Pedestrian Crash Risk on Boundary Roadways

University Campus Case Study

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Prominent pedestrian trip attractors, such as college campuses and major urban parks, are often surrounded by roadways with high volumes of motor vehicle traffic. Although many pedestrians cross busy boundary roadways, relatively little is known about the pedestrian crash risk along these types of facilities. This study quantifies pedestrian crash risk at roadway intersections on the boundary of the University of California, Berkeley, campus during typical spring and fall semester weekdays. Manual pedestrian counts were extrapolated with data from three automated counter locations to represent pedestrian exposure. Pedestrian crash risk was highest at intersections along the boundary roadways with the lowest pedestrian volumes. In addition, pedestrian risk in the evening (6:00 p.m. to midnight) was estimated to be more than three times higher than in the daytime (10:00 a.m. to 4:00 p.m.). The crash risk estimation approach presented can be used to study pedestrian safety on the boundary of campuses and other major attractors so that agencies can identify and prioritize engineering, education, and enforcement treatments to reduce pedestrian injuries.

College campuses, major urban parks, sports complexes, school complexes, and shopping malls are examples of prominent land uses that often generate high numbers of pedestrian trips. Since many of these major attractors prohibit or discourage through traffic, high volumes of motor vehicles travel along their boundary roadways. As a result, pedestrians often need to negotiate busy intersections at these boundaries and these crossings can lead to collisions and injuries (Figure 1). Although maps can show concentrations of reported pedestrian crashes surrounding prominent land uses in many cities, they also tend to highlight locations with high pedestrian activity. They do not show the relative likelihood (i.e., risk) of a pedestrian's being struck by a vehicle on a boundary roadway at any given location or time. Better information about pedestrian crash risk can be used for the following:

- To analyze differences in risk by time of day to help determine when to conduct targeted safety education or enforcement efforts.
- To understand differences in risk by location. This information can be considered when pedestrian safety improvements are prioritized.
- To develop safety performance functions that identify roadway design characteristics associated with high levels of pedestrian crash risk. This information can be used to estimate the overall cost and crash reduction benefits of implementing safety measures systematically at certain types of high-risk locations.
- To evaluate pedestrian crash risk before and after engineering, education, and enforcement safety treatments are implemented at boundary intersections.

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PURPOSE

The purpose of this study is to quantify pedestrian crash risk on the boundary of a major pedestrian trip attractor. With the University of California, Berkeley (UC Berkeley) campus as a case study, the analysis explores how the level of pedestrian risk differs by location and by time of day during a typical fall or spring semester weekday. Although further study is needed to identify pedestrian crash risk characteristics on the boundaries of other types of attractors, this case study provides several findings that can inform engineering, education, and enforcement countermeasures in Berkeley and outlines an approach that can be used for future boundary pedestrian safety studies.

DEFINITIONS

Crash risk can be quantified in several ways. In this study, pedestrian crash risk is represented by the total number of pedestrian crashes reported at a boundary roadway intersection during a specific time period divided by the total number of times pedestrians crossed any leg of the intersection during that time period.

LITERATURE REVIEW

This study builds on several areas of previous pedestrian safety research. The following sections summarize existing knowledge about pedestrian safety near university campuses, on the boundary of pedestrian attractors, and at night. Specifically, analysis of the literature suggests that there is a need to

- Include exposure to measure pedestrian risk rather than simply raw crash frequencies,
- Explore pedestrian crash risk in campus areas and along roadways bounding major pedestrian attractors, and
- Better understand the temporal variations in pedestrian crash risk.

