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ABSTRACT

For more than thirty years, pedestrian safety studies have considered pedestrian-vehicle collision patterns and pedestrian and driver behavior at marked and unmarked crosswalks at uncontrolled crossings. Recent research in this area conducted by the UC Berkeley Traffic Safety Center on behalf of Caltrans, and summarized in a 2008 *Transportation Research Record* paper by Mitman et al., "The Marked Crosswalk Dilemma: Uncovering Some Missing Links in a 35-Year Debate," was designed to fill key gaps in the literature by analyzing driver/pedestrian behavior and knowledge of right-of-way laws regarding marked and unmarked crosswalks.

The Caltrans study, as with most previous crosswalk studies, focused on urban and suburban areas (in this case the San Francisco Bay Area), where the driver and pedestrian characteristics do not change significantly from day to day. Following this study was the recognition that similar research was needed in rural/recreational locations where the population frequently changes. As such, this paper summarizes results from field observations of driver and pedestrian behavior at marked and unmarked crosswalks at uncontrolled crossings during the summer in the Tahoe Basin of California.

This study, also funded by Caltrans, concludes that the behavior trends identified in the urban/suburban Bay Area study are largely similar in a rural/recreational context. This finding is significant for Caltrans, a statewide agency that is seeking to provide a consistent crosswalk installation/ treatment policy for its facilities across California. Other regional and state agencies may similarly benefit from this study.

INTRODUCTION

In 2007 over 74,000 pedestrians were injured or killed in the United States (*1*). While the majority of pedestrian-vehicle collisions occur in urban areas, the National Highway Traffic Safety Administration (NHTSA) reports that in 2007, 27% of all pedestrian fatalities occurred in rural areas (areas with low population densities).

For more than thirty years, pedestrian safety studies have considered pedestrian-vehicle collision history and pedestrian and driver behavior at marked and unmarked crosswalks at uncontrolled crossings. However, most of the studies have focused on urban or suburban areas where the driver characteristics do not change significantly from day to day. The focus area for this study, California's Tahoe Basin, is recreational and rural in nature and driver and pedestrian characteristics change due to the many tourists that frequent the area.

As much of the California State Highway System traverses rural and/or recreation areas, the findings from this pedestrian safety study may be beneficial for Caltrans, as well as other state transportation agencies. The results of this study may inform district decisions on the installation of marked crosswalks/ enhancements (based on pedestrian and driver behavior), and help the public understand why a location is suitable or not for a marked crosswalk/ enhancements.

BACKGROUND

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

Collision Trends Research

Significant research on the safety impacts of marked and unmarked crosswalks provides an important background for this study. Herms'1972 study in San Diego found that marked crosswalks were the sites of twice as many pedestrian-vehicle collisions as unmarked crosswalks, controlling for pedestrian volume (*2*). Several other studies found similar results (Gibby, 1994), but their methodologies, as with the Herms' study, have been criticized based on their data collection, variable inclusion/exclusion, or statistical analysis methodologies (Campbell, 1997) (*3, 4*).

A more comprehensive study conducted by Zegeer et al. in 2001 for the Federal Highway Administration (FHWA) analyzed five years of pedestrian-vehicle collisions at 1,000 marked crosswalks and 1,000 matched unmarked comparison sites in 30 U.S. cities (*5*). 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 rates 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 (*5*).

Given the need to do more than just paint white lines to ensure pedestrian safety in some cases, a 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 were recommended 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

Research regarding pedestrian behavior in crosswalks has largely centered on 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 (*2*).

Although this hypothesis is often cited as a reason to remove or fail to provide marked crosswalks, Knoblauch et al. (2001) and Nitzburg (2001) statistically measured the effects of crosswalk markings on driver and pedestrian behavior at uncontrolled intersections on two- and three-lane roads and found no evidence of this (*7, 8*). Both researchers 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, 1997) have also found that pedestrian behavior improves in well-marked crosswalks compared to unmarked or poorly marked crosswalks (*9*).

