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STATE BICYCLE + PEDESTRIAN PLAN

Technical Report

Bicycle and Pedestrian Safety Trends

California Department of Transportation

April 2017

alta
PLANNING + DESIGN

Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

Document Information		
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Document Revision Schedule			
Bicycle and Pedestrian Safety Trends			
Rev.	Description	Date	Reviewed by
v1	Draft report	9/9/2016	Hugh Louch
v2	Second draft	12/21/2016	Hugh Louch
v3	Final	4/17/2017	Hugh Louch

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1. Introduction

Caltrans has set ambitious goals to triple bicycling and double walking in the state by 2020, but these goals will be difficult to achieve without a transportation system that improves safety for users and accommodates the needs of all members of the community. Further, Caltrans has stated goals of a 10% reduction in number of fatalities in a calendar year in each of the following mode types: car, transit, pedestrian, and bicyclist[1]. Bicycling and walking has the potential to bring numerous health, economic, and environmental benefits; however, the benefits are diminished if people are injured or killed while trying to access them. Safety is a serious public health issue and acts as a barrier to bicycling and walking. In 2013, there were 743 bicyclists and 4,735 pedestrians killed in a traffic collision in the United States. California ranked 24th in terms of the number of bicyclist fatalities per bicycle commuter, and 16th in terms of the number of pedestrian fatalities per walk commuter[2]. In addition to actual collisions and risk, the perception of safety is influential in travel behavior and choices, shaping attitudes and perceptions about bicycling and walking.

Bicyclists and pedestrians encounter unique safety challenges from other road users. Many roadways are primarily designed for motor vehicles with high speeds and wide crossing distances, making it difficult for bicyclists and pedestrians to navigate the system and get to the destinations they wish to reach. Bicyclists and pedestrians are vulnerable to injury and fatalities because they have less protection in the case of a collision. Speed is a major determining factor in severity of injury. Bicyclists and pedestrians are also more sensitive to hazards such as uneven pavement or potholes. Often, low income populations and communities of color rely on bicycling and walking for their transportation needs, and are disproportionately impacted by safety issues.

In this report, California's pedestrian and bicyclist collision records are evaluated for 2005-2014. Police-reported collisions throughout the state are studied to answer questions such as whether the number of collision and the severity of collisions are increasing or decreasing, who is most impacted by traffic collisions while walking and bicycling, and what scenarios are resulting in these collisions.

While this report provides a high-level overview of safety trends across the state, California would benefit from more in-depth analysis of causal crash factors. However, to properly contextualize crashes, greater levels of data are needed on the levels of bicyclist and pedestrian activity across the system (i.e. traffic counts) and on built environment factors relevant to these modes, such as the existence of bicycle and pedestrian facilities. Detailed recommendations on these data needs can be found in the Baseline Data Methodology document prepared as a part of this planning effort.

Summary of Key Findings

Overall

Between 2005 and 2014, 134,125 bicycle-involved collisions and 136,618 pedestrian-involved collisions occurred in California. Over this time period, pedestrian collision risk (per the number of people walking to work) has been relatively consistent, and bicyclist collision risk (per the number of people bicycling to work) has been decreasing overall.

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[1] Caltrans Strategic Management Plan, 2015-2020
http://www.dot.ca.gov/perf/library/pdf/Caltrans_Strategic_Mgmt_Plan_033015.pdf

[2] Calculated using fatality data from Fatality Analysis Reporting System (FARS); Commute data from American Community Survey Table S0801.

Bicycle-Involved Collisions

- The vast majority (91%) of bicycle collisions occurred on non-state highways and public roads.
- The most common type of collision was broadside.
- State highways: Riding on the wrong side of the road accounted for 14% of fatalities that occurred; Improper turning accounted for almost 23% of fatalities that occurred. Under the influence of alcohol or drugs was less prevalent, but accounted for over 20% of fatalities.
- Non-state highways: Riding on the wrong side of the road, automobile right of way, and improper turning each accounted for 15% of fatalities.
- The counties with the highest bicycle collision rates (per million miles traveled) were Alpine (48.97), Santa Cruz (24.57), Santa Barbara (21.35), Shasta (18.51), and San Benito (17.58).
- Bicycle crashes along state highways were the most frequent along ORA 39 (10.0/mile), SCL 82 (9.6/mile), SD 282 (9.4/mile), ALA 123 (9.4/mile), and ORA 1 (8.1/mile). These are all surface highways in urban areas, presumably with high levels of pedestrian activity.
- Black cyclists are at elevated risk relative to other racial groups, both on a miles traveled and population adjusted basis.
- Bicyclists aged 10-29 years old are at elevated risk per miles traveled.
- Wrong-way bicycling is a substantial problem, resulting in 23% of all bicycle crashes statewide.
- The main driver violations in bicycle crashes are failures to yield while making left or U-turns (9.3% of all bicycle crashes) and failures to yield while entering or crossing the highway (4.5% of all bicycle crashes).

Pedestrian-Involved Collisions

- The majority (90.1%) of pedestrian collisions occurred on non-state highways and public roads.
- State highways: Pedestrian violations resulted in the most pedestrian fatalities, followed by unsafe speed, influence of alcohol or drugs, and improper turning. Over one quarter of collisions that involved pedestrian violations, impeding traffic, or wrong side of the road resulted in a fatality.
- Non-state highways: Pedestrian violations resulted in the most pedestrian fatalities, followed by pedestrian right of way violation, influence of alcohol or drugs, and unsafe speed.
- The counties with the highest pedestrian collision rates (per million miles traveled) were Humboldt (11.09), Alpine (7.71), Solano (7.19), Merced (7.16), and Santa Cruz (7.02).
- Pedestrian crashes per mile along state highways were the most frequent along ALA 123 (10.5/mile), LA 19 (8.3/mile), SF 101 (8.2/mile), ORA 39 (7.7/mile), and ALA 185 (7.1/mile). These are all surface highways in urban areas, presumably with high levels of pedestrian activity.
- Black pedestrians are at elevated risk relative to other racial groups, both on a miles traveled and population adjusted basis.
- The vast majority of primary collision factors in pedestrian crashes are failures to yield, either on the part of the driver at a marked or unmarked crosswalk (41% of pedestrian crashes statewide) or on the part of the pedestrian outside of crosswalks (25% of pedestrian crashes statewide).
- A large proportion (51%) of severe and fatal pedestrian crashes on state highways involve pedestrians in the road or shoulder.

Organization of this Report

The remainder of this report describes these findings in additional detail:

- Section 2 provides an overview of existing literature on bicycle and pedestrian safety
- Section 3 describes the data and methods used in the report
- Section 4 describes overall safety trends for bicyclist and pedestrian involved collisions
- Section 5 describes available information on collision causes
- Section 6 identifies high collision corridors on the state highway system

2. Literature Review

Methodological Approaches

There are two predominant approaches that have been taken to statistical modeling of traffic collisions: collision frequency models (or "safety performance functions") that express the average number of crashes within a given geography as a function of exposure and other salient risk factors, and collision severity models, which express the average collision severity conditioned on a collision having occurred. Overall methodological issues surrounding these two modeling approaches and some of their potential solutions have been reviewed in a pair of papers by Lord and Mannering and Savolainen et al[3][4]. This separation of model components (collision frequency and collision severity) is due in part to the paucity of available exposure data, which limits the ability of analysts to use all of the collision data in studying collision frequencies. By studying conditional collision severities, all captured collision data can be used in analyzing what factors increase collision severity.

For bicycle and pedestrian crashes, some of the issues highlighted by Lord and Mannering and Savolainen et al. are especially pronounced, particularly:

- Collision underreporting[5]
- Omitted variables bias (e.g. lack of appropriate exposure data)
- Endogenous variables (e.g. in the case of the installation of bicycle facilities)

Few of these methodological issues have been resolved in the literature on bicycle and pedestrian safety analysis.

One of the primary tools utilized by traffic safety engineers is the Safety Performance Function (SPF). SPFs, or crash-frequency models, express the expected number of crashes within a given geographical unit (e.g. intersections/segments, census tracts, cities) as a function of "exposure" within that unit, or the number of opportunities for crashes to occur, as well as other risk factors (e.g. roadway geometry, demographics). For intersections, pedestrian or bicycle counts are typically used as the unit of exposure, while for larger geometries miles traveled are more often used.

SPFs are used for a number of applications, including:

- Identification of factors which affect (exposure-adjusted) collision risk, such as the presence of bicycle or pedestrian facilities.
- Systemic safety analysis of networks.
- Hot-spot identification of networks by evaluation of residuals.

[3] Lord, D. and F. Mannering. "The statistical analysis of crash-frequency data: A review and assessment of methodological alternatives." Transportation Research Part A 44 (2010), pg. 291-305.