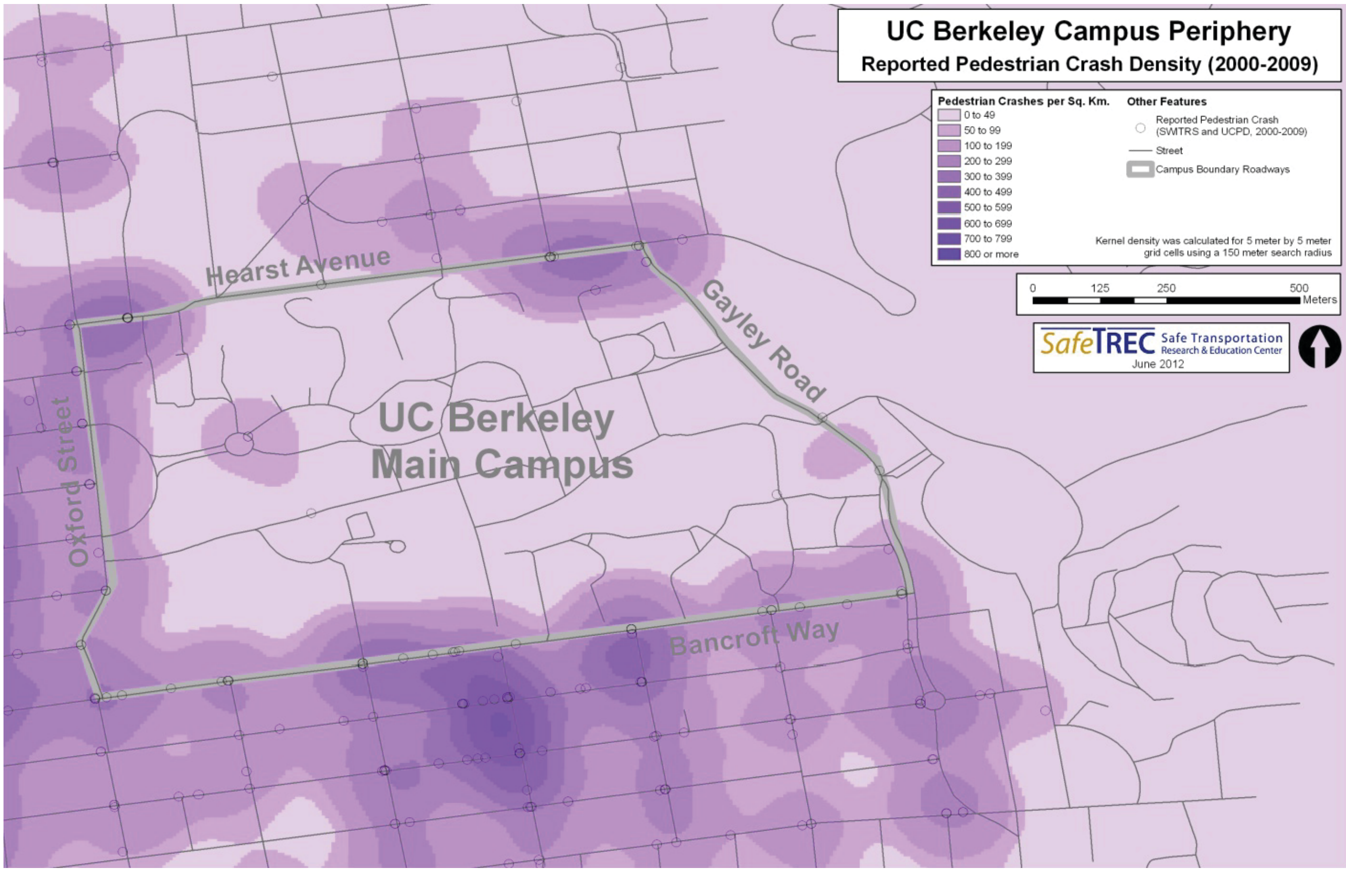


FIGURE 1 Density of reported pedestrian crashes near boundaries of University of California, Berkeley, campus. (Density map is for illustrative purposes only. All reported pedestrian crashes occurred along roadways and intersections.)

Campus Pedestrian Safety

Research has explored pedestrian safety as it relates to school and university campuses. Some studies have relied on the frequency of reported crashes to analyze campus pedestrian safety (*1, 2*). Other campus studies have supplemented reported crash data with pedestrian behaviors or perceptions of safety (*3–6*). More recent studies have incorporated aggregate social and built environment characteristics to evaluate pedestrian safety (*2, 7*). In addition to these research-oriented studies, a number of academic institutions have undertaken studies of pedestrian safety on and in the areas surrounding their campuses (*8–11*).

Boundary Road Safety

Previous studies have shown that after controlling for active travel by using household survey data, areas in the vicinity of pedestrian attractors such as parks exhibit a higher crash risk for pedestrians and bicyclists than other areas (*12*). Researchers have also acknowledged that roadways may act as boundaries to neighborhoods and activity centers of this type (*13*). In addition, arterial roadways have been identified as barriers to pedestrian access in local communities (*14, 15*). However, to the best of the authors' knowledge, no studies have quantified pedestrian safety along boundary roadways surrounding major trip attractors.

Pedestrian Safety at Night

Researchers have evaluated pedestrian safety by time of day, particularly in relation to visibility at night. One study examined the effect of daylight saving time transitions on fatal pedestrian crashes; that study showed pedestrian risk to be up to seven times higher in the darkness (i.e., between the hour after twilight in the evening until the hour before twilight in the morning) than during daylight (*16*). Previous studies have also emphasized reduced safety at twilight or night due to drivers' being unaware of how limited their visual capabilities are in the dark (*17–20*). A recent study on the frequency of pedestrian fatal collisions by time of day, day of week, and time of year observed that the greatest frequency of pedestrian fatal collisions is during twilight and the first hour of darkness (*21*). This study also emphasized the need to improve exposure estimates during these time periods to better quantify pedestrian risk and help formulate effective mitigation strategies.

Pedestrian Crash Risk

Many of these pedestrian safety studies are based only on raw crash frequency or measures of crash density. Crash frequencies and densities do not account for differences in pedestrian activity levels, so they cannot be used to quantify the relative risk of pedestrian crashes in different locations or variations in pedestrian risk by time of day. Efforts to account for exposure include use of factors such as population density and school enrollment as proxies for overall levels of pedestrian activity (*7, 22*). In addition, there has been a push to use pedestrian counts to quantify pedestrian crash risk. For example, studies have estimated pedestrian crash risk to range from 0 to 82 pedestrian crashes per 10 million pedestrian crossings at 50 arterial and collector roadway intersections in Alameda County, California (*23*), and from 0 to 11 pedestrian crashes per 10 million pedestrian crossings at 50 intersections in San Francisco, California (*24*). Pedestrian volume data have also been used to control for exposure when roadway characteristics associated with pedestrian crashes are analyzed (*25, 26*).

METHODOLOGY

Pedestrian crash and volume data were collected to analyze pedestrian crash risk at different locations and times on the boundary of the UC Berkeley campus.

Study Area

The main UC Berkeley campus is located on the east side of the city of Berkeley (census 2010 population, 112,580) within the nine-county San Francisco Bay Area metropolitan region (census 2010 population, 7.15 million) (*27*). On a typical class day, more than 34,000 students and more than 14,000 faculty and staff travel to and from the campus. Approximately 40% of these people commute by walking, 25% by public transit, 25% by private automobile, and 10% by bicycle (*28*). With the presence of over 9,000 automobile spaces within three blocks of campus and most transit access located off campus, many automobile and transit commuters cross campus boundary roadways as pedestrians when they travel to and from campus.

The campus is bounded by four main roadway corridors: Gayley Road, Bancroft Way, Oxford Street, and Hearst Avenue (Figure 2). In general, Gayley Road is a two-way street with one automobile lane in each direction; Bancroft Way is a one-way, westbound street with two lanes on its east end and three lanes on its west end; Oxford Street is a two-way street with two lanes in each direction divided by a median (1.2 m to 5.0 m wide); and Hearst Avenue is a two-way street with two lanes in each direction at its west end and one lane in each direction at its east end. These boundary roadways each serve between 10,000 and 30,000 automobiles per day.

The study focused on 22 intersections along the four campus boundary roadways (Figure 2). Pedestrian counts were taken in the field at 17 of these intersections and estimated at five minor intersections. The campus boundary roadway intersections have a variety of pedestrian crossing treatments, including traffic signals, stop signs, pedestrian warning signs with flashing beacons, marked crosswalks, curb extensions, and median islands.