Fewer studies of driver behavior are available in the literature, 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, with drivers yielding less frequently to pedestrians at night. 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. Drivers yielded to pedestrians more frequently in the second half and fewer pedestrians stayed within the marked crosswalk (in the "magnet study") in the second half of the crosswalk (*8*).

Mitman et al. (2007 and 2008), recently studied driver/pedestrian behavior and knowledge of right-of-way laws regarding marked and unmarked crosswalks in the San Francisco Bay Area. The study included a specific focus on driver and pedestrian behavior in multiple threat scenarios, the most common crash type for multi-lane roads. Findings from the behavior study revealed that (a) pedestrians exhibit a more intense measure of caution when crossing at unmarked crosswalks as compared to marked crosswalks; (b) drivers are more likely to yield to pedestrians at marked crosswalks rather than at unmarked crosswalks; and (c) multiple threat scenarios arise most frequently at marked crosswalks (*10*). The knowledge of right-of-way laws study found that both pedestrians and drivers lack an accurate knowledge of pedestrian right-of-way laws. This lack of knowledge is exacerbated with unmarked crosswalks, where a majority of drivers and pedestrians did not have an accurate understanding of the law (that is, in both marked and unmarked crosswalks, drivers must yield the right-of-way to pedestrians) (*11*).

Rural Areas Research

In the studies cited above, all data were collected from urban and/or suburban locations within the U.S. Current pedestrian research in rural areas is limited, and is largely based on analysis of collision data to determine contributing factors.

In 2000, Ivan et al., analyzed roadway and area type features from pedestrian-vehicle collision data in rural Maine to determine which variables were of the greatest significance to pedestrian crashes. Variables considered included crosswalk marking, signals, central barrels/cones, speed, and number of lanes. Ivan compared the number of model-predicted crashes at study locations to actual crash numbers. Overall the study found the safest crossing type is the unsignalized, unmarked, low-speed crossing (*12*).

In 2004, Hall et al. published an FHWA study of pedestrian collision data in rural areas. Major characteristics of rural pedestrian fatalities and overall crashes were identified, as were possible countermeasures. The goal of the research was to identify the characteristics of rural pedestrian fatalities in ten states with above-average rates of rural pedestrian fatalities. The most prominent characteristics of rural pedestrian fatalities in these states were clear weather, hours of darkness, weekends, non-intersection locations, and level, straight roads (*13*). However, Hall did not consider crosswalk type or other intersection geometry in this research.

Hall also examined all rural pedestrian collisions in New Mexico for a three-year period. Safety recommendations included improved visibility and a selected application of pedestrian amenities such as walkways, crosswalks, and warning signs.

No papers were identified on the topic of pedestrian and driver behavior within crosswalks on rural roads or within recreation areas.

This Study's Contribution

This paper summarizes results from field observations of driver and pedestrian behavior at marked and unmarked crosswalks on two-, three-, and four-lane rural roads in a recreational setting and interprets these results in light of the previously reported findings by Mitman et al. for the San Francisco Bay Area.

METHODS

Building on the prior behavioral research by Knoblauch (2001) and recent methodologies used in UC Berkeley Traffic Safety Center research, this study focused on roads with two, three, and four-lane cross-sections. Utilizing a matched pair approach, driver and pedestrian behavior within marked and unmarked crosswalks at intersections with similar characteristics were compared.

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

- One matched pair of marked/unmarked crossings on a two-lane rural highway.

- One matched pair of marked/unmarked crossings on a three-lane rural highway.
- One matched pair of marked/unmarked crossings on a four-lane rural highway – for this pair two marked crosswalk locations were studied: one on the edge of a town where drivers may not expect pedestrians, and another in the center of town where drivers are accustomed to pedestrian activity and may behave differently.
- One matched pair of marked/unmarked crossings at a "mid-block" location on a two-lane rural highway. These locations provided data about pedestrian and driver behavior in remote, recreational settings. A Class I (separated) multi-use path crosses the roadway in both areas. This comparison also evaluates the effectiveness of the enhanced treatment provided at the marked crosswalk (with flashing LED signs, advanced yield lines, and advanced beacons).

