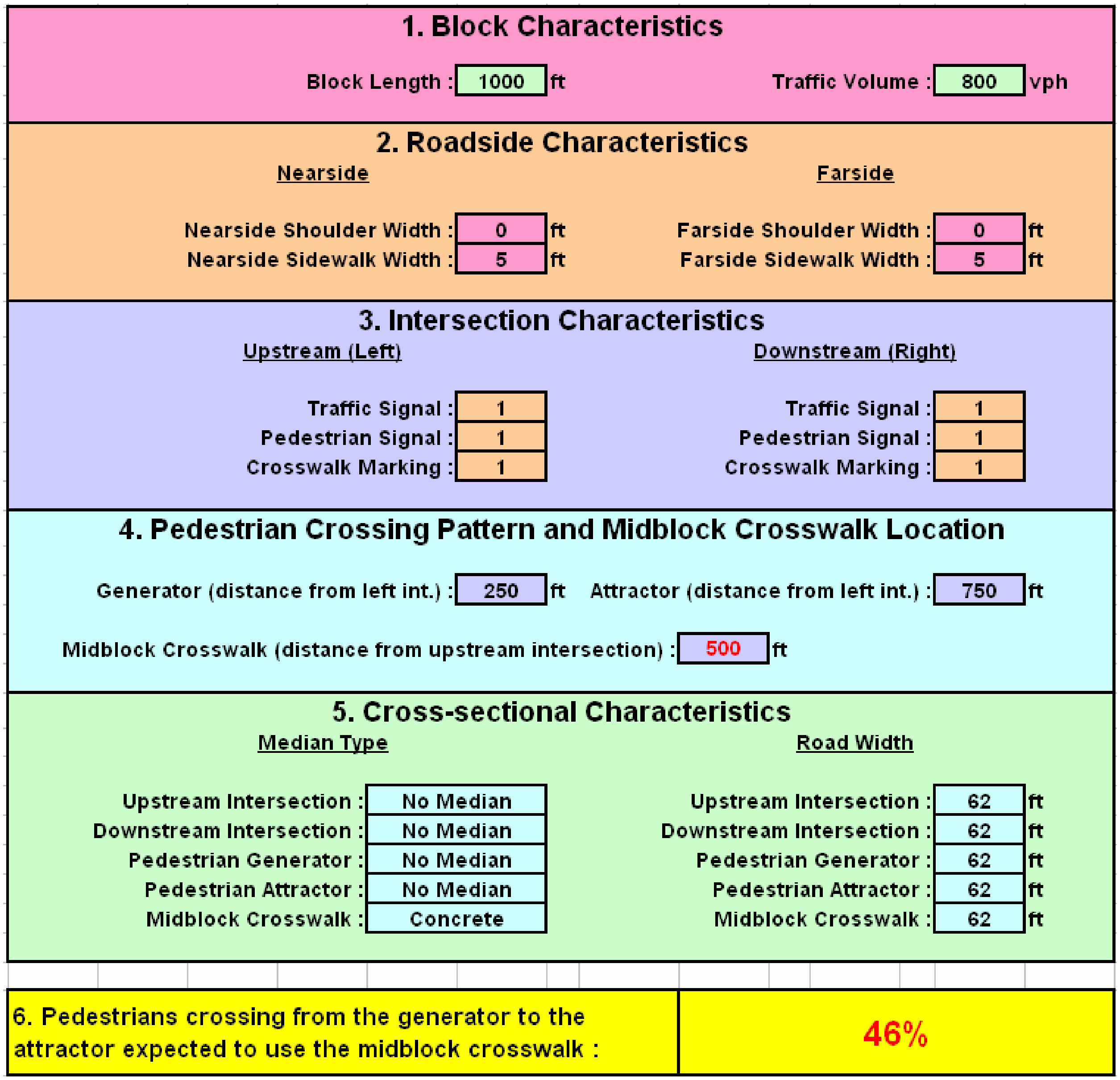
Likelihood of Usage

Use the spreadsheet template in Figure 7 to determine the expected share of the pedestrian crossing volume along the subject block that would cross in a proposed midblock crosswalk. This spreadsheet has six sections:

1. Block characteristics include block length in feet and total traffic volume for both directions in vehicles per hour.
2. Roadside characteristics include shoulder width and sidewalk width in feet. Enter zero if not present. The nearside is the side where the pedestrian generator is located. If pedestrian generators are present on both sides of the block, the nearside can be either side.
3. Intersection characteristics include the presence of traffic signals, pedestrian signals, and crosswalk markings. Whether an intersection is upstream or downstream is stated from the nearside of the block. Enter 1 if present and 0 otherwise.
4. The fourth section requires two input types. One includes the location of the pedestrian generator in feet from the upstream intersection and the location of the pedestrian attractor in feet from the upstream location. The other is the location of the proposed midblock crosswalk in feet from the upstream intersection.
5. Cross-sectional characteristics include median type (no median, concrete, grassy, or painted) and roadway width in feet at the various points along the subject block.
6. The last section shows the percent share of pedestrians crossing from the generator to the attractor that are expected to use the proposed midblock crosswalk. This share may be

applied to the pedestrian volume during the peak hour or during the peak four-hours crossing along the subject block to estimate the pedestrian volume crossing in the proposed crosswalk.

