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ABSTRACT

Largely in response to several landmark safety studies, as an official or unofficial policy, many agencies across the U.S. have elected to remove marked crosswalks at uncontrolled intersections, or have shown resistance to installing them in the first place. This approach results in unacceptable pedestrian mobility restrictions, yet such restrictions are often not considered in policy-making. As such, there is a need for roadway system owners to develop strategic safety guidelines to address the marked crosswalk dilemma.

Since 2005, the UC Berkeley Traffic Safety Center, in a study funded by the California Department of Transportation (Caltrans), has focused on developing a better understanding of driver and pedestrian behavior and safety in both marked and unmarked crosswalks in an effort to recommend more informed crosswalk policies. The study was designed to fill key gaps in the literature by analyzing pedestrian and driver behavior and knowledge of right-of-way laws regarding marked and unmarked crosswalks. The study also focused on driver and pedestrian behavior with regard to multiple threat scenarios, the most common type of pedestrian collisions at uncontrolled intersections.

This paper summarizes results from field observations of driver and pedestrian behavior at marked and unmarked crosswalks on low speed, two-lane and multi-lane roads. The behavioral observations are interpreted in light of findings reported by Mitman and Ragland (2007) from surveys and focus groups regarding driver and pedestrian knowledge of right-of-way laws. The paper concludes with recommendations for a comprehensive crosswalk safety policy to strategically address crash risk at uncontrolled crosswalks.

INTRODUCTION

At a time when the need for more sustainable transportation solutions is critical, a greater focus on non-motorized alternatives to the automobile is clearly warranted and is gaining momentum throughout the United States. Considering pedestrian safety in the process of reorienting transportation and land use is imperative. As Zegeer, *et al.* (2001) and others have argued, "Pedestrians have a right to cross roads safely and, therefore, planners and engineers have a professional responsibility to plan, design, and install safe crossing facilities (*1*)."

In an effort to provide a greater understanding of pedestrian crash risk, and in doing so encourage the facilitation of safe and convenient pedestrian crossings, this paper documents and discusses field observations of drivers and pedestrians at uncontrolled marked and unmarked crossings. The behavioral observations are then interpreted as they relate to recent findings from surveys and focus groups regarding driver and pedestrian knowledge of right-of-way laws (*2*).

More than 35 years of pedestrian safety research has focused on marked and unmarked crosswalks, making this topic one of the most debated in the field. Thus, it is instructive to open this paper with a summary of the background for this debate.

BACKGROUND

Previous research focusing on uncontrolled crosswalks can generally be grouped in two key areas: (1) safety research regarding collision trends, and (2) behavioral research analyzing driver and pedestrian behavior within crosswalks.

Safety Research at Uncontrolled Crosswalks

There is a long and influential history of research on the safety impacts of marked and unmarked crosswalks. Herms' famous 1972 study in San Diego found that marked crosswalks were the sites of twice as many crashes as unmarked crosswalks, controlling for pedestrian volume (*3*). Several other studies found similar results (Gibby, 1994), but their methodologies have been criticized (Campbell, 1997) (*4*, *5*).

A landmark study conducted by Zegeer, *et al.* in 2001 for the Federal Highway Administration (FHWA) analyzed five years of pedestrian collisions at 1,000 marked crosswalks and 1,000 matched unmarked comparison sites in 30 U.S. cities. The study concluded that no meaningful differences in crash risk exist between marked and unmarked crosswalks on two-lane roads or low-volume multi-lane roads. However, the researchers found that on multi-lane roads with traffic volumes greater than about 12,000 vehicles per day, marked crosswalks without other substantial roadway treatments were associated with higher pedestrian crash rate than having an unmarked crosswalk. The study concluded that, particularly on high-speed, high-volume and multi-lane roads, painted white lines are not enough to improve pedestrian safety (*1*).

A recent research effort jointly sponsored by the Transit Cooperative Research Program (TCRP) and the National Cooperative Highway Research Program (NCHRP) and conducted by the Texas Transportation Institute (TTI) focused on determining the effectiveness of many of the pedestrian safety engineering countermeasures for uncontrolled crossings recommended in the 2001 FHWA study. As a result of this study, specific engineering guidelines for selecting effective pedestrian crossing treatments for uncontrolled intersections and midblock locations are now available based on key input variables such as: pedestrian volume, street crossing width, and traffic volume. The study also suggested modifications to the pedestrian traffic signal warrant in the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (*6*).