Previous studies have noted that driver yielding is related to vehicle speeds. All matched pair observation locations had similar speed limits in an effort to reduce potential yielding behavior discrepancies based on speed. Table 1 presents the observation sites by major road type. All nine sites are located in the North Lake Tahoe Basin, California.

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

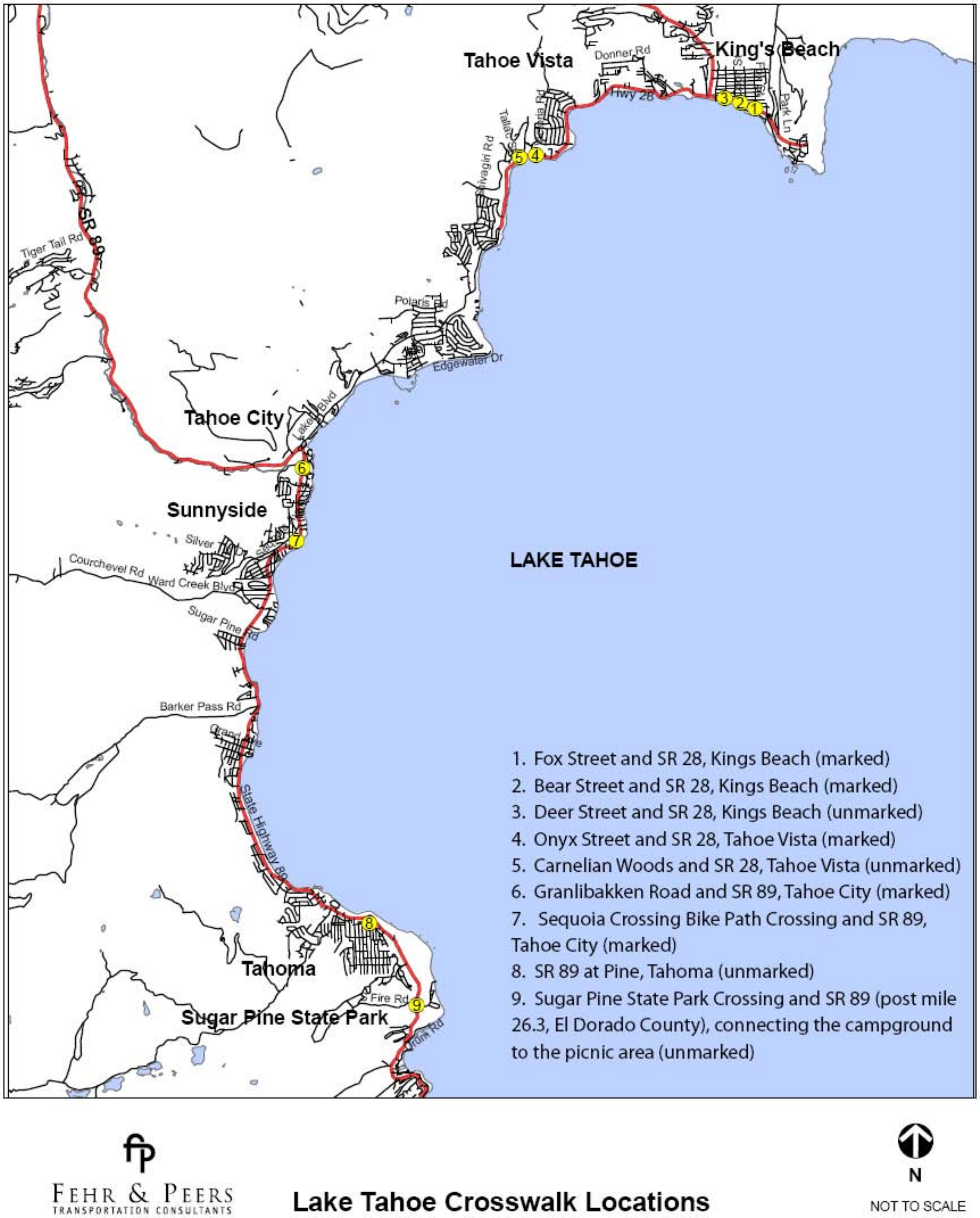
- Whether pedestrians use more, less, or the same amount of caution when crossing at a marked crosswalk (as compared to an unmarked crosswalk) — by recording the pedestrian's "looking behavior", gap acceptance, and level of assertiveness when using a marked versus unmarked crosswalk.
- Whether the age or gender of the pedestrian are associated with the use of marked versus unmarked crosswalks — 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.