[4] Savolainen, P.T., F.L. Mannering, D. Lord, and M.A. Quddus. "The statistical analysis of highway crash-injury severities: A review and assessment of methodological alternatives." Accident Analysis and Prevention 43 (2011) pg. 1666-1676.

[5] Elvik, Rune, and Anne Mysen. "Incomplete accident reporting: meta-analysis of studies made in 13 countries." Transportation Research Record: Journal of the Transportation Research Board 1665 (1999): 133-140.

For most of these applications, SPFs must be estimated based on small geographic regions such as intersections or segments because using larger geographies, even as large as Traffic Analysis Zones, requires combination of factors within an observation which may not be compatible. As a simple example, consider an analysis of bicycle collision frequency on the basis of TAZs. One feature that we might hypothesize to affect bicycle collision risk would be the presence of bicycle facilities. For most TAZs, some streets will include bicycle facilities and others will not. Modeling at this scale requires counting all crashes that occur within the TAZ, but it is not apparent which of those crashes occurred on which facility types, nor how much of the total exposure is attributable to each facility. Therefore, it is impossible to identify the extent to which the bicycle facilities reduce collision risk.

In order to avoid this problem, SPFs need to be estimated for intersections and road segments. This has historically been a problem for bicyclists and pedestrians due to the lack of quality traffic count data, which continues to stymie progress on the topic.

Project Prioritization methods

In addition to classifying the types of statistical models that can be used to understand traffic crashes, we can consider the different project prioritization methods available. "**Hotspot" analysis** is the traditional approach to the problem, and entails mapping collision locations and identifying locations where crashes tend to cluster, or "hotspots". These are either analyzed as raw frequencies (number of crashes), or as a normalized rate (number of crashes per unit of exposure). A newer technique, known as **systemic safety analysis**,[6] is a complementary approach to hotspot identification. The systemic approach entails identifying the types of locations/location characteristics that result in above average collision rates, subdivided by the types of crashes occurring, and then identifying appropriate countermeasures to reduce the particular types of crashes that have been observed. The advantage of this approach is that, even if crashes have not occurred at a given location, they can be proactively reduced by prioritizing locations that have features associated with above average collision or collision severity rates. This can be done either by creating contingency tables and tabulating collision totals within each cell, or by constructing a multivariate model.

Collision Factors

Despite these difficulties, there have been some attempts to identify the effects of various roadway geometry features on pedestrian and bicyclist safety. Results pertaining to some of these features are summarized below.

Bicycle Facilities

Findings on the effectiveness of bicycle facilities on reducing collision risk for bicyclists are equivocal, according to a recently completed Cochrane review that synthesized the results of 21 studies[7]. Mulvaney et al.'s conclusion is not that cycling infrastructure is ineffective at reducing collision risk, but that the evidence to date is not of sufficiently high quality to draw firm conclusions.

On the other hand, a review specifically focusing on cycletracks (Class IV Bikeways) found that these facilities can improve cyclists safety when constructed well[8]. Research from Australia and New Zealand yields similar findings about bike lanes – namely, that they can increase cyclist safety when designed to be

[6] https://safety.fhwa.dot.gov/systemic/
[7] Mulvaney CA, Smith S, Watson MC, Parkin J, Coupland C, Miller P, Kendrick D, McClintock H. Cycling infrastructure for reducing cycling injuries in cyclists. Cochrane Database of Systematic Reviews 2015, Issue 12. Art. No.: CD010415. DOI: 10.1002/14651858.CD010415.pub2.
[8] Thomas, Beth, and Michelle DeRobertis. "The safety of urban cycle tracks: A review of the literature." Accident Analysis & Prevention 52 (2013): 219-227.

greater than 3 feet wide, painted as colored lanes, and when intersections with bike lanes use exclusive left turn lanes[9].

On the whole, it appears that bicycle facilities may increase cyclist safety when they are designed following best practices.

Pedestrian Crossing Facilities

The most thorough and rigorous study of pedestrian crossing facilities, conducted by Zegeer et al., performed a comparison of pedestrian collision risk at marked and unmarked uncontrolled crossing locations[10]. They found that marked crosswalks at unsignalized locations on multilane roads with high traffic volumes (above 12,000 vehicles per day) results in an elevated collision risk compared with unmarked crosswalks, which could be associated with a false sense of security at the locations. Raised medians were found to help mitigate this elevated risk. Recently released research corroborates these findings and goes on to quantify the collision reduction benefits of additional pedestrian crossing infrastructure at unsignalized locations[11].

Previous Caltrans-funded research

Caltrans has funded a number of bicycle and pedestrian safety research projects.

Strategies for Reducing Pedestrian and Bicyclist Injury at the Corridor Level (SMART)

The SMART study developed a systemic safety analysis method for analyzing pedestrian collision patterns. Systemic safety analysis is a technique based on identifying the types of situations that produce above average collision frequencies, and to identify counter-measures to reduce collision rates at locations fitting these characteristics. SMART presents a case study of the San Pablo Avenue corridor through the East Bay (Richmond/El Cerrito/Berkeley/Oakland). Crashes are classified based on location type (binary variables for signalization, speed limit, and width) and collision type (based on vehicle/pedestrian movements and violations). The number of crashes falling into each stratum are tabulated, and these tables are used to identify "systemic hotspots," or location and collision type that represent the a significant proportion of collisions. Counter-measures are then identified for the location/collision type cells with above average collision rates.

Pedestrian Safety Improvement Plan (PSIP) Phase 1

PSIP continued developing the systemic analysis methods from the SMART study, with the addition of a pedestrian volume model.

Evaluate the causes of pedestrian and bicyclist traffic fatalities and injuries, and identify relevant countermeasures for use in California

The purpose of this project is to examine existing bicycle and pedestrian safety programs and guidelines in the U.S. and internationally, analyze existing data related to pedestrian and bicycle safety in California, and

[9] Turner, Shane, Graham Wood, Tim Hughes, and Rohit Singh. "Safety Performance Functions for Bicycle Crashes in New Zealand and Australia." Transportation Research Record: Journal of the Transportation Research Board, No. 2236 (2011): 66-73.
[10] Zegeer, Charles, J. Richard Stewart, Herman Huang, Peter Lagerwey, John Feaganes, and B.J. Campbell. "Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines." Report No. FHWA-HRT-04-100. 2005.
[11] Zegeer, Charles, Raghavan Srinivasan, Bo Lan, Daniel Carter, Sarah Smith, Carl Sundstrom, Nathan Thirsk, John Zegeer, Craig Lyon, Erin Ferguson, and Ron Van Houten. "Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments." NCHRP Report 841, 2016.

assist in developing methodologies for producing safety action plans, identifying and selecting projects, conducting education campaigns, and targeting enforcement campaigns.

Effects of Transportation Corridor Features on Driver and Pedestrian Behavior and on Community Vitality

This study reviews the impact of community oriented design features on traveler safety and economic vitality. The design features include in this review will be: trees, other plantings, bicycle facilities, pedestrian facilities (sidewalks, ADA ramps, bulb-outs and refuges, countdown signals), street furniture, signage, paving (lane widths, transitions, colors, materials), parking, calming, and speed-transition zones.

UTC - Bicycle Crash Risk: How Does it Vary and Why, (UCCONNECT)

This study examines bicycle collision data along with bicycle count data in Los Angeles County to better understand the factors that correlate with bicycle collision risk. Bicycle count data will be collected to supplement existing data and create a varied data set. Researchers will model bicycle collision risk at about 100 intersections in the Los Angeles area as a function of design characteristics and operational variables.

UTC - What Can a Bike Lane Do? Performance Metrics for Proposed Bicycle Infrastructure, (UCCONNECT)

This project will develop multi-criteria performance metrics related to bicycle demand and safety for evaluating proposed bicycle infrastructure. These metrics will include evaluations of environmental impacts, such as reduction in motorized vehicle use through mode shift and emissions reductions, economic impacts and the changes in the consumer surplus, health/safety impacts, changes in expected number of crashes and expected collision risk, and changes in bicycle miles traveled.

3. Data and Methodology

Collision Data

This report uses data from the Statewide Integrated Traffic Records System (SWITRS) and examines bicycle and pedestrian collisions that occurred between 2005 and 2014. SWITRS data contains all collisions that were reported to California Highway Patrol. However, there are known underreporting issues with non-motorized collision data in traffic collision databases[12]. Higher severity crashes are more likely to reported, so considering that severe and fatal injuries are the most important to prevent, analysis based on police-reported collision data is justifiable. The most recent available data over a 10 year period was analyzed in order to comprehensively evaluate trends and safety issues.

Exposure Data

"Exposure" is a quantification of the opportunities for crashes to occur, as explained in the sidebar below. Because crashes are analyzed on an area-wide basis here, exposure is quantified using either the number of commuters or estimated miles traveled, depending on data availability.