Figure 7. Template on Likelihood of Usage



1. Block Characteristics

Block Length : 1000 ft
Traffic Volume : 800 vph

2. Roadside Characteristics

Nearside
Nearside Shoulder Width : 0 ft
Nearside Sidewalk Width : 5 ft

Farside
Farside Shoulder Width : 0 ft
Farside Sidewalk Width : 5 ft

3. Intersection Characteristics

Upstream (Left)
Traffic Signal : 1
Pedestrian Signal : 1
Crosswalk Marking : 1

Downstream (Right)
Traffic Signal : 1
Pedestrian Signal : 1
Crosswalk Marking : 1

4. Pedestrian Crossing Pattern and Midblock Crosswalk Location

Generator (distance from left int.) : 250 ft
Attractor (distance from left int.) : 750 ft

Midblock Crosswalk (distance from upstream intersection) : 500 ft

5. Cross-sectional Characteristics

Median Type
Upstream Intersection : No Median
Downstream Intersection : No Median
Pedestrian Generator : No Median
Pedestrian Attractor : No Median
Midblock Crosswalk : Concrete

Road Width
Upstream Intersection : 62 ft
Downstream Intersection : 62 ft
Pedestrian Generator : 62 ft
Pedestrian Attractor : 62 ft
Midblock Crosswalk : 62 ft

6. Pedestrians crossing from the generator to the attractor expected to use the midblock crosswalk : 46%

Engineering Study

The requester for marking an uncontrolled midblock crosswalk along a specific block on the State Highway System is responsible for having an engineering study arranged and completed. Upon its completion and submission, FDOT should determine if the study meets its standards for an engineering study. Using the new guidelines, FDOT should decide whether an uncontrolled midblock crosswalk be marked along this block and what enhanced treatments shall be installed. The requirement of an engineering study is consistent with MUTCD guidance that crosswalks should not be used indiscriminately, and an engineering study should be performed before they are installed at uncontrolled midblock locations.

Monitoring

The available evidence indicates that crosswalk markings alone lead to higher pedestrian-vehicle collision risks, and this evidence is subject to a high degree of uncertainty. As a result, it is important these guidelines are viewed as provisional until the safety effects are certain. In addition, it is important that a process is set up through which the Department will monitor any midblock crosswalk installed at uncontrolled locations as a result of these new guidelines. For each newly marked midblock crosswalk, this process will need to include the selection and monitoring of a comparable unmarked midblock location that is similar to the newly marked location. As part of this monitoring process, an already marked location under these guidelines may be studied again to determine if additional enhanced treatments should be implemented. Finally, the guidelines themselves should be subject to revisions when new engineering treatments become available and new information on the safety effects of crosswalk markings and related treatments become available.

CONCLUSIONS

This second part of this report has proposed a set of guidelines for marking midblock crosswalks at uncontrolled locations on Florida's State Highway System. The process used in developing these guidelines and the guidelines are common with similar efforts in other localities:

- The process is based on a review of actual guidelines from other localities.
- The process is based on a solicitation of practitioner inputs.
- The guidelines include a set of demand criteria.
- The guidelines include a set of basic safety criteria.
- The guidelines include a set of basic treatments and a set of enhanced treatments.
- The guidelines reflect all MUTCD guidance.

In addition to these common features, the process used and the resultant guidelines are unique in many ways:

- The process is more comprehensive and includes many forms of inputs.
- The process follows an inclusive philosophy toward marking crosswalks. Rather than excluding wide roads, roads with high traffic volumes, or roads with high speed from being considered for midblock crosswalks at uncontrolled locations, the focus is on selecting appropriate treatments for these environments when there is a well established crossing demand and adequate sight distance and lighting. The most serious problem of pedestrian crossing safety exists largely on those situations, doing nothing for well established demand is not a sound public policy.
- The guidelines are structured to avoid gaps that would make their implementation difficult.
- The guidelines include a spreadsheet tool that uses information on block characteristics, roadside characteristics, intersection characteristics, cross-sectional characteristics, and crossing patterns to estimate the likelihood of pedestrians who currently cross in the block using the marked crosswalk.

- The guidelines take into account available evidence that crosswalk markings appear to increase pedestrian-vehicle collision risks. The development process sets up a simple model of pedestrian-vehicle collision risks. This model is used to identify three mechanisms through which pedestrian-vehicle collision risks may be higher in marked crosswalks. These mechanisms are multiple-threat collisions, pedestrians having a false sense of security, and lack of additional treatments in addition to simple two-line markings. This model is further used to identify treatments to counter these mechanisms so that crosswalk markings do not lead to higher collision risks.
- The guidelines take into account the fact that the available evidence is uncertain. These guidelines are designed to be provisional and include a monitoring process for any new uncontrolled midblock crosswalks implemented under these guidelines.