TABLE 1. FIELD OBSERVATION SITES

Location	Number of Lanes	Marked/ Unmarked Crosswalk	Speed Limit	Estimated Pedestrian Volume (hour)
Fox Street and SR 28, Kings Beach	4	Marked	30	48
Bear Street and SR 28, Kings Beach	4	Marked	30	96
Deer Street and SR 28, Kings Beach	4	Unmarked	30	24
Onyx Street and SR 28, Tahoe Vista	3	Marked	45	2
Carnelian Woods and SR 28, Tahoe Vista	3	Unmarked	45	6
Granlibakken Road and SR 89, Tahoe City	2	Marked	35	2
Sequoia Crossing and SR 89, Tahoe City	2 midblock	Marked	35	52
SR 89 at Pine Street, Tahoma	2	Unmarked	35	18
Sugar Pine State Park Crossing and SR 89	2 midblock	Unmarked	40	2

Notes: Pedestrian volumes estimated from 15 minute counts. SR 28 AADT: 13,000. SR 89 AADT: 16,000.

FIGURE 1. STUDY AREA LOCATIONS



One of the mid-block study locations was a multi-use trail crossing used by both bicyclists and pedestrians. Data were collected for both user groups at this location.

Field Observation Sites

All observation sites were located along North Lake Boulevard/State Route 28 and West Lake Boulevard/State Route 89, a rural highway that runs along the northwest shore of Lake Tahoe. Figure 1 shows a map of the study area. Table 1 lists key attributes of each site. A more detailed description of each site follows.

1. **Fox Street and SR 28, Kings Beach –** This intersection has the first marked crosswalk in Kings Beach, California that drivers encounter when approaching from the Nevada side of Lake Tahoe. This three-legged, side-street stop controlled intersection has a marked crosswalk (ladder) on the east side of SR 28. In this location SR 28 has four lanes and a speed limit of 30 MPH. Area destinations include several shops, restaurants, and a movie theater. Signage and an (informal) pedestrian flag program have been installed at this crosswalk due to ongoing yielding issues. However, no pedestrians were observed using the flags. Pedestrian volumes are higher at this location than at most other study locations.

2. **Bear Street and SR 28, Kings Beach –** This intersection is centrally located in downtown Kings Beach, approximately a quarter mile west of the Fox Street/SR 28 intersection. This location provides direct access to the Kings Beach State Park, parking lot, and weekly farmers' market. This site has similar attributes to the Fox Street/SR 28 intersection (four travel lanes, marked crosswalk, side-street stop control, speed limit of 30 MPH), and was chosen to compare and contrast driver and pedestrian behavior at a peripheral/unexpected location to a more centralized/expected crossing location. A marked (continental) crosswalk is located on the west approach of SR 28. Motorists' failing to yield to pedestrians has been an issue at this intersection. Signage and an (informal) pedestrian flag program have been installed at this crosswalk. However, very few pedestrians used the flags during the observations for this study. Bear Street/SR 28 is estimated to have the highest pedestrian volumes of all the study locations.

3. **Deer Street and SR 28, Kings Beach –** The third location in Kings Beach is located approximately 700 feet west of the Bear Street/SR 28 site, at the western edge of town. SR 28 has four travel lanes at this location. The intersection is side-street stop controlled and does not have a marked crosswalk across SR 28. This area has lower pedestrian volumes than the other Kings Beach locations. Area destinations include motels, shops, and restaurants.