Study Time Frame

The study explored pedestrian crash risk on weekdays (Monday through Friday) during the spring and fall semesters between January 1, 2000, and December 31, 2009. The specific study periods

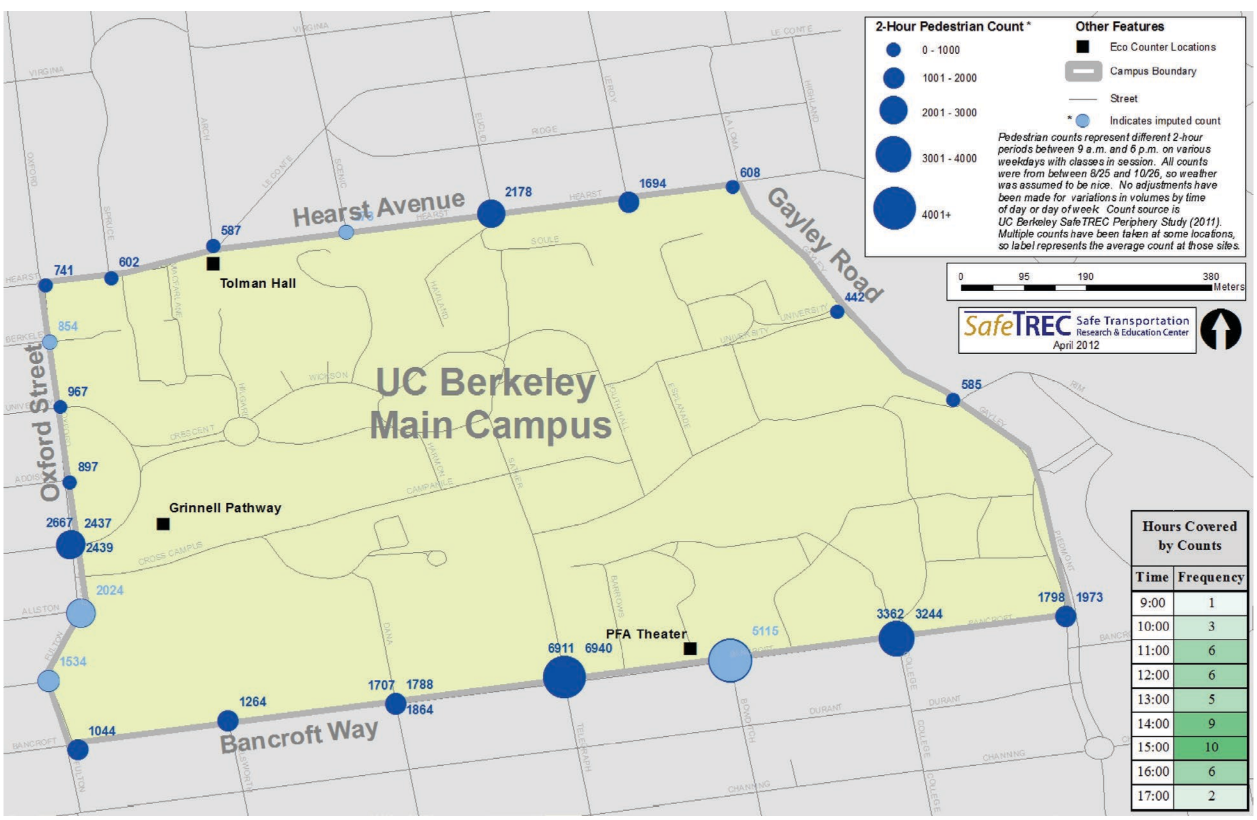


FIGURE 2 UC Berkeley campus collection locations for pedestrian volume data.

represented days of the week and months of the year with the highest overall levels of pedestrian activity (Figure 3). Summer term, weekends, holidays, and other breaks were excluded because they do not represent typical university and boundary roadway activity patterns.

Pedestrian Crash Data

The study used the 60 pedestrian crashes reported to police along campus boundary roadways during semester weekdays over the 10-year study period. The majority of crashes were taken from the California Highway Patrol Statewide Integrated Traffic Records System, and four additional crashes were provided by the University of California Police Department.

Crashes that occurred between intersections were assigned to the nearest intersection, which is a common practice (*26, 29*). In order to analyze crash risk along the four boundary roadway corridors, the intersections along each specific boundary roadway were grouped together. Intersections at the corners of the campus were assigned to two different boundary roadways. For further analysis, crashes were divided into 2-h intervals based on the time of the crash.

Pedestrian Volume Data

Pedestrian volume estimates were created by using a combination of manual and automated counts, an approach used in several previous studies (*23, 24*). Manual counts were collected for 2 h at each of the 17 study intersections during weekdays of fall semester 2011. The five busiest intersections were counted more than once, and these values were averaged for further analysis (Figure 2). Overall, 48 h of manual counts were logged during this study. The counts were recorded by using a mobile device with a commercial application for traffic counts. Pedestrians were counted each time they crossed a leg of the intersection. This count included people crossing within the crosswalk and people crossing the roadway leg up to 50 ft (15 m) from the crosswalk. Pedestrian counts at three-leg T-intersections did not include pedestrians using the sidewalk side of the intersection.

A simple procedure was applied to impute pedestrian volumes at the five minor intersections not counted in the field (Figure 2). Pedestrian volume was estimated by taking the average of two adjacent intersections (Bancroft Way at Bowditch Street and Oxford Street at Berkeley Way) or a weighted average based on proximity to adjacent intersections (Oxford Street at Kittredge Street and Oxford Street at Allston Street). Since there is no way to cross Hearst Avenue at Scenic Street, the imputed volume at this location was based only on the crossings along Hearst Avenue at the adjacent intersections.

Intersection pedestrian exposure was estimated by extrapolating the short-duration manual pedestrian counts over the 10-year study period. Expansion factors were developed from pedestrian volume patterns collected at three different campus locations with automated counting devices between November 2010 and April 2012 (Figure 2). These counters documented the total number of people per hour passing the sensor location.

The automatic counters do not differentiate between pedestrians and bicyclists, so the counts include bicyclists. However, most of the people passing the sensor locations were pedestrians. Automatic sensors also undercount because of pedestrians walking side by side. Undercounting is most common during times with high pedestrian volumes. To correct for undercounting, a recently published adjustment function developed from automated counter validation data in San Francisco and Alameda County, California, was refit on the basis of the data collected at the campus sites (*24*). The following correction equation was used:

$$y = 0.0022x^2 + 1.0679x \qquad (1)$$

where y is the corrected hourly pedestrian volume and x is the hourly count recorded by the automatic sensor.

Manual intersection counts were extrapolated by using the pedestrian volume pattern from a nearby automated counter location. Intersections along Bancroft Way were matched with the PFA Theater counter, intersections along Oxford Street were matched with the Grinnell Pathway counter, intersections along Hearst Avenue were matched with the Tolman Hall counter, and intersections along Gayley Road were matched with the closest counter (Figure 2).