Behavioral Research at Uncontrolled Crosswalks

One of the central debates regarding pedestrian behavior in crosswalks is whether pedestrians are less cautious in marked crosswalks than in unmarked crosswalks or non-crosswalk locations. Herms' 1972 analysis hypothesized that this "lack of caution" may lead to the higher rate of crashes observed in marked crosswalks compared to unmarked crosswalks (*3*).

However, more recently, Knoblauch, *et al.* (2001) measured the effects of crosswalk markings on driver and pedestrian behavior at uncontrolled intersections on two- and three-lane roads (*7*). Knoblauch (2001) and Nitzburg (2001) found no difference in pedestrian assertiveness in marked and unmarked crosswalks, while pedestrian searching behavior (looking left and right for oncoming traffic) actually improved at crossings after they were marked (*7, 8)*. Others (for example, Hauck, 1979) have also found that pedestrian behavior improves in well-marked crosswalks compared to unmarked or poorly marked crosswalks (*9*).

There have been fewer studies of driver behavior, but it is generally agreed that drivers often fail to yield to pedestrians at both marked and unmarked crosswalks. The effects on driver behavior of marking a crosswalk have remained unclear.

In a before-after study, Knoblauch (2001) found that marking a crosswalk had no effect on driver yielding. However, he found a slight reduction in speed by drivers approaching a pedestrian in a marked crosswalk compared to a crossing that is unmarked (*7*).

Nitzburg (2001) found strong differences between day and nighttime driver behavior. Nitzburg's study also found differences in both driver and pedestrian behavior when the pedestrian was in the second half of the crosswalk compared to the first half (*8*).

This Study's Contribution

In recent years, many agencies have elected to remove marked crosswalks at uncontrolled intersections, or have shown resistance to installing them in the first place. This approach results in unacceptable pedestrian mobility restrictions and should not be embraced as policy. Instead, streets need to be more-pedestrian friendly, and new traffic control options should be developed to allow pedestrians more crossing opportunities along a street

Since 2005, the UC Berkeley Traffic Safety Center, in a study funded by the California Department of Transportation (Caltrans), has focused on developing a better understanding of driver and pedestrian behavior in both marked and unmarked crosswalks in an effort to recommend more informed crosswalk policies. Specifically, the study was designed to fill key gaps in the literature by:

- Analyzing pedestrian and driver behavior in marked and unmarked crosswalks on multi-lane roads—the critical road type identified by safety studies but not considered in previous behavioral studies
- Analyzing pedestrian and driver knowledge of the law as relates to right-of-way in marked and unmarked crosswalks—a factor which may at least partially explain behavioral patterns

In an earlier paper from this study, Mitman and Ragland (2007) presented the results of intercept surveys and focus groups which assessed driver and pedestrian knowledge of right-of-way laws. Previous studies have shown that both drivers and pedestrians have a limited knowledge of pedestrian right-of-way laws. Mitman and Ragland expanded on these studies by specifically considering knowledge of right-of-way laws related to marked and unmarked crosswalks. Results confirmed that a substantial level of confusion exists with respect to pedestrian right-of-way laws. This confusion was exacerbated by intersections with unmarked crosswalks (*2*).

This paper summarizes results from field observations of driver and pedestrian behavior at marked and unmarked crosswalks on multi-lane roads and interprets these results in light of the previously reported findings regarding knowledge of right-of-way laws.

METHODS

Building on the Knoblauch (2001) behavioral research, this study followed a similar methodology, except that instead of repeating studies on two and three-lane roads, this analysis focused primarily on roads with four or more lanes. Utilizing a matched pair approach, driver and pedestrian behavior within marked and unmarked crosswalk pairs at the same intersection were compared. Intersections with matched pairs of marked and unmarked crosswalks were considered desirable because most exogenous factors are held constant, allowing for a direct comparison between the crosswalks.