4. **Onyx Street and SR 28, Tahoe Vista –** This location is a four-legged intersection and is side-street stop controlled. SR 28 has three lanes (two travel lanes and a center turn lane), and sidewalks on the north and south sides. A crosswalk is striped (continental) on the east approach of SR 28, connecting to a walking path that accesses the Lake Tahoe shoreline. Area destinations include public lake access, Placer County Health and Human Services, and a mini-golf course. The posted speed limit is 45 MPH.

5. **Carnelian Woods Avenue and SR 28, Tahoe Vista –** This site was chosen as the matched pair to the Onyx Street/SR 28 location, which is 400 feet to the east. Carnelian Woods

Avenue/SR 28 is a three-legged intersection and is side-street stop controlled. Area destinations include a marina and mini-golf course. The posted speed limit is 45 MPH.

6. **Granlibakken Road and SR 89, Tahoe City –** Granlibakken Road/SR 89 is on the south side of Tahoe City, a popular tourist town on Lake Tahoe. SR 89 is a two-lane road in this area. The intersection has three legs and is side-street stop controlled. A class I multi-use trail runs parallel to SR 89 and crosses the road at this intersection. A marked crosswalk has been striped (continental) across Granlibakken Road and the northern approach of SR 89. Area destinations include shops and residential neighborhoods, although this location is outside the downtown area of Tahoe City and has low pedestrian volumes. The posted speed limit on SR 89 is 35 MPH.

7. **Sequoia Crossing and SR 89, Tahoe City –** This "mid-block" location is a Class I multi-use trail crossing on SR 89, and is only accessed by pedestrians and bicyclists using the trail. Caltrans has significantly enhanced the crossing with an advanced flashing beacon, yield to pedestrians signage, advanced yield limit lines, camera-actuated flashing LED crosswalk signage, and continental crosswalk striping. SR 89 is a two-lane road in this area, and sight distances to the crossing are limited. The posted speed limit in this area is 35 MPH.

8. **SR 89 at Pine Street, Tahoma –** SR 89 is a typical two-lane rural road in this location. The four-way intersection with Pine Street is side-street stop controlled with an unmarked crosswalk. Area destinations include lake access, local shops and restaurants and residential neighborhoods. The posted speed limit in this area is 35 MPH.

9. **Sugar Pine State Park Crossing and SR 89 –** This site was chosen as the second "mid-block" crossing, and is located at the main entrance to Sugar Pine Point State Park on SR 89 in Tahoma, California. The three-way intersection is side-street stop controlled, and the speed limit on SR 89 is 40 MPH. A Class I multi-use path runs parallel to SR 89 and crosses the road in this location. Pedestrians are recreational users of the state park and cross SR 89 to access the Lake Tahoe waterfront to the east.

DATA COLLECTION

Data collection occurred during daylight hours on non-rainy days in June 2008. As the Lake Tahoe area is a popular tourist destination, data were collected during the weekday and on weekends to record pedestrian behavior from both local residents and tourists that may have varying degrees of familiarity with local traffic patterns. As pedestrian volumes varied depending on the study location, certain locations were observed for a longer period to capture a consistent number of pedestrian crossing occurrences.

Based on prior UC Berkeley Traffic Safety Center studies, clipboard-based (manual) data collection was selected as the best method for the purposes of this study. Observers included planning and engineering consultants from Fehr & Peers, as well as paid graduate students from the University of Nevada – Reno who completed a full-day training tailored to this project. The training included one-on-one observation by the trainers and cross-comparisons/group discussions of observations across data collectors to provide consistency.

The graduate students entered their data into the database, with each students performing cross-check quality control for all data entry.

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 with five comparison tests (matched pairs). These comparisons were 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. The Fisher's Exact Test is used for categorical data with small, sparse, or unbalanced data. It assumes a hypergeometric distribution.