The following steps describe how the manual counts and automated counter data were combined to provide estimates of pedestrian exposure at each study intersection:

1. Identify the distribution of hourly pedestrian volumes across the five weekdays at each of the automatic counter locations.
2. Extrapolate the 2-h manual counts at each intersection on the basis of the pedestrian volume distribution of the matched automatic counter to estimate the number of crossings in a typical school week (this step makes it possible to compare manual counts taken during different times of day and days of the week).
3. Extrapolate the estimated weekly crossings to a 10-year period; this step assumes that there are 27 school weeks in an academic year.
4. Distribute the estimated 10-year pedestrian volume across hours of the week based on the pedestrian volume pattern at the relevant automatic counter.

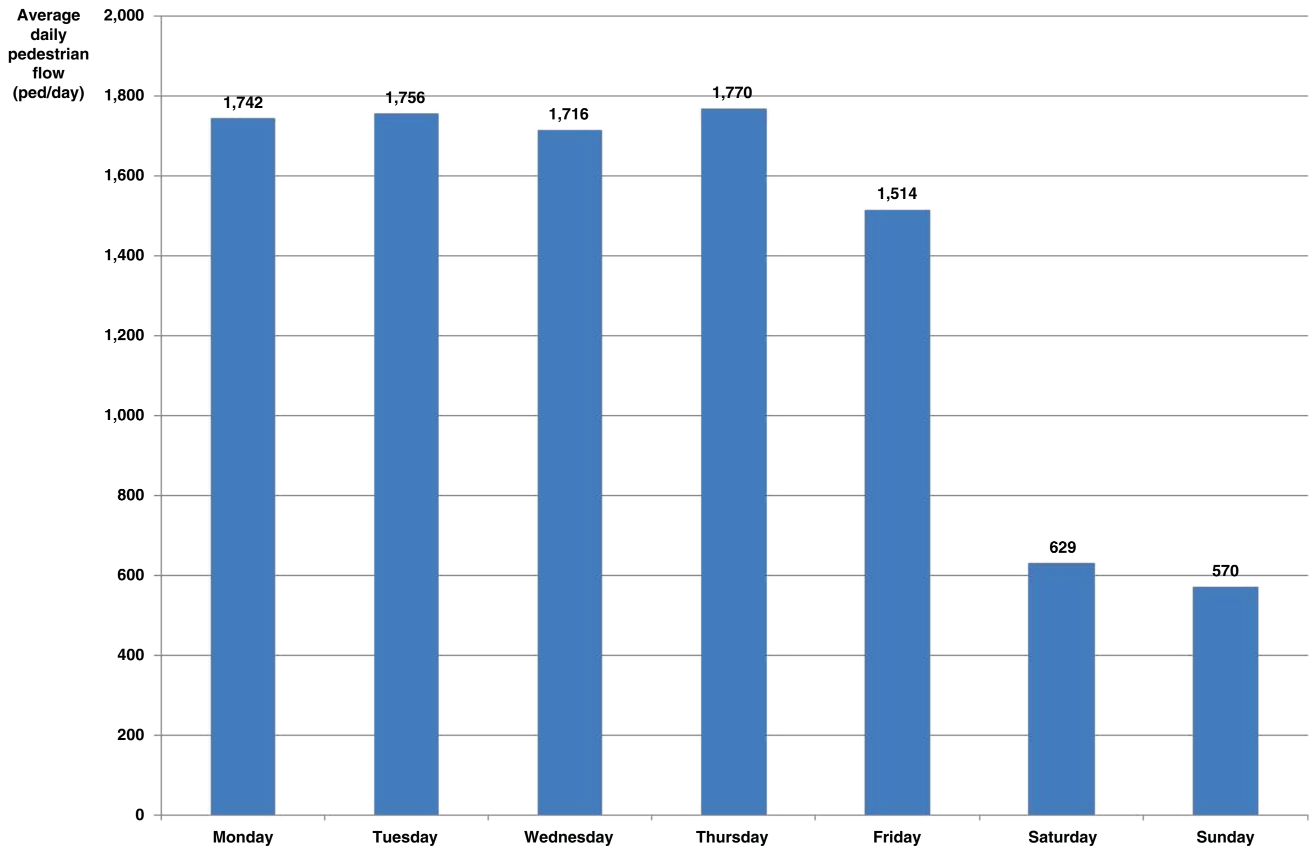
Figure 4 illustrates this process at the intersection of Hearst Avenue and Euclid Avenue. Figure 4*a* shows the distribution of hourly pedestrian volumes for the Tolman Hall automatic counter from Monday to Friday. The manual count at this intersection (2,178 pedestrian crossings) was taken on a Wednesday from 8:50 a.m. to 10:50 a.m., which represents 3.42% of the total school week crossings. This count means that there were approximately 63,700 crossings during a typical school week. This weekly volume was multiplied by 27 weeks and 10 years to estimate a total of approximately 17,200,000 crossings during the study period. Figure 4*b* shows the hourly distribution of crossings near Tolman Hall. This information makes it possible to estimate exposure for each hour of the school week. For example, crossings between noon and 1:00 p.m. account for 8.27% of all daily crossings, or 1,420,000 crossings. The same method was applied to estimate the total number of crossings at each intersection along the campus boundary.

FINDINGS

Analysis of crash and volume data at intersections along the four UC Berkeley campus boundary roadway corridors showed differences in pedestrian crash risk by location and by time of day.