Six sites were selected for the purposes of the study. The locations were chosen with the following guidelines:

- One matched pair of crosswalks at an intersection on a two-lane major road
- One matched pair of crosswalks at an intersection on a three-lane major road
- Four matched pairs of crosswalks at intersections on four- to five-lane major roads

TABLE 1 Field Observation Sites

2 Lanes	3 Lanes	4+ Lanes	
		No Median	*Median*
Cedar St. and Walnut St., Berkeley	16th St. and Capp St., San Francisco	International Blvd. and 37^{th} Ave., Oakland	University Ave. and Walnut St., Berkeley
		Telegraph Ave. and $41^{st}/63^{rd}$ St., Oakland	Sacramento St. and Blake St., Berkeley

Previous studies have noted that driver yielding is related to vehicle speeds. All six observation locations had speed limits of 25 to 30 MPH in an effort to reduce potential yielding behavior discrepancies based on speed. Of the multi-lane sites, two locations with medians and two locations without medians were selected. The sites with two- and three-lanes were selected to allow for comparison with previous studies and with multi-lane crossings. Table 1 presents these sites by major road type. All six sites are located in the San Francisco Bay Area.

At each of our observation locations, the following study questions were addressed:

- Whether pedestrians use more, less, or the same amount of caution when crossing at a marked crosswalk (as compared to an unmarked crosswalk) — by recording the pedestrian's "looking behavior" and waiting location (curb or street) when using a marked versus unmarked crosswalk.

- Whether the age or gender of the pedestrian are correlated with his or her behavior — by recording the gender and approximate age of the pedestrian observed.
- Whether drivers yield more often to pedestrians in marked crosswalks than unmarked crosswalks — by recording whether or not the driver yielded when encountering a pedestrian in the crosswalk.

Data Collection

For this study, a pilot evaluation of video and clipboard-based data collection methods was conducted to determine the best data collection methodology. The evaluation considered accuracy, reliability, validity, and cost. Clipboard-based (manual) data collection was selected as the best method for the purposes of this study.

Data collection occurred during daylight hours on non-rainy days from May to October, 2006. Marked and unmarked crosswalk observations were collected concurrently at each site, except at International and 37th, where they were collected in series. Observers included professional field data collectors from Population Research Systems (PRS), selected based on inter-rater reliability tests from the pilot evaluation, as well as undergraduate work-study students from UC Berkeley who completed a one-hour training course tailored to this project.

For the 16th and Capp three-lane intersection in San Francisco, video footage available from another Traffic Safety Center project was utilized in lieu of in-person observations. Trained field observers completed the video observations in the office using QuickTime® video-playback software. When collecting data from the video, observers used the same data collection form as was used for the field observations.

Data Analysis

The statistical analysis package SAS was utilized to compare driver and pedestrian behavior observations in marked versus unmarked crosswalks at each of the six observation locations. This comparison was typically accomplished via a Chi-Squared test, a non-parametric test of statistical significance appropriate for bivariate tables. However, in some instances comparison cells had expected values of less than five. In these cases, the Fisher's Exact Test was used instead of the Chi-Squared test.

In addition to the observation variables included on the data collection form, the following derived variables were analyzed for each observation location:

- **Average gap acceptance (lanes):** This variable measures the number of times that no vehicle was present in a lane encountered during a pedestrian's crossing. The maximum number of gaps is equal to the number of lanes across which the crosswalk extends. The average number of gaps for pedestrians in marked versus unmarked crosswalks was compared in the statistical analysis for each site.
- **Average number of immediate yields (drivers):** This variable is the sum of the number of times the first driver encountered by a pedestrian in each lane yielded (as opposed to not yielding and trapping the pedestrian on the curb or within the street). The average number of immediate yields for pedestrians in marked versus unmarked crosswalks was compared in the statistical analysis for each site.

- **Average vehicle exposure (pedestrians):** This variable is the sum of the total number of vehicles encountered by a pedestrian during a crossing. The average exposure for pedestrians in marked versus unmarked crosswalks was compared in the statistical analysis for each site.
- **Multiple threat opportunity:** This variable measures for each pedestrian the number of times in which a driver yielded in one lane (the first encountered in the crossing direction) while a driver in the adjacent lane of the same direction of travel (the next encountered) did not yield. The incidence of multiple threat opportunities was applicable only for the crosswalks across the multi-lane intersections. For the four- and five-lane intersections, two pairs of multiple threat opportunities were considered, the first set of same direction lanes encountered in a crossing and the second set. The incidence of multiple threat opportunities for pedestrian crossings in marked versus unmarked crosswalks was compared in the statistical analysis for each site.