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

- 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 total number of gaps for pedestrians in marked versus unmarked crosswalks was compared in the statistical analysis for each site.
- 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 number of immediate yields 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. 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 an excerpt from the statistical analysis results for marked versus unmarked crosswalk comparisons. Reported p-values are for the statistical test of each variable (age, sex, etc.) in the marked versus unmarked crosswalk. A discussion of overall trends across all analysis locations follows the Bear Street/ Deer Street excerpt.

Comparison Excerpt: Bear Street (marked) versus Deer Street (unmarked)

Descriptive Statistics:

TABLE 2. PEDESTRIAN AND DRIVER BEHAVIOR BY CROSSWALK TYPE: BEAR VERSUS DEER

Observation Variable	Bear (Marked) n (column %)	Deer (Unmarked) n (column %)	Total N (column %)	*p*-value
Pedestrians	278	286	564	
Age				Fisher's Exact Test (p<0.001)
Child	4 (1.44)	4 (1.44)	8 (1.42)	
Teen	12 (4.32)	28 (9.79)	40 (7.09)	
Young adult	146 (52.52)	136 (47.55)	282 (50.00)	
Older adult	99 (35.61)	116 (40.56)	215 (38.12)	
Elderly	17 (6.12)	1 (0.35)	18 (3.19)	
Not recorded	0 (0.00)	1 (0.35)	1 (0.18)	
Sex				Fisher's Exact Test (p<0.001)
Male	127 (45.68)	199 (69.58)	326 (57.80)	
Female	151 (54.32)	86 (30.07)	237 (42.02)	
Not recorded	0 (0.00)	1 (0.35)	1 (0.18)	

Analysis Results:

TABLE 3. PEDESTRIAN AND DRIVER BEHAVIOR BY CROSSWALK TYPE, BEAR VERSUS DEER

Observation Variable	Bear (Marked) n (column %)	Deer (Unmarked) N (column %)	Total N (column %)	p-value
Pedestrian Assertiveness				Fisher's Exact Test (p=0.2632)
Waited on curb	61 (21.94)	79 (27.62)	140 (24.82)	
Waited on street	144 (51.8)	127 (44.41)	271 (48.05)	
Did not wait	72 (25.9)	78 (27.27)	150 (26.6)	
Forced driver to yield	1 (0.36)	1 (0.35)	2 (0.35)	
Not recorded	0 (0.00)	1 (0.35)	1 (0.18)	
Pedestrian Looking				Fisher's Exact Test (p<0.0001)
Didn't look	1 (0.36)	1 (0.35)	2 (0.35)	
Looked one way	51 (18.35)	3 (1.05)	54 (9.57)	
Looked both ways	218 (78.42)	207 (72.38)	425 (75.35)	
Looked more than 2 times	5 (1.8)	74 (25.87)	79 (14.01)	
Not recorded	3 (1.08)	1 (0.35)	4 (0.71)	

Observation Variable	Bear (Marked) n (column %)	Deer (Unmarked) N (column %)	Total N (column %)	p-value
Pedestrian Pace				Fisher's Exact Test (p<0.001)
Slow	5 (1.8)	0 (0)	5 (1.8)	
Normal	230 (82.73)	96 (33.57)	326 (116.3)	
Fast	11 (3.96)	36 (12.59)	47 (16.55)	
Ran	18 (6.47)	124 (43.36)	142 (49.83)	
Not recorded	14 (5.04)	29 (10.14)	43 (15.18)	
Driver Behavior / Traffic				
Total Vehicle Exposure	288	276	564	
Lane Gaps				Chi square (p<0.0001)
0	32 (11.51)	1 (0.35)	33 (5.83)	
1	63 (22.66)	2 (0.69)	65 (11.48)	
2	85 (30.58)	16 (5.56)	101 (17.84)	
3	61 (21.94)	49 (17.01)	110 (38.95)	
4	37 (13.31)	220 (76.39)	257 (19.43)	
Immediate Yields				Chi square (p<0.0001)
0	38 (13.67)	229 (79.51)	267 (47.17)	
1	68 (24.46)	42 (14.58)	110 (19.43)	
2	94 (33.81)	15 (5.21)	109 (19.26)	
3	51 (18.35)	1 (0.35)	52 (9.19)	
4	27 (9.71)	1 (0.35)	28 (4.95)	
Multiple Threat Scenarios				Chi square (p=0.214)
0	265 (95.32)	284 (98.61)	549 (97.86)	
1	8 (2.90)	4 (1.39)	12 (2.14)	