Pedestrian Crash Risk by Location

Overall, 60 pedestrian crashes were reported at the 22 campus boundary roadway intersections on weekdays during spring and fall



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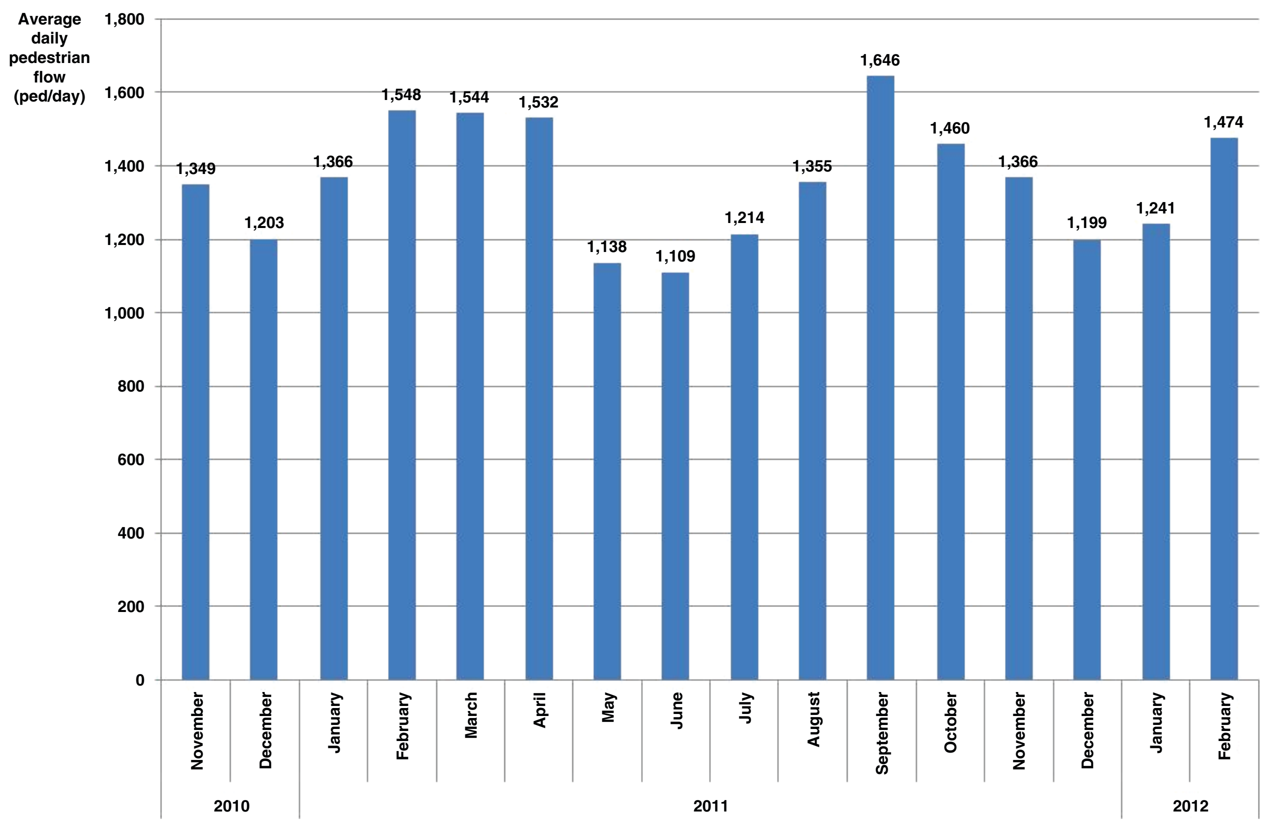

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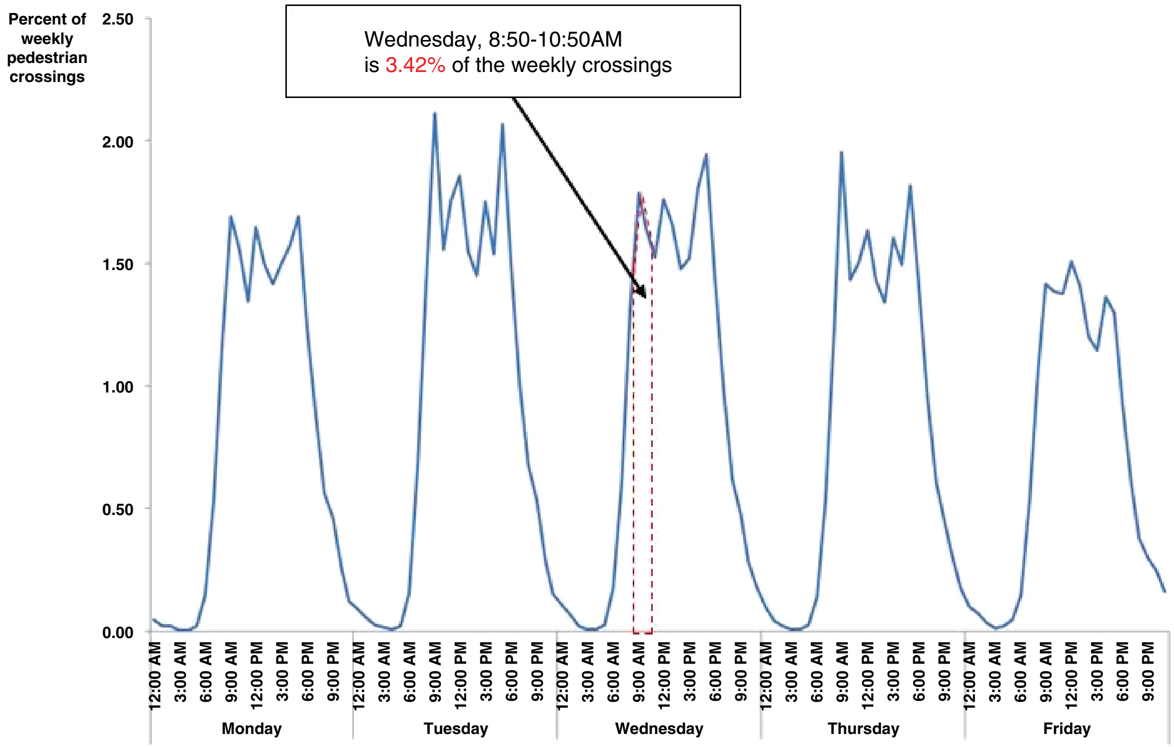
FIGURE 3 Pedestrian volume patterns at major campus entrance: (*a*) average pedestrian crossings (in and out) by day of week during classes and (*b*) average weekday pedestrian crossings (in and out) by month.