Risk and Exposure

When analyzing collision data, simply inspecting the raw collision data can be misleading. Traffic crashes result from transportation – the more that people travel, the more opportunity they have to experience crashes. Key terms used include:

- *Exposure*: A quantification of the opportunity for traffic crashes to occur. As exposure increases, so too does the number of crashes. Exposure can be quantified in a number of ways, depending on the scale of the study. When looking at specific locations, traffic volumes are often used; when looking at larger areas, such as counties, miles traveled is typically considered a good measure of exposure.
- *Collision risk:* Collision risk is the probability of any given exposure event resulting in a crash. Collision risk can be affected by a number of different *risk factors*, such as traffic speed or crosswalk presence. As exposure for a particular group (e.g. pedestrians or bicyclists) increases, such as through mode shift, the number of crashes may increase unless measures are taken to reduce collision risk.

These definitions are important to keep in mind throughout this report. Without controlling for exposure, misleading conclusions can be reached. For example, the number of bicyclist-involved crashes statewide has generally increased over the past 10 years. However, this does not mean that collision risk for bicyclists has been increasing. This rise in crashes is more likely attributable to the rapidly growing rates of bicycling statewide, and after controlling for this trend it appears that collision risk is in fact decreasing.

Despite the importance of understanding risk to determine what factors can affect the frequency of crashes, it is also critical to know things such as who bears the majority of the burden of traffic crashes. Accordingly, both collision frequencies and rates are presented throughout this report wherever available.

Multiple sources of exposure data are used here. These include the American Community Survey's (ACS) estimated number of commuters by each mode, as well as census tract-level estimates of bicycle and pedestrian miles traveled based on the ACS and the 2010-2012 California Household Travel Survey

[12] Stutts, Jane, and William Hunter. "Police reporting of pedestrians and bicyclists treated in hospital emergency rooms." *Transportation Research Record: Journal of the Transportation Research Board* 1635 (1998): 88-92.

(CHTS). In addition to these survey datasets, a previous study by Salon and Handy[13] produced estimates of bicycle and pedestrian miles traveled on weekdays by the residents of each census tract statewide, making use of both the ACS and CHTS datasets to produce their estimates. A combination of these exposure estimates is used in this report, depending on the particular analysis being conducted.

Methods to Estimate Exposure

To estimate exposure, we rely on scaling methods based on numbers from the ACS, CHTS, and previous work by Salon and Handy. Wherever possible the number of miles traveled for the relevant group and time period is used. For example, in evaluating spatial differences in collision frequency, we consider the total number of crashes observed in each county between 2005 and 2014 normalized by an estimate of the total number of miles traveled within the county over the same timeframe. This allows for comparisons of the number of crashes per mile traveled, or in other words evaluation of how risk varies.

As one example of how miles traveled estimates are developed, for comparisons of bicyclists risk across counties we use:

$$BMT_i = BMT_i^{H2012} * WW_i * 365 * Growth_i * 10$$

Where the terms are defined as:

BMT_i = Total Bicycle Miles Traveled in county *i*

BMT_i^{H2012} =Weekday BMT estimate for county *i* from Salon and Handy.

WW_i = Ratio of weekend miles traveled to weekday miles traveled for county *I*'s district, based on the CHTS

$Growth_I$ = Annual growth term for county *i*, based on the ACS.

The rationale behind this analysis is that the number of miles traveled on a weekday in 2012 may not be representative of the total number of miles traveled between 2005 and 2014. To correct for this, we include a weekend-weekday correction term and a growth-over-time correction.

For the weekday-weekend correction (WW_i), we rely on the CHTS. For all observed bicycle trips in the 2012 CHTS we multiply the trip distance with the population extrapolation weight and trip correction factor to achieve an "effective population-level miles traveled[14]." These miles traveled are then aggregated to the Caltrans district level separately for weekdays and weekends, and the average number of weekend miles traveled is divided by the average number of weekday miles traveled. Separate rates are calculated for each Caltrans district because these rates could vary depending on location – in urban areas, for instance, we might expect more weekday cycling than weekend cycling due to higher commute rates. However, the more spatially fine-grained of units of analysis that are used, the less reliable the rates become because they are based on fewer and fewer survey responses, hence the decision to use Caltrans districts as opposed to individual counties.

The annual growth term ($Growth_i$) has a similar basis – rates of walking and cycling have changed over the study period, and at different rates in different counties. To correct for this we make use of commute figures from the ACS, as this is the only widely available longitudinal dataset on travel demand with both spatial and temporal detail. One limitation is that it only provides information about commute activity, so it is assumed that the change in commute rates over time is representative of the overall rates of change in

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[13] Salon, Deborah and Susan Handy. "Estimating Total Miles Walked and Biked by Census Tract in California." Prepared for State of California Department of Transportation, 2014. URL: http://ultrans.its.ucdavis.edu/projects/estimates-miles-walked-and-biked-california-census-tract.html.

[14] For a detailed description of the CHTS extrapolation weights, see the survey's final report, available at http://www.dot.ca.gov/hq/tpp/offices/omsp/statewide_travel_analysis/chts.html.

walking and bicycling activity. The growth rate is calculated separately for each county by taking the average number of bicycle commuters in each year divided by the number of reported bicycle commuters in 2012.

In the other risk comparisons, exposure rates are calculated following a similar logic. For example, comparisons of risks to different segments of the population such as gender are evaluated using miles traveled estimates from the CHTS. Details on these exposure calculations will be introduced when relevant throughout the report.

For some topics, such as the number of crashes on state highways compared with statewide frequencies, exposure data is not available. Therefore, estimates of variation in collision risk are not possible limiting the lessons that can be learned. These analyses are presented as such, with the caveat that the apparent patterns in the collision data could be entirely attributable to differences in exposure. This caveat is particularly important for collision factors with fine-grained spatial variation. We are not able to evaluate the impacts of factors such as bicycle facility presence, crosswalks presence, or status as a state highway on collision risk because of the lack of spatially resolved exposure data. This is a widely known and acknowledged problem in traffic safety analysis, and the first step to resolving it is collecting more non-motorized count data.

4. Overall trends

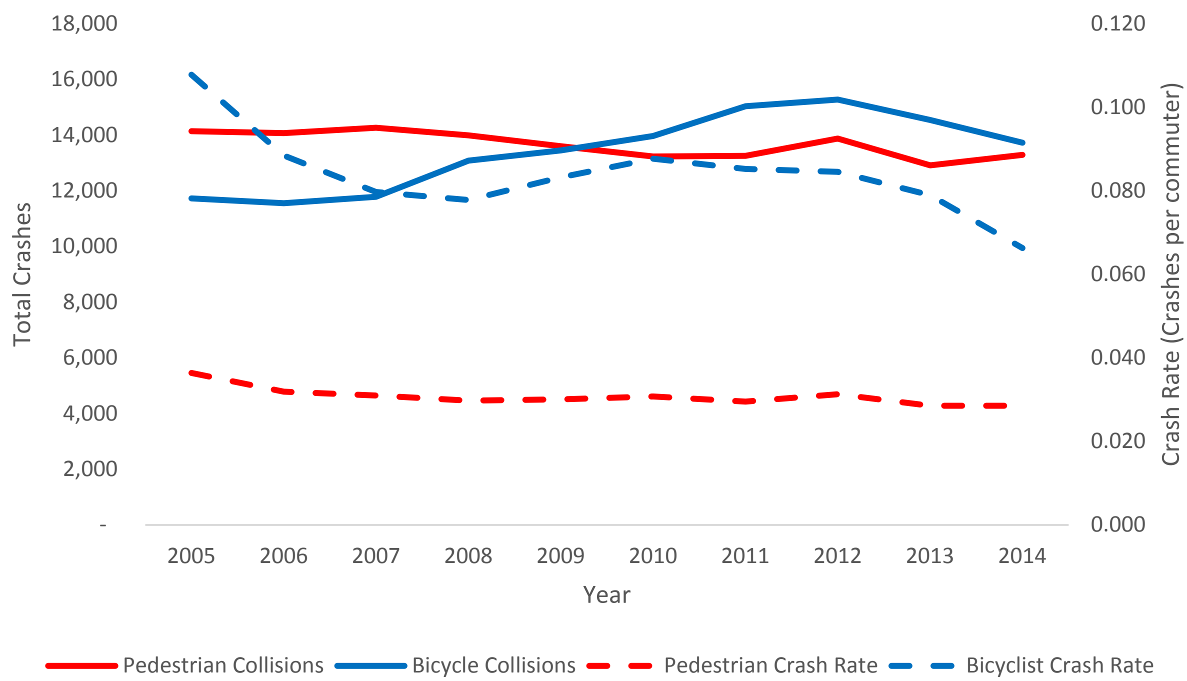
Change over Time

Between 2005 and 2014, 134,125 bicycle-involved collisions and 136,618 pedestrian-involved collisions occurred in California. The bicycle collisions resulted in 1,349 bicyclist fatalities and 121,194 bicyclists injured. The pedestrian collisions resulted in 6,853 pedestrians killed and 130,752 pedestrians injured.