Summary of Statistically Significant Findings, Bear versus Deer:

- Pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to be teens.
- Pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to be male.
- 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 to be assertive than pedestrians in the marked crosswalk

- Pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to look two or more times.
- 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 unmarked crosswalk were less likely than pedestrians in the unmarked crosswalk to have drivers immediately yield the right-of-way to them.

Overall Results

Several overall trends are evident from the study's comparison of pedestrian and driver behavior at nine uncontrolled crosswalks. These trends are summarized in Table 4 and discussed in detail below.

Age

Age was a statistically significant variable for the Fox/Deer, Bear/Deer, Pine/Granlibakken, and Sequoia/Sugar Pine pairs. In all but the Sequoia/Sugar Pine case, pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to be teens or young adults, while pedestrians in the marked crosswalk were more likely than pedestrians in the unmarked crosswalk to be children or elderly. The pattern was different at Sequoia/Sugar Pine, but the different land uses at these sites (the Sugar Pine crossing connects a campground to the Lake while the Sequoia crossing is away from major destinations) may partially account for the difference in age groups using marked versus unmarked crosswalks.

Gender

Gender was a statistically significant variable for all but the Onyx/Carnelian comparison. For the four comparisons where it was statistically significant, pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to be male.

Assertiveness

Pedestrian assertiveness was a statistically significant variable for the Onyx/Carnelian, Pine/Granlibakken, and Sequoia/Sugar Pine comparisons. For these comparisons, 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 for all but the Onyx/Carnelian comparison. For the four comparisons where it was statistically significant, pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to look more than twice before crossing.

Pace

Pedestrian pace (walking speed) was a statistically significant variable for all five comparisons. At the three locations where a clear pattern is discernable (Fox/Deer, Bear/Deer, and Onyx/Carnelian), pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to run when crossing.

Gap Acceptance

Gap acceptance was a statistically significant variable for all five comparisons. For all comparisons, pedestrians in the unmarked crosswalk were more likely than pedestrians in the marked crosswalk to wait for larger gaps in traffic before crossing.

Driver Yielding

Driver yielding behavior (immediate yielding) was a statistically significant variable for all five comparisons. In all cases, drivers at unmarked crosswalk locations were less likely than drivers at marked crosswalk locations to yield the right-of-way to pedestrians.

Multiple Threat

The incidence of multiple threat opportunities was a not a statistically significant variable for either of the two four-lane comparisons. For both comparisons, pedestrians in the marked crosswalks were involved in a potential multiple threat scenario more often than pedestrians in the unmarked crosswalk. However, this is not a statistically significant finding. The low traffic volumes may be associated with the lack of statistical significance, with a longer observation period potentially reaching statistical significance.

Table 4 presents a summary of the above findings. The shaded cells indicate the statistically significant results, presented as the more likely behavior.

TABLE 4 SUMMARY OF ANALYSIS RESULTS – UNMARKED CROSSWALKS COMPARED TO MARKED CROSSWALKS

Comparison (marked/unmarked)		Fox/ Deer	Bear/Deer	Onyx/ Carnelian Woods	Granlibakken/ Pine	Sequoia/ Sugar Pine[1]
Lanes		4	4	3	2	2 (midblock)
Speed Limit		30 MPH	30 MPH	45 MPH	35 MPH	35 MPH/ 40 MPH
Estimated Hourly Pedestrian Volume		50/25	100/25	5/10	5/20	55/5
Number of Pedestrian Observations		276/286	278/286	248/232	227/177	346/259
Factors	**Age**	More Young Adults	More Teens		More Young Adults	(excluded)
	Gender	More Males	More Males		More Males	More Males
	Assertiveness			More Assertive	More Assertive	More Assertive
	Looking	More Looking	More Looking		More Looking	More Looking
	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