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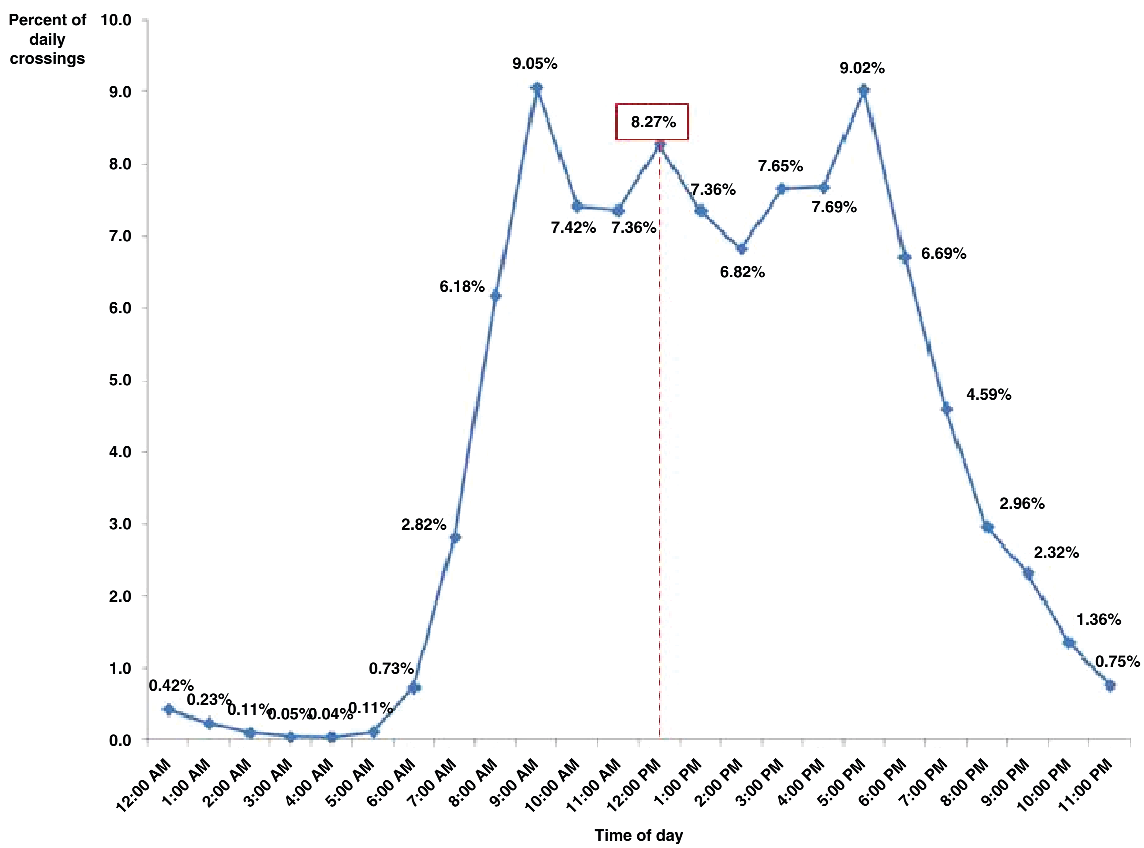


(b)

FIGURE 4 Pedestrian count extrapolation at intersection of Hearst Avenue and Euclid Avenue from automatic counter near Tolman Hall: (*a*) typical weekly pedestrian volume pattern and (*b*) typical daily pedestrian volume.

semesters between 2000 and 2009. Estimates from the manual and automated counts show that there were approximately 324,000,000 pedestrian crossings at all 22 intersections in 10 years. Therefore, the estimated semester weekday risk across campus boundary intersections between 2000 and 2009 was 1.85 pedestrian crashes per 10 million pedestrian crossings.

Pedestrian activity levels and reported pedestrian crashes are not distributed evenly around campus. Therefore, intersection pedestrian crash risk was compared between each of the four main campus boundary roadway corridors (Table 1). Intersections along Bancroft Way had the highest number of pedestrian crashes. However, this corridor also had the greatest level of pedestrian activity. So the pedestrian crash risk on Bancroft Way (1.61 pedestrian crashes per 10 million pedestrian crossings) was actually lower than that of the other three corridors.

Comparing the four corridors showed that corridors with lower levels of pedestrian activity had higher levels of pedestrian crash risk. This finding lends support to previous research that has identified the phenomenon of "safety in numbers" for pedestrians (*25, 30, 31*). This phenomenon may occur on semester weekdays because large numbers of pedestrians fill campus-area sidewalks and cross campus boundary streets at once and cause drivers to use extra caution. Pedestrians crossing in large groups may be easier to see or may be able to warn each other of approaching vehicles.

It was not possible to evaluate how specific roadway design features are associated with crash risk. Gayley Road is the only two-lane roadway and tends to have shorter crossing distances than the other corridors. Narrower roadways are often associated with safer pedestrian conditions (*26, 32*), but this corridor had the highest pedestrian crash risk. Multivariate analysis is needed to control for additional factors; however, this type of analysis was not possible with only four boundary corridors.

Pedestrian Crash Risk by Time of Day

Pedestrian crash risk was analyzed by time of day by dividing the typical semester weekday into 2-h periods. From 2000 and 2009, no crashes were reported between midnight and 5:59 a.m. Five to seven crashes were reported each 2-h period between 8:00 a.m. and 3:59 p.m., and the greatest number of reported crashes (14) occurred between 6:00 and 7:59 p.m. Several crashes were also reported after 8:00 p.m. By comparison, most classes and other activities on campus occur between 8:00 a.m. and 6:00 p.m. Pedestrian crossings at boundary roadway intersections are fairly consistent during the morning and afternoon periods, peaking between noon and 2:00 p.m. and decreasing steadily after 4:00 p.m. (Figure 5).

The greatest number of crashes occurred after most classes are completed, during a time period when pedestrian volumes are lower than in the middle of the day. The analysis of risk underscores this relationship:

- Pedestrian crash risk nearly doubled between 4:00 and 5:59 p.m. and 6:00 and 7:59 p.m.
- The overall pedestrian crash risk between 6:00 p.m. and midnight (3.92 crashes per 10 million pedestrian crossings) is more than 3.25 times higher than the overall pedestrian crash risk between 10:00 a.m. and 4:00 p.m. (1.20 crashes per 10 million crossings).
- The pattern of high pedestrian crash risk during the evening and night was evident on all of the boundary roadways except Gayley Road, which had the highest level of risk between 6:00 and 9:59 a.m.