Multiple threat scenarios were specifically addressed in this analysis because the 2001 FHWA study noted, "The greatest difference in pedestrian crash types between marked and unmarked crosswalks involved 'multiple-threat' crashes (*1*)." Multiple-threat crashes occur on multi-lane roads when the pedestrian and/or driver's line of sight is blocked by a driver yielding to the pedestrian in an adjacent lane.

RESULTS

This section presents general characteristics and the statistical analysis results for behavior observations at a representative sample of two study sites, followed by a summary of the overall trends identified across the six observation sites. The two sites were selected for this paper to provide a comparison of our results for a two lane and multi-lane location. The multi-lane site presented here yielded the most robust results across the observation variables. Reported p-values are for the statistical test of each variable (age, sex, etc.) in marked versus unmarked crosswalks.

Site 1: Cedar St. and Walnut St., Berkeley

Site Characteristics:

- Number of Lanes Main Road (Cedar): 2
- Peak Pedestrian Volume: 19 pedestrians/hour (marked), 4 pedestrians/hour (unmarked)
- Surrounding Land Uses: Mostly residential and churches with restaurants, a grocery store, and a pharmacy within 1 block
- Speed Limit Main Road (Cedar): 25 MPH
- Distance from Nearest Traffic Signal: 1 block (320 feet) on Main Road
- Note: Cedar is on a slight grade, sloping downhill from east to west. This topography may affect driver and pedestrian behavior.

Descriptive Statistics:

TABLE 2 Pedestrian Characteristics by Crosswalk Type, Cedar and Walnut

	Unmarked n (column %)	**Marked** n (column %)	**Total** N (column %)	***p*-value**
Pedestrians	206	639	845	
Age				0.9094
Child	0 (0.0)	1 (0.2)	1 (0.1)	
Teen	1 (0.5)	6 (0.9)	7 (0.8)	
Young adult	89 (43.6)	291 (45.7)	380 (45.2)	
Older adult	97 (47.5)	292 (45.8)	389 (46.3)	
Elderly	17 (8.3)	47 (7.4)	64 (7.6)	
Sex				0.0451
Male	109 (52.9)	286 (44.9)	395 (46.9)	
Female	97 (47.1)	351 (55.1)	448 (53.1)	

Analysis Results:

TABLE 3 Pedestrian and Driver Behavior by Crosswalk Type, Cedar and Walnut

	Unmarked n (column %)	**Marked** n (column %)	**Total** N (column %)	***p*-value**
Pedestrian Behavior				
Waiting Location/ Behavior				0.1977
Waited on curb	77 (37.7)	209 (33.0)	286 (34.1)	
Waited on street	56 (27.5)	222 (35.0)	278 (33.2)	
Did not wait	71 (34.8)	201 (31.7)	272 (32.5)	
Forced driver to yield	0 (0.0)	2 (0.3)	2 (0.2)	
Looking				0.3166
Didn't look	4 (2.0)	13 (2.1)	17 (2.0)	
Looked one way	34 (17.0)	126 (20.0)	160 (19.3)	
Looked both ways	127 (63.5)	413 (65.5)	540 (65.0)	
Looked more than 2 times	35 (17.5)	79 (12.5)	114 (13.7)	
Pace				0.0003
Slow	1 (0.5)	1 (0.2)	2 (0.2)	
Normal	177 (85.9)	586 (92.0)	763 (90.5)	
Fast	5 (2.4)	13 (2.0)	18 (2.1)	
Ran	23 (11.2)	37 (5.8)	60 (7.1)	

Driver Behavior / Traffic	**Unmarked**	**Marked**	**Total**	***p*-value**
Average gap acceptance (lanes)	1.1	0.9	1.0	0.0005
Average number of immediate yields (drivers)	0.4	0.7	0.6	<0.0001
Average vehicle exposure (pedestrians)	1.4	1.4	1.4	0.5381

Summary of Statistically Significant Findings, Cedar and Walnut:

- Pedestrians in the marked crosswalk were more likely than pedestrians in the unmarked crosswalk to be female.
- Pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to run when crossing.
- Pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to wait for larger gaps in traffic before crossing.
- Pedestrians in the marked crosswalk were more likely than pedestrians in the unmarked crosswalk to have drivers immediately yield the right-of-way to them.