1 This comparison includes enhanced treatments (LED signs, advanced yield lines, and advanced flashing beacons)

Discussion and Interpretation of Findings

The overall trends generally apply the observed crosswalks on the two- and three-lane roads as well as on the four-lane roads. They also apply to the midblock crossings. However, the differences in marked versus unmarked crosswalks do illustrate that a faster crossing pace is more associated with the multi-lane unmarked crossing than the two- and three-lane unmarked crossings. Assertiveness is greater for the two- and three-lane unmarked crossings than the multi-lane unmarked crossing.

As with the previous crosswalk study in the San Francisco Bay Area, differences in pedestrian behavior in this study suggest pedestrians exhibit an enhanced level of caution (looking more than two ways, waiting for gaps in traffic, and hurrying across the street) when crossing in unmarked crosswalks compared to crossing in marked crosswalks. This finding is particularly robust in terms of looking behavior and gap acceptance, although it is also evident for pace and assertiveness.

Also similar to the San Francisco study, results from this study suggest that drivers yield more frequently to pedestrians in marked crosswalks compared to unmarked crosswalks. This finding is likely at least partially explained by previous studies that illustrate differences in the knowledge of the right-of-way law with respect to marked and unmarked crosswalks.

Table 5 presents a comparison of the San Francisco study results with the Lake Tahoe study results for the key variables:

TABLE 5. COMPARISON OF ANALYSIS RESULTS – SAN FRANCISCO VERSUS LAKE TAHOE STUDY

Comparison Variable	San Francisco Unmarked versus Marked Crosswalks	Lake Tahoe Unmarked versus Marked Crosswalks
Age	1 of 6 comparisons significant: more teens (multi-lane only)	3 of 5 comparisons significant: more teens/young adults
Gender	3 of 6 comparisons significant: more males	4 of 5 comparisons significant: more males
Assertiveness	1 of 6 comparisons significant: more assertive (multi-lane only)	3 of 5 comparisons significant: more assertive (two and three-lane only)
Looking	2 of 6 comparisons significant: more looking	4 of 5 comparisons significant: more looking
Pace	4 of 6 comparisons significant: faster pace	5 of 5 comparisons significant: 3 are faster pace (multi-lane only) and 2 are not definitive
Gap	5 of 6 comparisons significant: more gaps	5 of 5 comparisons significant: more gaps
Yield	6 of 6 comparisons significant: less yielding	5 of 5 comparisons significant: less yielding
Multiple Threat	3 of 5 comparisons significant: less multiple threat	0 of 2 comparisons significant

The primary difference in the two studies is with respect to the multiple threat variable. The incidence of multiple threat opportunities was a statistically significant variable at three of the five multi-lane observation sites for the San Francisco study, including three of the four sites with four or more lanes, and both sites with median refuges. The variable was not statistically significant for the Lake Tahoe study. The most likely explanation for this is the low traffic volumes at the four-lane crosswalks. Observations and discussions with Caltrans staff indicate volumes are likely not sufficient to warrant a four-lane facility. A road diet (to reduce the number of travel lanes) has previously been proposed for this section in Kings Beach for this reason. With low traffic volumes, the pedestrian observation sample size may have been insufficient to detect any potential significant difference in this variable at marked versus unmarked locations. The data do illustrate a trend in greater multiple threat incidences at marked crosswalks.

The primary finding for this study is that the statistically significant trends demonstrated between marked and unmarked crosswalks in the San Francisco urban/suburban study hold for the rural/recreational context at Lake Tahoe. For this reason, the recommendations for engineering, education, and enforcement presented in the San Francisco study are likely applicable for this context as well and thus for Caltrans in general.

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