These proposed guidelines improve upon the existing guidelines in Florida so that they are more useful to the practitioner. What remains to be carried out are improvements in the consistency of guidelines across different sections of a given manual or handbook and across different manuals and handbooks. The overall guidelines for placing midblock crosswalks may be contained in one section of the *Traffic Engineering Manual*, but a separate set of guidelines are in a different section for installing in-roadway lights. These two sets of guidelines would be inconsistent if the general guidelines allow the consideration of in-roadway lights under a particular environment, but the guidelines on in-roadway lights exclude this environment from consideration. It will require close coordination among FDOT offices in order to eventually get guidelines on placing midblock crosswalks at uncontrolled locations in the different manuals and handbooks to be consistent with each other. One approach to reaching this consistency would be to include a final set of guidelines for placing midblock crosswalks at uncontrolled locations in a single manual, such as the *Traffic Engineering Manual*, and to require all other manuals or handbooks to cite the *Traffic Engineering Manual* or repeat the same guidelines without alterations.

Some have dismissed the notion of a false sense of security by pedestrians (FHWA 1998), and have suggested instead to focus exclusively on enforcing the vehicle code. But having a false sense of security while crossing in a marked crosswalk is nothing more than one form of the behavior of risk compensation, whose existence is widely recognized in the literature (Assum 1999). In contrast to this dismissal, the negative effects of this behavioral adaptation should be actively countered through engineering treatments. The problem is that available treatments are few for uncontrolled locations, including pavement markings and median treatments. Future efforts should focus on developing new treatments in this area. One example would be a big sign at each end of a crosswalk that reads: Look Both Ways Constantly While in Crosswalk! Another example would be an electronic sign with animated eyes at each of a crosswalk even at uncontrolled midblock locations.

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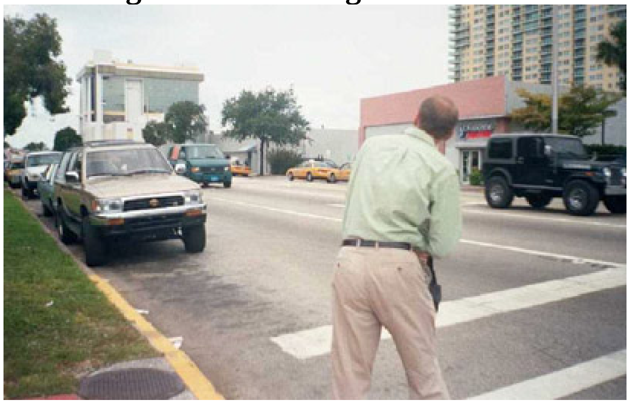
APPENDIX: GRAPHICAL ILLUSTRATION OF TREATMENTS

Basic Safety

Figure A1. Bulbouts

Adopted from City of Stockton (2003).

Figure A2. Parking Restrictions



Adopted from http://safety.transportation.org/htmlguides/peds/description_of_strat.htm

Figure A3. Lighting

Adopted from Zegeer et al. (2005).

Basic Treatments

Figure A4. High Visibility Marking

Adopted from FDOT (1999).

Figure A5. Pavement Legends for Pedestrians

Adopted from http://www.reprehensible.net/~orulz/asheville/asheville15.jpg

Figure A6. Advance Warning Sign

Figure A7. Yield Bar and Safety Zone

Provided by Michael Frederick of St. Petersburg, Florida

Figure A8. YIELD HERE TO PEDESTRIAN Sign

Adopted from http://www.pedbikeimages.org/imageDetail.cfm.

Figure A9. Raised Medians

Adopted from Zegeer et al. (2002).

Figure A10. Refuge Islands

Adopted from FDOT (1999).

Enhanced Treatments

Figure A11. Overhead Signs

Adopted from FDOT (1999)

Figure A12. Pedestrian-Actuated Flashing Beacons

Adopted from www.novax.com.

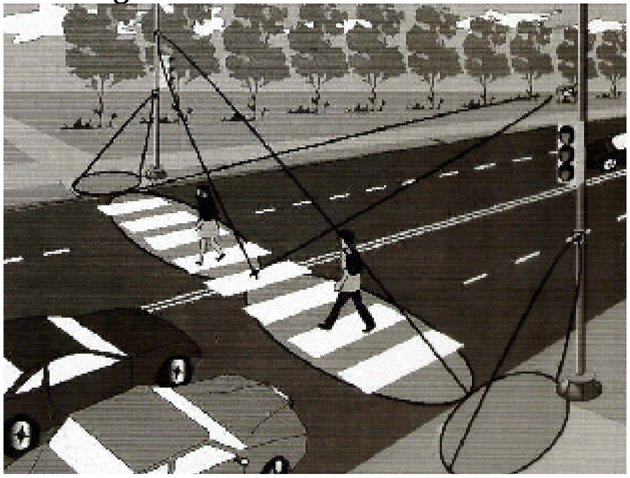
Figure A13. Pedestrian-Actuated In-Roadway Lights

Adopted from http://safety.transportation.org/htmlguides/peds/description_of_strat.htm

Figure A14. Electronic Signs

Provided by Michael Frederick of St. Petersburg, Florida

Figure A15. Automated Detection



Adopted from Hughes et al. (2001).

Figure A16. High-intensity Activated CrossWalK (HAWK) Signal

Adopted from Harkey and Zegeer (2004).