More in-depth analysis of pedestrian and driver behaviors, roadway, and environmental characteristics is needed to explain why pedestrian crash risk along the UC Berkeley campus boundary roadways is highest in the evening and before midnight. Several possibilities should be investigated:

- Pedestrian crash risk may be higher after 6:00 p.m. because dusk and darkness reduce the ability of drivers to see pedestrians.
- Because there are lower pedestrian volumes in the evening, higher pedestrian crash risk could also be explained as an inverse "safety in numbers" relationship.
- Roadways tend to be less congested, so drivers may travel faster in free-flow conditions in the evening and night. Higher speeds may reduce a driver's ability to see pedestrians and increase the stopping distance required to yield to pedestrians.
- Alcohol use may be more likely in the evening.

TABLE 1 Pedestrian Crashes, Volume, and Crash Risk by Boundary Roadway Corridor, 2000–2009

Boundary Roadway	Reported Pedestrian Crashes	Estimated Crossing Volume	Crashes per 10 Million Crossings
Bancroft Way	29	180,654,595	1.61
Oxford Street	18	89,056,477	2.02
Hearst Avenue	18	60,215,955	2.99
Gayley Road	8	22,572,373	3.54
Total	60	324,243,069	1.85

NOTE: Totals shown in bottom row represent full campus boundary. However, crashes at intersections of two boundary roadway corridors (e.g., intersection of Bancroft Way and Oxford Street) were counted in total for each boundary roadway; therefore sums of four individual boundary roadways do not equal totals shown in bottom row.

DISCUSSION OF RESULTS

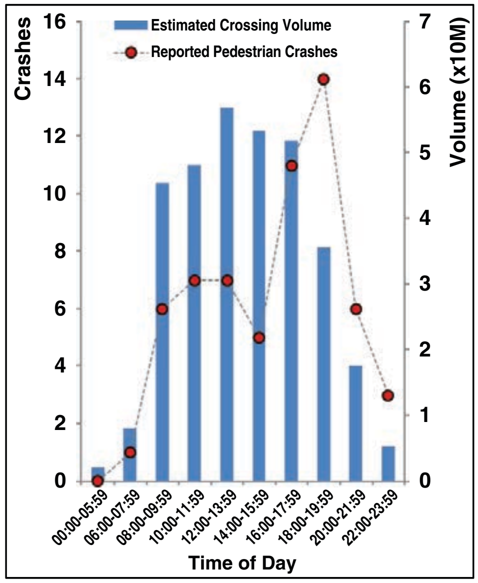
The UC Berkeley campus is an example of a major activity center with many pedestrians crossing intersections along its boundary. These boundary roadway intersections also serve high volumes of vehicle traffic. The case study presented here reveals two main findings about pedestrian crash risk in this context:

- Pedestrian crash risk is highest along the boundary roadways with the lowest pedestrian volumes.
- Pedestrian crash risk is higher during the evening and night than it is during the daytime.

Several countermeasures could be used to address greater crash risk when pedestrian volumes are relatively low. For example, rectangular rapid flashing beacons and pedestrian hybrid beacons can be installed at uncontrolled crossing locations. These devices are activated only when pedestrians are present. Roadway crossing improvements to reduce crossing distance, such as reducing motor vehicle travel lanes and providing median islands and curb extensions, may also reduce pedestrian crash risk.

Countermeasures could also be developed to address evening and nighttime crashes. For example, lighting could be improved at and on the approaches to street crossings to increase pedestrian visibility to drivers. In addition, pedestrian warning devices such as pedestrian hybrid beacons or rectangular rapid flashing beacons could be installed at uncontrolled pedestrian crossings. Although crossing locations may be easy for drivers to see in the daytime, flashers can help increase driver awareness at night.

All 22 Boundary Roadway Intersections			
Time Period	Reported Pedestrian Crashes	Estimated Crossing Volume	Crashes/10M crossings
00:00-05:59	0	2,025,899	0
06:00-07:59	1	8,025,759	1.25
08:00-09:59	6	45,451,089	1.32
10:00-11:59	7	48,181,827	1.45
12:00-13:59	7	56,791,023	1.23
14:00-15:59	5	53,333,999	0.94
16:00-17:59	11	51,804,940	2.12
18:00-19:59	14	35,643,980	3.93
20:00-21:59	6	17,638,689	3.40
22:00-23:59	3	5,345,865	5.61
Total	**60**	**324,243,069**	**1.85**



(a)

Bancroft Way			
Time Period	Reported Pedestrian Crashes	Estimated Crossing Volume	Crashes/10M crossings
00:00-05:59		955,908	0.00
06:00-07:59		2,656,846	0.00
08:00-09:59	3	24,071,762	1.25
10:00-11:59	3	27,909,318	1.07
12:00-13:59	5	33,986,941	1.47
14:00-15:59	2	32,076,120	0.62
16:00-17:59	6	26,548,567	2.26
18:00-19:59	6	19,559,799	3.07
20:00-21:59	3	10,221,547	2.93
22:00-23:59	1	2,667,788	3.75
Total	**29**	**180,654,595**	**1.61**

Oxford Street			
Time Period	Reported Pedestrian Crashes	Estimated Crossing Volume	Crashes/10M crossings
00:00-05:59		536,079	0.00
06:00-07:59		3,357,961	0.00
08:00-09:59		13,005,889	0.00
10:00-11:59	4	12,237,191	3.27
12:00-13:59	1	14,393,893	0.69
14:00-15:59		13,481,968	0.00
16:00-17:59	5	16,072,149	3.11
18:00-19:59	5	9,915,918	5.04
20:00-21:59	1	4,551,169	2.20
22:00-23:59	2	1,504,259	13.30
Total	**18**	**89,056,477**	**2.02**

Hearst Avenue			
Time Period	Reported Pedestrian Crashes	Estimated Crossing Volume	Crashes/10M crossings
00:00-05:59		551,677	0.00
06:00-07:59		2,165,595	0.00
08:00-09:59	2	9,139,769	2.19
10:00-11:59	1	8,824,912	1.13
12:00-13:59	2	9,429,687	2.12
14:00-15:59	3	8,741,619	3.43
16:00-17:59	2	10,164,633	1.97
18:00-19:59	6	6,785,961	8.84
20:00-21:59	2	3,165,849	6.32
22:00-23:59		1,246,254	0.00
Total	**18**	**60,215,955**	**2.99**

Gayley Road			
Time Period	Reported Pedestrian Crashes	Estimated Crossing Volume	Crashes/10M crossings
00:00-05:59		157,816	0.00
06:00-07:59	1	521,062	19.19
08:00-09:59	3	3,180,888	9.43
10:00-11:59	2	3,426,309	5.84
12:00-13:59		3,957,380	0.00
14:00-15:59		3,709,636	0.00
16:00-17:59	1	3,500,235	2.86
18:00-19:59	1	2,485,242	4.02
20:00-21:59		1,242,829	0.00
22:00-23:59		390,975	0.00
Total	**8**	**22,572,373**	**3.54**

(b)

FIGURE 5 Pedestrian crashes, volume, and crash risk by time of day during fall and spring semesters over 10 years (2000–2009): (*a*) across all boundary intersections and (*b*) at each of four boundary roadways. For crashes per 10 million crossings, the darker the shading, the greater is the risk (M = million).