Site 2: International Blvd. and 37th Ave., Oakland

Site Characteristics:

- Number of Lanes Main Road (International): 5
- 2-Way Traffic Volume Main Road (International): 30,000/day
- Peak Pedestrian Volume: 30 pedestrians/hour (marked), 4 pedestrians/hour (unmarked)
- Surrounding Land Uses: Restaurants, Nail Salon, Apartments, Clothing Stores
- Speed Limit Main Road (International): 30 MPH
- Distance from Nearest Traffic Signal: 1 Block (320 feet) on Main Road
- Notes:
  - There was a large sample size for this site, making the analysis particularly robust
  - This site is in a low-income neighborhood with a large Hispanic population, and pedestrians and drivers in this area may have different characteristics and cultural norms than those observed at other study locations

Descriptive Statistics:

TABLE 4 Pedestrian Characteristics by Crosswalk Type, International and 37th

	Unmarked n (column %)	**Marked** n (column %)	**Total** N (column %)	***p*-value**
Pedestrians	186	153	339	
Age				0.0004
Child	0 (0.0)	0 (0.0)	0 (0.0)	
Teen	29 (15.6)	6 (3.9)	35 (10.3)	
Young adult	72 (38.7)	78 (51.0)	150 (44.2)	
Older adult	85 (45.7)	67 (43.8)	152 (44.8)	
Elderly	0 (0.0)	2 (1.3)	2 (0.6)	
Sex				<0.0001
Male	148 (80.0)	80 (52.3)	228 (67.5)	
Female	37 (20.0)	73 (47.7)	110 (32.5)	

Analysis Results:

TABLE 5 Pedestrian and Driver Behavior by Crosswalk Type, International and 37th

	Unmarked N (column %)	**Marked** n (column %)	**Total** (N column %)	***p*-value**
Pedestrian Behavior				
Waiting Location/ Behavior				0.0283
Waited on curb	25 (14.0)	38 (25.0)	63 (19.1)	
Waited on street	97 (54.5)	67 (44.1)	164 (49.7)	
Did not wait	56 (31.5)	46 (30.3)	102 (30.9)	
Forced driver to yield	0 (0.0)	1 (0.7)	1 (0.3)	
Looking				<0.0001
Didn't look	0 (0.0)	4 (2.6)	4 (1.2)	
Looked one way	72 (40.9)	110 (72.4)	182 (55.5)	
Looked both ways	104 (59.1)	38 (25.0)	142 (43.3)	
Pace				<0.0001
Slow	5 (2.7)	1 (0.7)	6 (1.8)	
Normal	98 (52.7)	137 (89.5)	235 (69.3)	
Fast	13 (7.0)	9 (5.9)	22 (6.5)	
Ran	70 (37.6)	6 (3.9)	76 (22.4)	

	Unmarked N (column %)	Marked n (column %)	Total (N column %)	***p*-value**
Driver Behavior / Traffic				
Multiple Threat				
First ½ of crossing pair				0.0211
No	176 (94.6)	134 (87.6)	310 (91.4)	
Yes	10 (5.4)	19 (12.4)	29 (8.6)	
Second ½ of crossing pair				<0.0001
No	154 (82.8)	96 (62.8)	250 (73.7)	
Yes	32 (17.2)	57 (37.3)	89 (26.3)	

	Unmarked	**Marked**	**Total**	***p*-value**
Average gap acceptance (lanes)	3.4	2.7	3.1	<0.0001
Average number of immediate yields (drivers)	0.9	1.6	1.2	<0.0001
Average vehicle exposure (pedestrians)	2.7	3.5	3.1	0.0174

Summary of Statistically Significant Findings, International and 37th:

- Pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to be teens, while pedestrians in the marked crosswalk were more likely than pedestrians in the unmarked crosswalk to be young adults or elderly.
- Pedestrians in the marked crosswalk were more likely than pedestrians in the unmarked crosswalk to be female.
- Pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to be assertive, waiting in the street instead of on the curb before crossing.
- Pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to look both ways before crossing.
- Pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to run when crossing.
- Pedestrians in the marked crosswalk, in both the first and second halves of their crossings, were more likely than pedestrians in the unmarked crosswalk to be involved in potential multiple threat scenarios.
- Pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to wait for larger gaps in traffic before crossing.
- Pedestrians in the marked crosswalk were more likely than pedestrians in the unmarked crosswalk to have drivers immediately yield the right-of-way to them.
- Pedestrians in the marked crosswalk had a higher exposure to vehicles when crossing than pedestrians in the unmarked crosswalk.