Between 2006 and 2012, the number of bicycle-involved collisions increased each year, but decreased from 2012-2014. Overall, the number of pedestrian collisions decreased between 2005 and 2013. Figure 1 shows the statewide trends in bicycle and pedestrian collisions between 2005 and 2014. In addition to the raw number of crashes, depicted by the solid lines, the number of crashes for each mode divided by the estimated number of commuters are shown as dashed lines. The estimated number of bicycle commuters and walk commuters here come from the American Community Survey's 1-year estimates of mode share and number of commuters. On this basis, bicyclist collision risk appears to have decreased from 2005 to 2014, from approximately 0.11 to 0.06 crashes per bicycle commuter, with a slight rise between 2008 and 2010. Pedestrian collision risk, on the other hand, has been relatively constant over the same time period at roughly 0.03 crashes per walking commuter.

Using commute rates as a proxy for exposure assumes that overall rates of travel by each mode is proportional to the rate of commuting. Ideally, overall miles traveled would be used, but high quality longitudinal data on total miles traveled by bicyclists and pedestrians is not available.

Figure 1 Bicycle and Pedestrian Collisions, 2005-2014



Cross-sectional comparison

In addition to evaluating how collision rates have evolved over time, we can consider how they vary across the state. The methods for calculating exposure in this section are discussed in detail in the methodology section above. Figure 2 and Figure 3 present an estimate of the number of pedestrian and bicycle crashes per pedestrian and bicycle mile traveled, respectively, within each county.

Figure 2 Pedestrian Collisions per Estimated Pedestrian Mile Traveled, 2005-2014

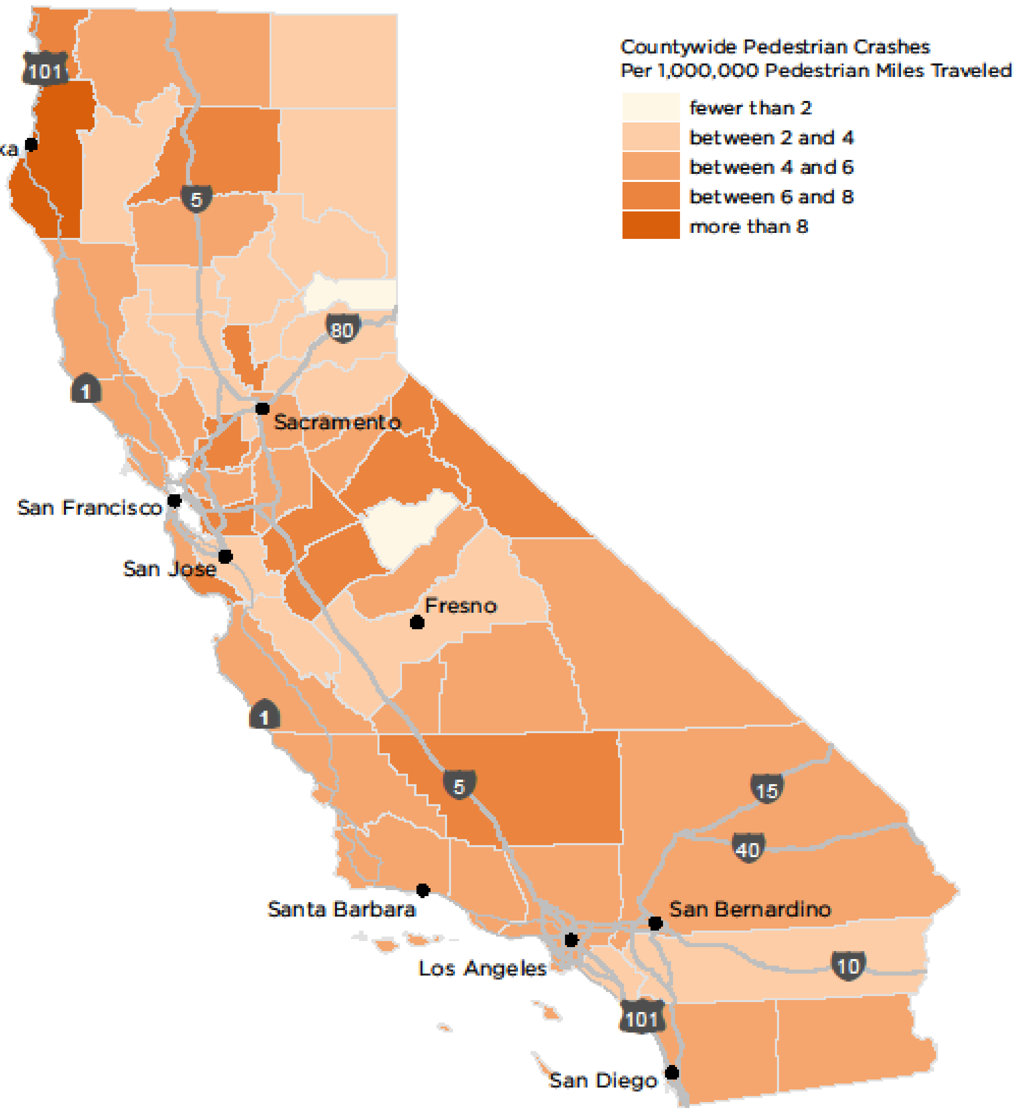
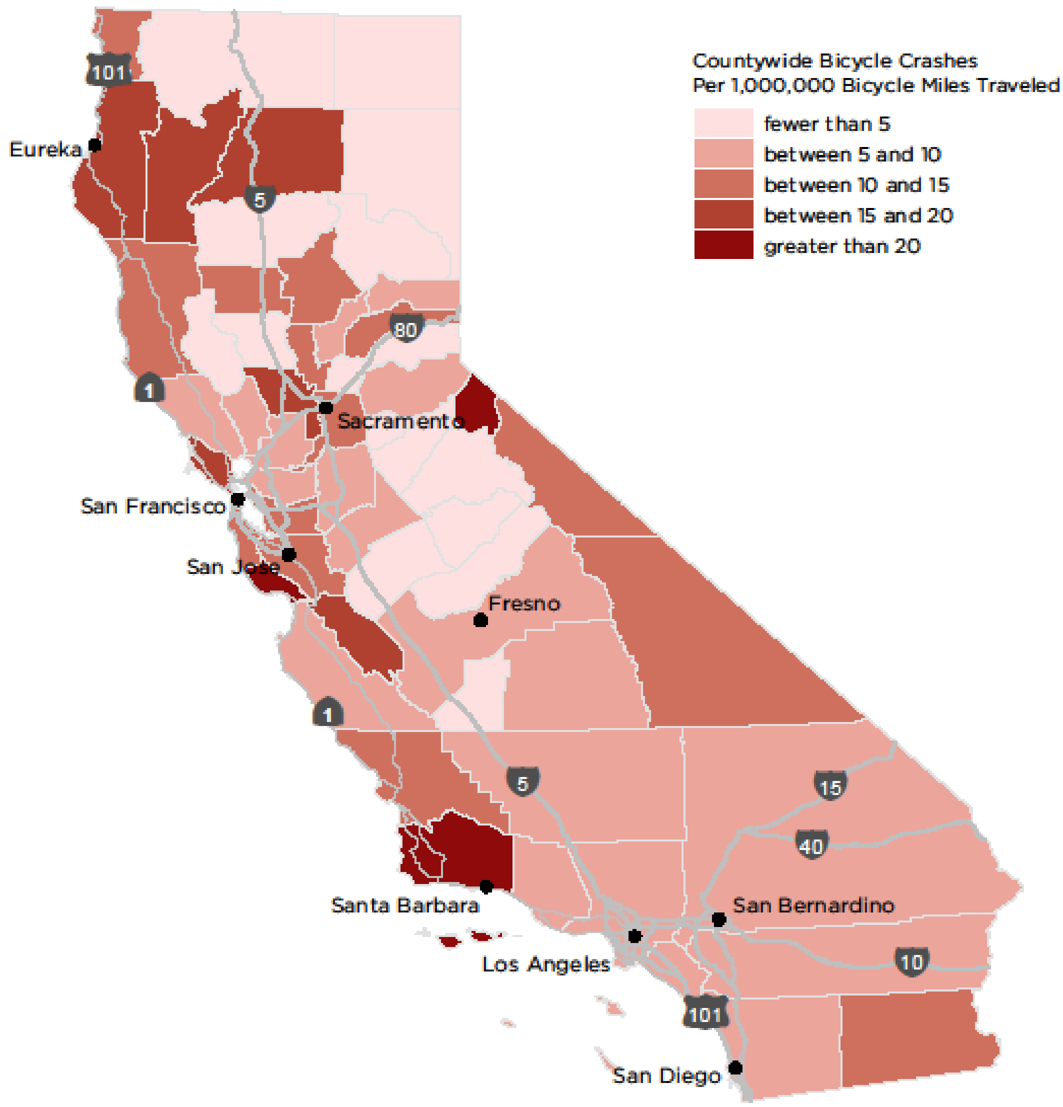


Figure 3 Bicycle Collisions per Estimated Bicycle Mile Traveled, 2005-2014



The counties with the highest calculated collision rates for each mode are shown in Table 1 and Table 2. For pedestrians, the three highest collision rate counties are Humboldt, Alpine, and Solano. For bicyclists, they are Alpine, Santa Cruz, and Santa Barbara. Alpine's apparently high rates are due in part to the relatively low rates of walking and bicycling – small deviations in the exposure rate (or small inaccuracies in its estimation) could lead to large changes in the calculated rate. Further, there could be inaccuracies in the exposure estimates for regions of the county which experience high rates of bicycle tourism, which is travel that would not be attributed to residents of the county. This could partially explain the apparently high risk rates in Santa Cruz and Santa Barbara counties. There is no immediately clear relationship or similarity between the high risk counties, although more in-depth study into the factors affecting these collision rates is warranted.