The differences in pedestrian crash risk by time of day along the UC Berkeley campus boundary roadway intersections suggest that separate safety analyses should be done for daytime and nighttime crashes. Collecting data on characteristics such as pedestrian and driver behavior as well as roadway lighting conditions at night may lead to countermeasures that address nighttime pedestrian crash problems better than standard, daytime-based safety studies.

Future studies can determine if the properties of pedestrian crash risk are consistent in other locations. If they are consistent, the foregoing crash countermeasures could be applied broadly to roadways on the boundary of other major attractors in similar contexts. In addition, future studies will help build knowledge about other possible characteristics of boundary roadways associated with higher or lower pedestrian risk (e.g., intersection designs, motor vehicle speed and volume, and traffic control devices).

This methodology could also be used in before-and-after studies to explore the following questions:

- What types of pedestrian safety treatments lead to the greatest reduction in pedestrian risk and ultimately the fewest pedestrian injuries?
- Should pedestrians be channelized to cross at specific locations with traffic signals, warning signs, and other facilities, or is it better to create slow traffic zones where pedestrians are allowed to cross anywhere along a boundary roadway?

CONSIDERATIONS

This paper presents a case study of pedestrian crash risk at 22 intersections along UC Berkeley campus boundary roadways. As a case study, the specific findings may not necessarily apply to other locations. For example, other university campus, major urban park, or shopping center boundary roadways may not have three times higher pedestrian crash risk during the evening than during the daytime. However, the general findings showing higher pedestrian crash risk at night and higher risk when there is less pedestrian activity are likely to be found elsewhere. In addition, the data collection and analysis methodology can be applied in other pedestrian safety analyses.

This study focuses on pedestrian risk in order to compare the safety of individual pedestrians at different locations and times. However, with the data collected in this study, it is not possible to isolate the independent effects of overall pedestrian volumes and nighttime pedestrian conditions on pedestrian crash risk. It is possible that the lower number of pedestrians at night is the main factor increasing risk after 6:00 p.m. This possibility would mean that factors such as nighttime visibility or alcohol use may not be associated with higher levels of risk. The data do show that pedestrian crash risk was consistently higher at night for the three roadway corridors with the greatest number of crashes, even though Bancroft Way had more than twice as much pedestrian activity as Hearst Avenue or Oxford Street. Multivariate analysis is needed to explore these different pedestrian risk factors, along with other design factors, in more detail.

Pedestrian risk is not the only metric that should be considered when locations and times for countermeasures are chosen (*33*). For example, improving pedestrian visibility, reducing pedestrian crossing distance, or decreasing motor vehicle speeds approaching a crossing location with high pedestrian volumes may reduce more pedestrian crashes than improving a higher-risk location that has low existing or potential pedestrian volumes. In addition, strategies that may have broad effects, such as reducing motor vehicle speeds at all times of day, may benefit pedestrians during the day as well as at night when the highest risk per crossing exists.

Further research should examine the possibility that pedestrian crash risk was overestimated after 6:00 p.m. Since the pedestrian exposure estimates were based on pedestrian volume patterns collected within the campus boundary, it is possible that some of the evening and night estimates are too low given that evening activity levels in residential and commercial areas near campus are likely to be higher than on campus. However, pedestrian activity at the specific campus boundary roadway intersections mainly involves movements between campus and surrounding land uses. It is unlikely that the higher evening activity off campus affects pedestrian volumes on the boundary roadways significantly. Also, it is possible that the ratio of automobiles to pedestrians at campus boundary intersections is higher at night. Motor vehicle volumes were not considered in the pedestrian exposure calculation, so if automobile volumes increase relative to pedestrian volumes at night, the chance of collisions could be underestimated.

Pedestrian crashes are relatively infrequent events, so a 10-year analysis period was used to provide sufficient pedestrian crash data for analysis. However, it is possible that the estimated pedestrian crash risk was not constant between 2000 and 2009. Physical changes, such as installation of new pedestrian countdown signals and new crosswalks, may have occurred during the decade at some locations. In addition, pedestrian exposure may have changed because of the construction of new buildings or changes in land use. Since the pedestrian counts were taken after the end of the analysis period, they may have represented the last few years better than the early part of the analysis period. Finally, it is likely that there was some day-to-day variation in pedestrian activity at the locations where manual 2-h counts were taken (*34*). Therefore, there is a chance that the 2-h count was slightly different than the 10-year average volume for those two hours. However, the analysis was done by roadway corridor, so counts from several nearby intersections were combined; this method reduced the variability in the exposure estimates at the corridor level. This variation was even smaller for the analysis of all campus boundary roadways, since counts were combined from 22 intersections.

The study did not attempt a detailed analysis of risk at individual intersections. There were only 22 intersections with pedestrian crash and exposure data, and this sample size is typically too small to obtain statistically significant relationships between intersection characteristics and crash risk. This analysis was done in previous studies and should be pursued in the future (*25, 26*).

Overall, 60 crashes were considered in this analysis. When categorized by 2-h time periods for each of the four boundary roadways, the number of crashes in any particular analysis period was small, resulting in a high degree of variability in the risk estimates for each period. However, the analysis illustrated clear general trends in pedestrian crash risk for different levels of pedestrian activity and at different times of day.

CONCLUSION

It is important to identify pedestrian safety problems along the boundaries of major trip attractors with high levels of interaction between pedestrians and motorists. This case study of the UC Berkeley campus boundary roadway intersections revealed that pedestrian crash risk was highest along roadway corridors with relatively low pedestrian volumes and during the evening and night. The exposure-based methodology described here can be used on the periphery of other major attractors in order to quantify pedestrian risk. The results can help agencies identify and prioritize engineering, education, and enforcement treatments to reduce pedestrian injuries in these important corridors.

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