Summary of Statistically Significant Results Across All Study Locations

Several overall trends are evident from the study's comparison of pedestrian and driver behavior at six uncontrolled, matched pair intersections. These trends are summarized in Table 6 and discussed in detail below.

Age

Age was a statistically significant variable at the International Blvd. and 37th Ave. observation site. The large sample size at this location in comparison to other observation sites may have contributed to this result. At this intersection, pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to be teens, while pedestrians in the marked crosswalk were more likely than pedestrians in the unmarked crosswalk to be young adults or elderly.

Gender

Gender was a statistically significant variable at three of the observation sites, including both sites with five lanes and no median refuge. At all three locations, pedestrians in the marked crosswalk were more likely than pedestrians in the unmarked crosswalk to be female.

Waiting Behavior

Pedestrian waiting behavior was a statistically significant variable only at the International Blvd. and 37th Ave. observation site. As with pedestrian age, the large sample size at this location may have contributed to this result. Assertive crossing behavior may also be associated with the socio-economic or cultural norms of pedestrians at this location. At this intersection, pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to be assertive, waiting in the street instead of on the curb before crossing.

Looking Behavior

Pedestrian looking behavior was a statistically significant variable at the 16th and Capp and International Blvd. and 37th Ave. observation sites. At both locations pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to look both ways before crossing. Both sites are multi-lane roads with no median refuge.

Pace

Pedestrian pace (walking speed) was a statistically significant variable at four of the observation sites. At all four locations, pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to run when crossing. This finding was consistent across all road types.

Gap Acceptance

Average gap acceptance was a statistically significant variable at five of the observation sites. At all five locations, pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to wait for larger gaps in traffic before crossing. This finding was consistent across all road types.

TABLE 6 Summary of Analysis Results – Unmarked Crosswalks Compared to Marked Crosswalks

Intersection		Cedar/ Walnut	16th/ Capp	Sacramento/ Blake	University/ Walnut	International/ 37th	Telegraph/ 41st
Lanes		2	3	4	4	5	5
Speed Limit		25 MPH	25 MPH	30 MPH	25 MPH	30 MPH	25 MPH
Hourly Pedestrian Volume (Unmarked/Marked)		4/19	8/29	2/3	5/32	4/30	4/20
Median		None	None	Grass Median	Concrete Median	None	None
Number of Observations (Unmarked/Marked)		206/639	70/383	84/150	61/712	186/153	38/536
Factors	**Age**					More Teens	
	Gender	More Males				More Males	More Males
	Waiting					More Assertive	
	Looking		More Looking			More Looking	
	Pace	Faster Pace			Faster Pace	Faster Pace	Faster Pace
	Gap	More Gaps	More Gaps		More Gaps	More Gaps	More Gaps
	Yield	Less Yielding	Less Yielding	Less Yielding	Less Yielding	Less Yielding	Less Yielding
	Exposure		Fewer Vehicles Encountered			Fewer Vehicles Encountered	
	Multiple Threat	N/A		Lower Threat	Lower Threat	Lower Threat	

Driver Yielding

Driver yielding behavior was a statistically significant variable at all six observation sites. For all road types, pedestrians in the marked crosswalk were more likely than pedestrians in the unmarked crosswalk to have drivers immediately yield the right-of-way to them.

Pedestrian Exposure

Average pedestrian exposure to vehicles was a statistically significant variable at two of the observation sites. At both locations, pedestrians in the marked crosswalk had a higher exposure to vehicles when crossing than pedestrians in the unmarked crosswalk. Both sites are multi-lane roads with no median refuge.

Multiple Threat

The incidence of multiple threat opportunities was a statistically significant variable at three of the five multi-lane observation sites, including three of the four sites with four or more lanes, and both sites with median refuges. The small sample size at Telegraph and 41st Street may be associated with the lack of statistical significance at this location, as a similar trend is present.

At all three locations, pedestrians in the marked crosswalk were more likely than pedestrians in the unmarked crosswalk to be involved in a potential multiple threat scenario.