Table 1 Top pedestrian crash-rate counties, 2005-2014

County	Pedestrian Collision Rate (Per Million Miles)	Number of Pedestrian Crashes, 2005-2014
Humboldt	11.09	578
Alpine	7.71	4
Solano	7.19	1202
Merced	7.16	715
Santa Cruz	7.02	953
Tuolomne	7.00	154
Sutter	6.86	261
Kern	6.52	2506
Stanislaus	6.43	1741
Del Norte	6.38	80

Table 2 Top bicycle crash-rate counties, 2005-2014

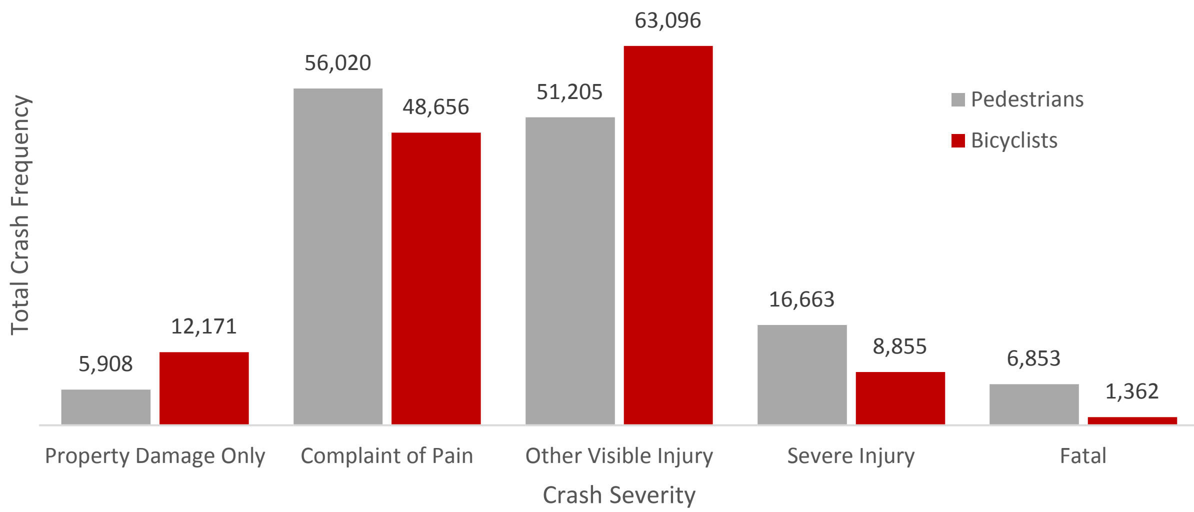
County	Bicycle Collision Rate (Per Million Miles)	Number of Bicycle Crashes, 2005-2014
Alpine	48.97	17
Santa Cruz	24.57	1944
Santa Barbara	21.35	2587
Shasta	18.51	469
San Benito	17.58	148
Marin	17.05	1422
Yolo	16.90	1094
Humboldt	16.76	644
Trinity	15.54	27
Glenn	13.78	52

Collision Severity

Figure 4 depicts the total number of reported pedestrian and bicyclist-involved crashes between 2005 and 2014 statewide by collision severity. "Collision severity" here refers to the level of the highest severity injury incurred within a given crash. Low-severity crashes, especially Property Damage Only and Complaint of Pain, are known to be disproportionately underreported, as the data being used here comes from police reports which are only created when police are called to a crash. One study found that 55 percent of trauma center patients were not associated with a record in SWITRS.[15] While the total number of crashes experienced is comparable between pedestrians and bicyclists, a greater share of the pedestrian crashes are high severity (severe injury or fatality).

[15] See Lopez, D. S., Sunjaya, D. B., Chan, S., Dobbins, S., & Dicker, R. A. (2012). Using trauma center data to identify missed bicycle injuries and their associated costs. *Journal of Trauma and Acute Care Surgery*, 73(6), 1602-1606. https://www.ncbi.nlm.nih.gov/pubmed/23032807

Figure 4 Pedestrian and Bicyclist Collision Severity, 2005-2014



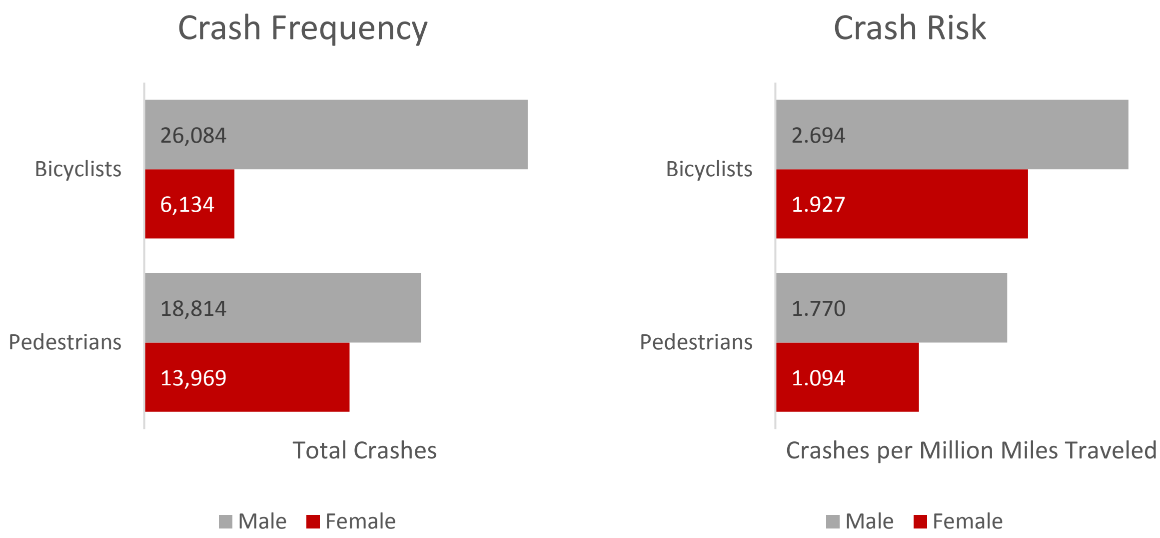
Victim Characteristics

This section presents the demographic breakdown of collision victims (parties who sustained any degree of injury). For each demographic factor, the raw number of crashes is presented, as well as on an exposure-adjusted basis. A relatively naïve calculation of miles traveled is used, based entirely on the CHTS statewide results. Longitudinal changes in the relative rates of change between subpopulations (e.g. rising rates of women bicycling) have not been accounted for due to a lack of high quality longitudinal data with demographic information. Therefore, all of the analysis in this section assumes that these relative rates do not change, and simply uses the total.

Gender

The majority of victims sustaining injuries while walking or bicycling are male, as can be seen in Figure 5. The difference is particularly pronounced in the case of bicycle collision victims, where 80% of the collision victims are male. However, these differences are largely attributable to differences in exposure. Controlling for exposure yields respective pedestrian collision rates (per million miles traveled) of 1.09 for females and 1.76 for males, and bicycle collision rates of 1.93 for females and 2.69 for males, suggesting that males are at a slightly elevated collision risk relative to females.

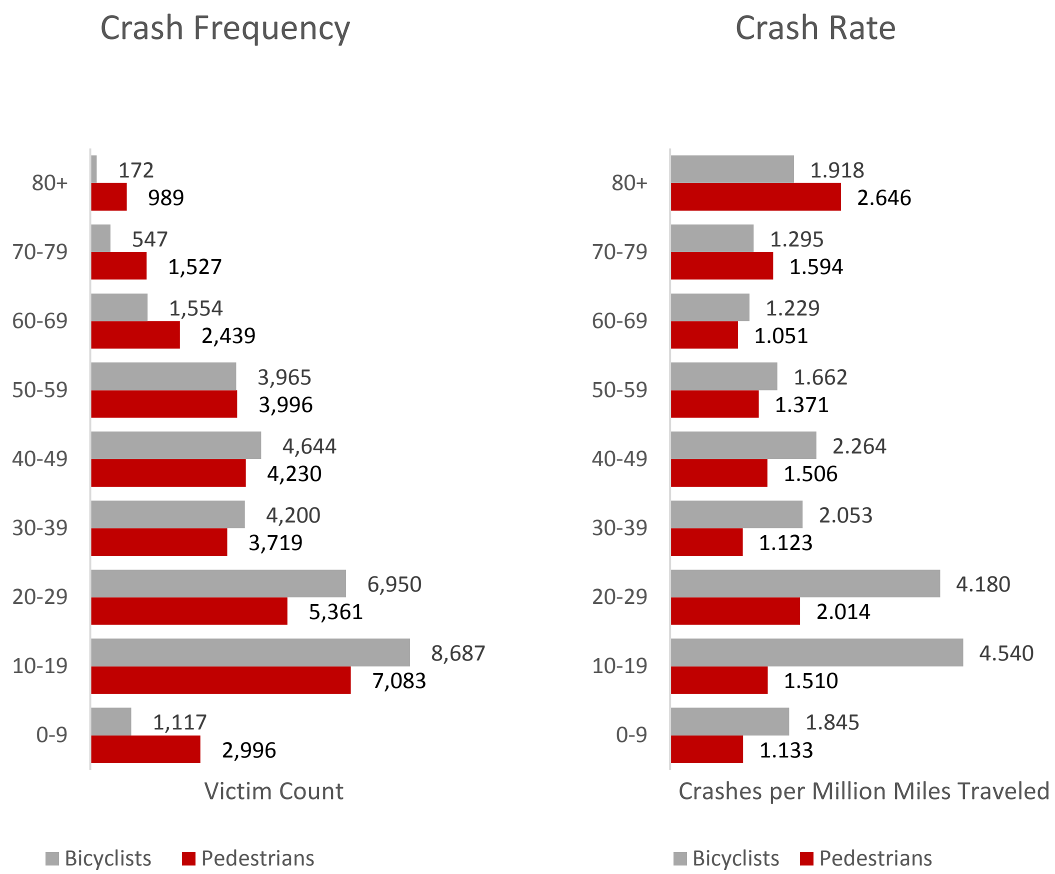
Figure 5 Pedestrian and Bicyclist Collision Frequencies and Rates by Gender, 2005-2014



Age

Pedestrians and bicyclists between **10-19 years old** were the most frequently injured in collisions between 2005 and 2014, followed by victims aged **20-29 years old**. The full age distribution of collision victims is shown in Figure 6 alongside the number of crashes normalized by miles traveled for each age group. On this basis, it appears that pedestrian collision risk increases above 80 years of age, while bicyclists between 10 and 29 years old are at an elevated risk.

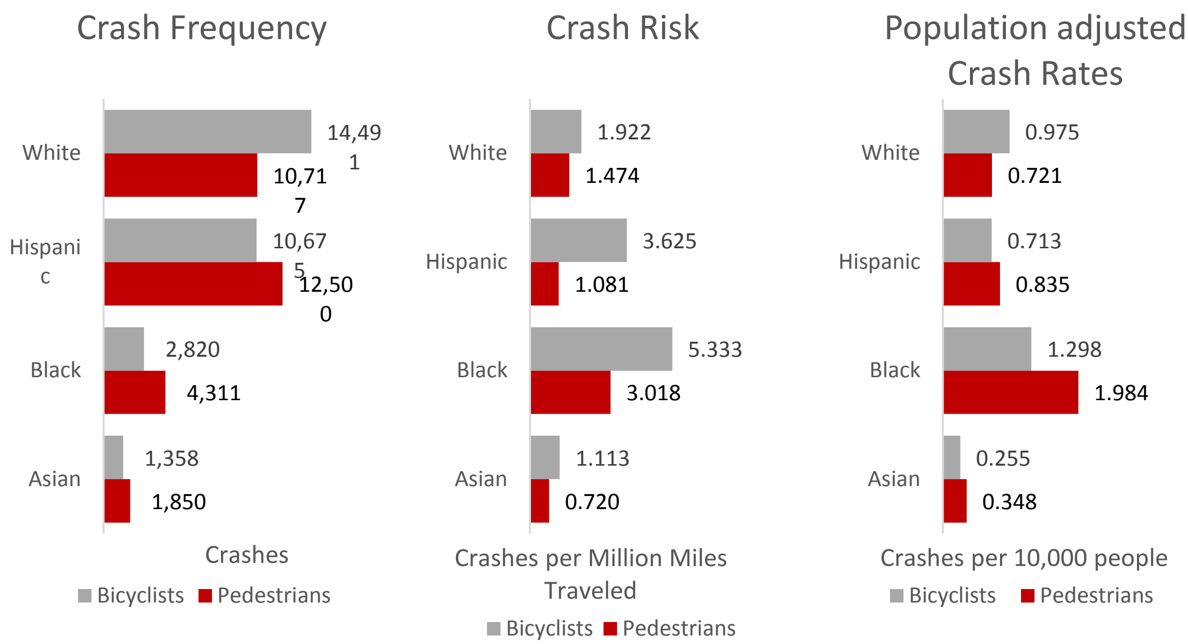
Figure 6 Age Distribution of Pedestrian and Bicycle Collision Victims and Collision Risk, 2005-2014



Race

Figure 7 shows the racial breakdown of pedestrian and bicycle collision victims statewide between 2005 and 2014. The majority of collision victims are white or Hispanic, as these are the largest racial groups by population statewide. Adjusting for miles traveled, it appears that Hispanic and black bicyclists are at elevated risk levels relative to white bicyclists, but pedestrian risk levels are more balanced across racial groups. In comparison to relative population sizes (based on the 2014 American Community Survey), black members of the population appear to bear a disproportionate burden of traffic crashes, particularly as pedestrians.

Figure 7 Racial Distribution of Pedestrian and Bicycle Collision Victims, 2005-2014



There is some discrepancy between the definitions of race used in the collision data and the CHTS data, so these results are not entirely conclusive. SWITRS uses single race categories, while CHTS allows respondents to self-identify up to 4 races, and includes "Hispanic" as a separate question and not as a predominant racial category. Furthermore, miles traveled could be a misleading exposure unit to use for analyzing racial disparities, as disadvantaged populations may have higher walking/bicycling exposure rates due to lack of access to alternatives, leading to a disproportionate burden. To help account for this, we also consider population adjusted rates which suggest that black individuals experience a disproportionate share of bicycle and pedestrian crashes.