Discussion and Interpretation of Findings

Unlike previous behavioral studies, differences in pedestrian behavior in this study suggest pedestrians exhibit a greater level of caution (looking both ways, waiting for gaps in traffic, and hurrying across the street) when crossing in unmarked crosswalks than in marked crosswalks. This finding is particularly robust in terms of pace and gap acceptance, although it is also evident regarding looking behavior; whereas previous studies on two- and three-lane roads found looking behavior improved in marked crosswalks.

Also unlike previous studies which found no significant differences, results from this study suggest that drivers do yield more frequently to pedestrians in marked crosswalks compared to unmarked crosswalks.

These study results generally apply to two- and three-lane roads as well as four- and five-lane roads. However, the differences in marked versus unmarked crosswalks do appear more pronounced across several variables for multi-lane roads, with International and 37th being the most significant example. This finding is consistent with the 2001 FHWA study, which illustrated gradients in crash rate differences related to the number of lanes, with the difference in marked versus unmarked crosswalks becoming significant only for multi-lane roads (*1*). Also consistent with the FHWA study is the finding that potential multiple threat scenarios arise more commonly in marked crosswalks, a critical behavioral variable that has not been considered in the behavioral literature to date (*1*).

These observed behavioral differences, in combination with previously reported study findings regarding driver and pedestrian knowledge of right-of-way laws, represent "missing links" in the marked crosswalk debate and may help to explain the differences in crash risk in marked versus unmarked crosswalks on certain multi-lane roadways. Key insights include the following points:

1. Based on field observations, pedestrians in the marked crosswalk were more likely than pedestrians in the unmarked crosswalk to have drivers immediately yield the right-of-way to them. Additionally based on surveys and focus groups, drivers were likely to be confused regarding right-of-way laws at unmarked crosswalks. Thus, it seems reasonable that a lower driver yielding (motorist compliance) rate at unmarked crosswalks may be at least partially a result of a lack of knowledge of the pedestrian's right-of-way within unmarked crosswalks.
2. Based on surveys and focus groups, pedestrians were also likely to be confused regarding right-of-way laws at unmarked crosswalks. Taken in combination with the finding that pedestrians in the marked crosswalk were more likely than pedestrians in the unmarked crosswalk to have drivers immediately yield the right-of-way to them, it seems reasonable that pedestrians exhibit extraordinary caution in unmarked crosswalks because either (1) they do not know motorists must legally yield the right-of-way when they are crossing in unmarked and marked crosswalks, or (2) experience has taught them that drivers are not likely to yield, or a combination of both.
3. It is then also plausible that pedestrians exhibit ordinary (as opposed to extraordinary) caution when crossing in marked crosswalks for similar reasons: (1) they are more likely to know that drivers must yield the right-of-way to them, or (2) experience has taught them that drivers are more likely to yield, or a combination of both.

4. Another observed paradox is that the higher rate of yielding in marked crosswalks can result in an increased incidence of multiple threat crashes. However, this paradox may have a rational explanation. Even in marked crosswalks, motorist compliance (yielding) rates are not 100 percent, and thus a driver yielding in one lane does not assure a driver will yield in an adjacent lane. Further, the first driver is more likely to yield at a marked crosswalk than at an unmarked crosswalk. Therefore, it is reasonable that there is a greater risk that a pedestrian crossing in a marked crosswalk will be involved in a potential multiple threat scenario than a pedestrian crossing in an unmarked crosswalk, unless other needed treatments are implemented. For example, there may be a need to consider installing advance stop lines or yield lines with the sign "Stop Here (or Yield Here) for Pedestrians," improving nighttime lighting, installing traffic signals with pedestrian signals (if warranted), and/or installing raised median islands to provide a safer pedestrian crossing.

RECOMMENDATIONS

The results of this study should not be interpreted as justification to simply remove marked crosswalks or to fail to install marked crosswalks at appropriate pedestrian crossings. Such an approach does not address the safety and mobility needs of pedestrians.

Instead, these new insights underscore the need for a policy re-prioritization to embrace a broader range of countermeasure treatments and better address the role of human factors in pedestrian collisions. The following guidelines are illustrative components of a more balanced, "3-E" strategy to mitigate crash risk within crosswalks.