Collision Characteristics

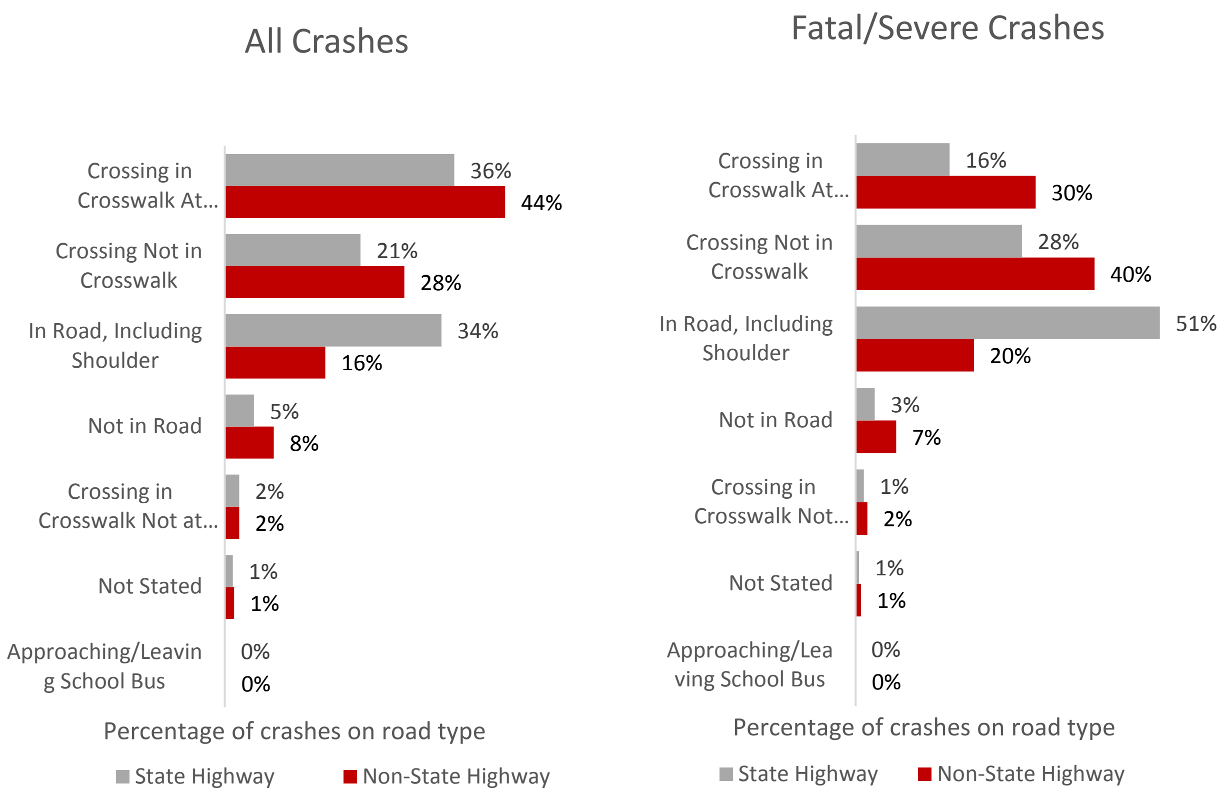
Pedestrian Action

To classify pedestrian crashes, we consider the pedestrian's recorded action for each of the observed pedestrian crashes. On state highways, just over one third of collisions occurred within a crosswalk at an intersection, while 44 percent of crashes off the state highway system occurred in this situation (Figure 8). The second most commonly reported scenario for state highways is pedestrians in the road or shoulder (34%). Crashes not in crosswalks make up 21 percent of pedestrian-involved crashes on state highways and 28 percent on state highways off state highways.

It stands to reason that the majority of pedestrian crashes occur in crossing situations, as this is when the pedestrian is most exposed to conflicting motor vehicle traffic. It is unclear from the data if some of the crashes recorded as pedestrian crossing not in a crosswalk are crossing in unmarked crosswalks at intersections or at midblock locations without a crosswalk.

Focusing on pedestrian crashes resulting in severe or fatal injuries, a slightly different pattern emerges. On state highways, the majority of these crashes (51%) occur with the pedestrian in the road or highway shoulder. As speed is known to be a major contributing factor to collision severity, this makes sense considering that the scenarios resulting in pedestrians being in the road or shoulder on state highways are likely to largely be along grade separated highways with high traffic speeds. On non-state highways, a much larger share of high severity crashes (compared with all crashes) occur with pedestrians crossing outside of crosswalks.

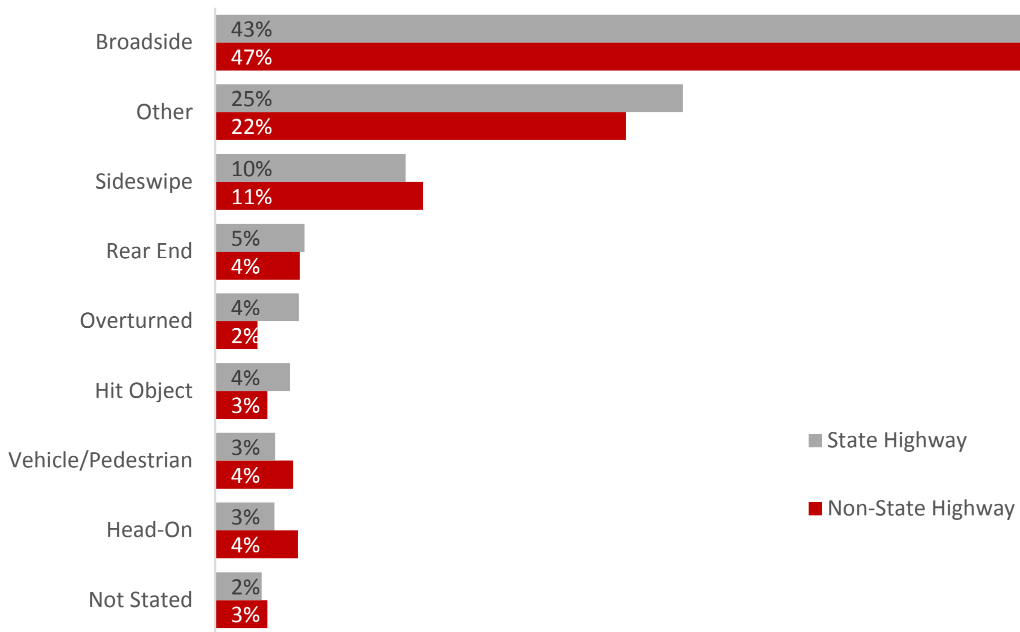
Figure 8 Pedestrian actions in pedestrian crashes, 2005-2014



Bicycle Collision Types

On both state highways and non-state highways, **broadside was the most common type of collision that occurred, accounting for over 44 percent of bicycle collisions on each road type**. Figure 9 shows the types of bicycle collisions that occurred on state highways and non-state highways.

Figure 9 Type of Bicycle Collisions on State Highways vs. Non-State Highways, 2005-2014



Time of Day

Pedestrian collisions on state highways and non-state highways followed a similar pattern, peaking at **6pm-midnight** on weekdays, and at midnight-6am on weekends. Figure 10 and Figure 11 show the percentage of pedestrian collisions that occurred by time periods on weekdays and weekends, respectively.

Figure 10 Pedestrian Collisions by Time Periods on Weekdays, 2005-2014

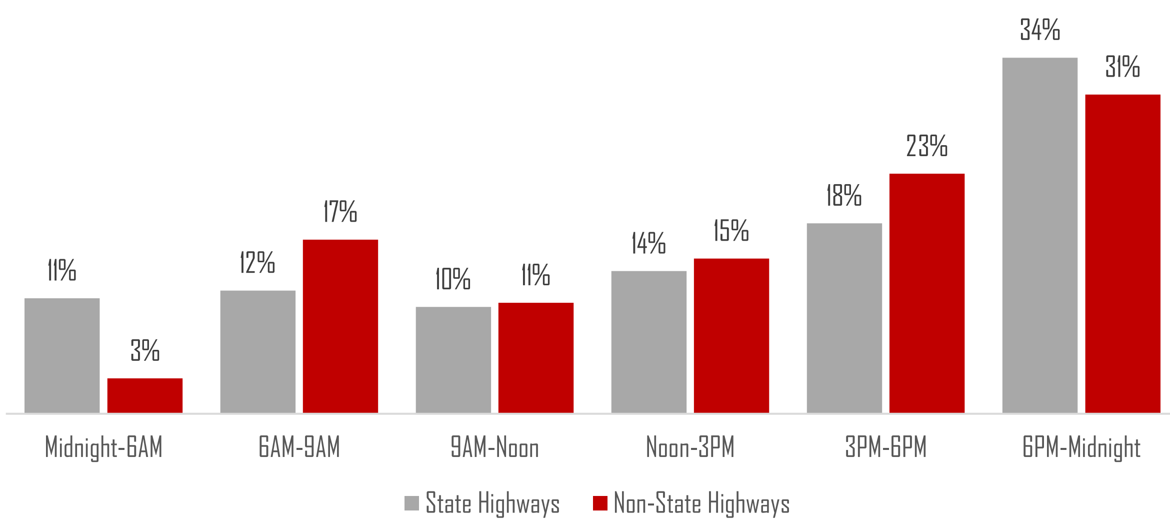
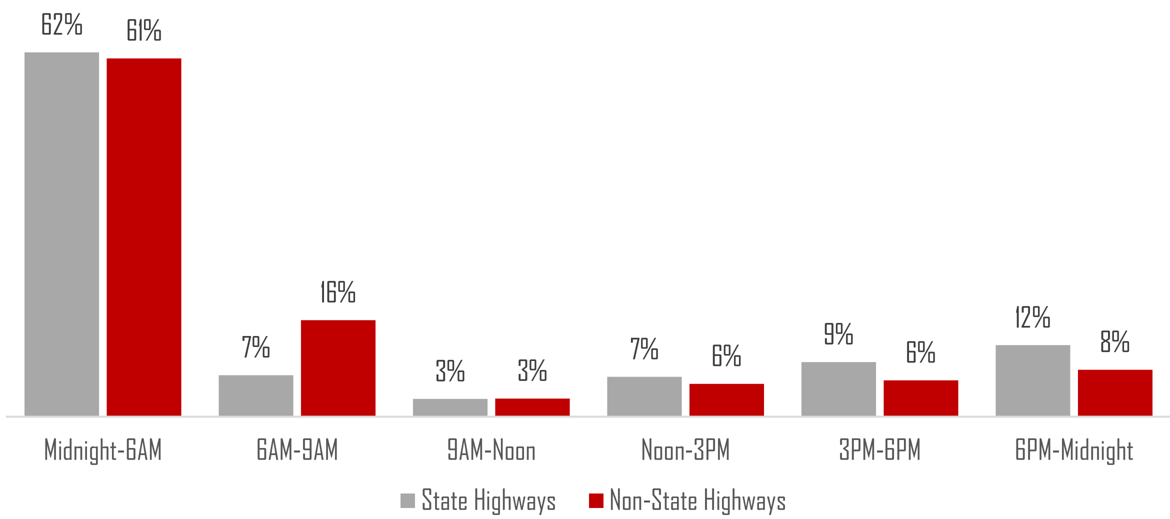


Figure 11 Pedestrian Collisions by Time Periods on Weekends, 2005-2014



Bicycle collisions on weekdays followed a similar pattern for both state highways and non-state highways, peaking at **3-6pm**. On weekends, more collisions occur at **9am-noon** on state highways, while on non-state highways the majority of collisions occur at **midnight-6am**.