Engineering Countermeasures

Recognizing the limited funds available for engineering countermeasures and the significant number of potential implementation sites, there is a need for strategic planning to maximize the benefits of countermeasure deployment. It is recommended that system owners obtain a full inventory of "at risk" crosswalks using the Seattle model for strategic crosswalk safety planning (*10*). By developing a crosswalk inventory, system owners would then be able to prioritize locations for engineering countermeasure installation. At each of the identified treatment locations, appropriate engineering countermeasures should be selected from resources such as:

- *Guidelines on Improving Pedestrian Safety at Uncontrolled Crossings* (NCHRP/TCRP Report 562, 2006)
- *PEDSAFE Safety Guide and Countermeasure Selection System* (FHWA, 2002)
- *AASHTO Guidelines for Reducing Collisions Involving Pedestrians* (NCHRP Report 500, Vol. 10, 2004) (*6, 14, 15*).

A potential treatment for multi-lane roads is the new HAWK or "Pedestrian Beacon" technique that is under consideration in the next edition to the Manual on Uniform Traffic Control Devices (MUTCD). This traffic control device has been demonstrated as an effective treatment for reducing pedestrian collisions (*6*).

Education Countermeasures

Engineering countermeasures should be supplemented with education and enforcement at each of the treatment sites. Additionally, broader education and enforcement initiatives can be designed to address crosswalk safety at all locations, not just those prioritized for engineering countermeasure installation.

Specifically, installation of a sign encouraging pedestrians to make eye contact with drivers when crossing should be considered. The supplemental inclusion of this sign would serve to maintain the pedestrian's right-of-way but help pedestrians more accurately internalize the risk associated with crossing a roadway.

It is further suggested that a thorough review and revision of the pedestrian section of Driver's Handbooks be conducted to provide enhanced explanations of right-of-way laws and common risk scenarios. Sarkar, Van Houten, and Moffatt (1999) concluded that while state driver licensing manuals can play a key role in education, manuals need significant improvements. They note that better manuals, with "well-written, well-illustrated information on pedestrian conflicts associated with different traffic regulations" are increasingly important with the gradual phasing out of driver education in schools (*12*).

Finally, opportunities to educate non-driver pedestrians should be explored. A statewide pedestrian safety campaign is recommended to emphasize safe crossing practices (with a message similar to the classic advice of "Stop, Look Left, Look Right") regardless of crosswalk markings or treatments.

Enforcement Countermeasures

As with educational measures, it is important that enforcement measures target both pedestrians and drivers. Recommended innovative enforcement strategies that seek to enhance pedestrian and driver knowledge of and compliance with right-of-way laws include enforcement "stings," educational warnings in lieu of or in addition to fines, and community enforcement programs. In a study of an enforcement sting in Miami Beach, Florida, Van Houten and Malenfant (2004) found that "the percentage of drivers yielding to pedestrians increased following the introduction of the enforcement operation in each corridor (*13*)." They note, "These increases were sustained for a period of a year with minimal additional enforcement, and that the effects generalized to untreated crosswalks in both corridors as well as crosswalks with traffic signals (*13*)."

Sustained enforcement efforts can also serve as valuable educational campaigns by incorporating warnings, informational pamphlets, media coverage, and community involvement activities. In this way, road users may learn the right-of-way laws through enforcement of these laws.

Concluding Thoughts

Crosswalks at uncontrolled intersections are numerous and widespread. While engineering countermeasures offer significant potential for reducing pedestrian crash risk, not every intersection is in need of an engineering treatment. Prioritizing implementation of engineering countermeasures to the areas with the highest risk and potential for the greatest improvement represents the best use of limited resources. For the other portions of a roadway system, there is a need for a paradigm shift to include broader deployment of education and enforcement countermeasures. These treatments must supplement engineering treatments to provide pedestrian safety benefits for all and ensure walking is embraced as a legitimate and important transportation mode.

While the current study was able to address some of the gaps in the literature, there is still much to be learned regarding motorist and pedestrian interactions and safety. Further research is particularly needed to address the safety effects of many of the treatments that have been proposed for uncontrolled crossings.

It is recognized that the results of this study are based on a limited number of low speed intersections in the San Francisco Bay Area and may not necessarily represent conditions or pedestrian and motorist behaviors at other location conditions or in other parts of the U.S. It would be helpful for future research to continue to explore pedestrian and motorist conflicts and behaviors in uncontrolled pedestrian crossings under a wide range of traffic and roadway conditions.

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