Figure 12 and Figure 13 show the percentage of bicycle collisions that occurred by time periods on weekdays and weekends.

Figure 12 Bicycle Collisions by Time Periods on Weekdays, 2005-2014

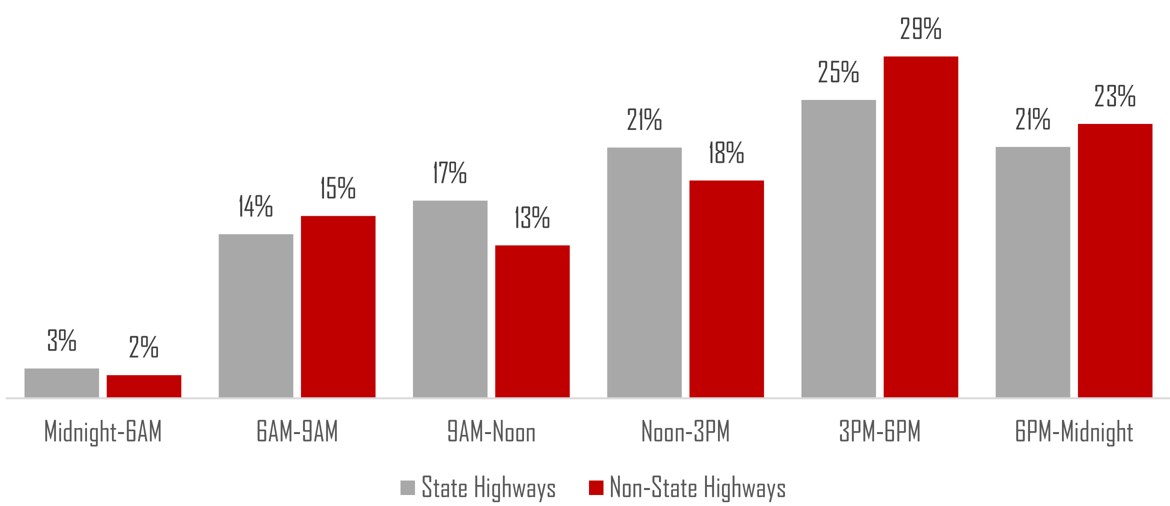
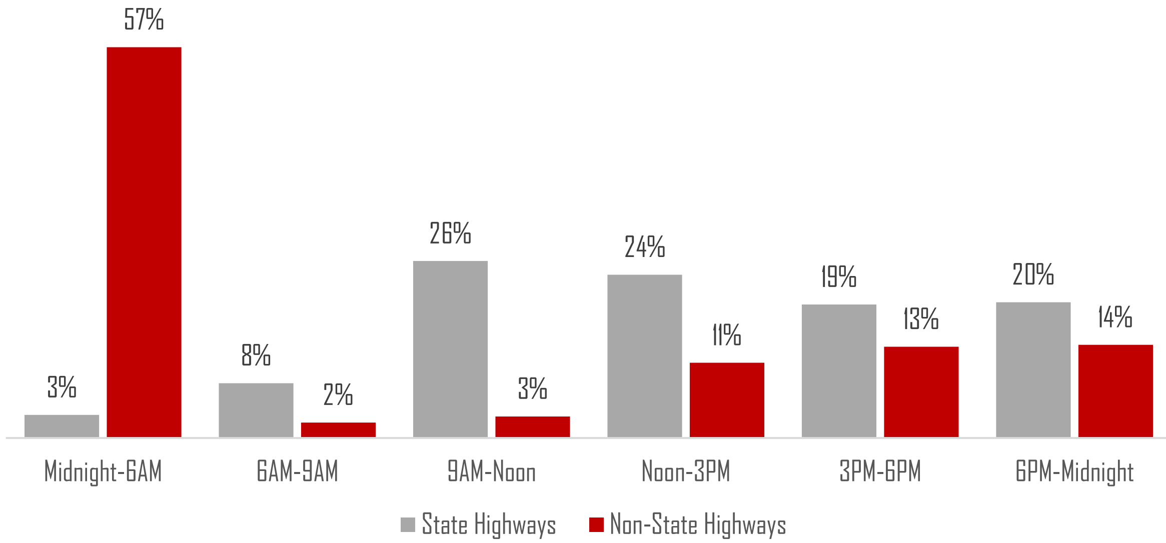


Figure 13 Bicycle Collisions by Time Periods on Weekends, 2005-2014



5. Collision Causes

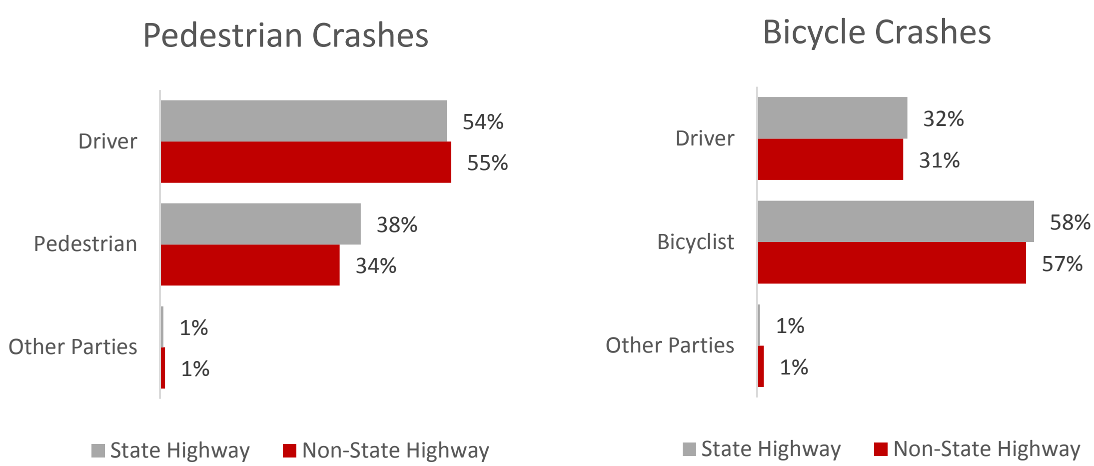
Fault

In most crashes[16], one party is found to be at fault for the collision, and other parties may have "Other Associated Factors" assigned to them based on their involvement in the collision cause. Figure 14 shows the percentage of pedestrian and bicycle crashes both on and off state highways in which each party of type was found at fault. The percentages do not add to 100%, as some crashes do not include any at-fault parties.

The determination of fault in crashes is an inexact science. The California Highway Patrol's Collision Investigation Manual does not provide detailed guidance on the method to determine fault, and there may be some inaccuracies in how fault gets coded, particularly in controversial cases.

Drivers are found to be at fault in approximately 55% of all pedestrian crashes, and pedestrians are at fault in approximately 35%. Bicyclists are found to be at fault in approximately 58% of all bicycle crashes, while drivers are found at-fault in approximately 31% of bicycle-involved crashes. These rates do not substantially differ between crashes on state highways and crashes not on state highways.

Figure 14 At-fault parties in pedestrian and bicycle-involved crashes, 2005-2014



Violations

For observed crashes where the primary collision factor was found to be a vehicle code violation[17], Tables Table 3-Table 6 show the most common vehicle code violations for each primary mode group in both pedestrian and bicycle crashes, including all crashes statewide and crashes occurring on state highways. Violations making up small shares of the total have been omitted from the tables, so the percentages do not sum to 100%. The tables are sorted by the share of crashes attributed to a given violation statewide. The ranking of shares is similar between statewide and for crashes on state highways.

[16] 89.6% of pedestrian crashes and 89.0% of bicycle crashes

[17] As opposed to "other improper driving", "other than driver", "unknown", or "fell asleep".

Table 3 Primary Pedestrian Violations in Pedestrian Crashes, 2005-2014

		Statewide		State Highways	
Violation	Description	Number	Percent [18]	Number	Percent
21954(a)	Pedestrians on road outside of crosswalks shall yield right-of-way to all vehicles	25,519	65%	2,910	66%
21950(b)	Pedestrians must exercise due care for own safety when entering a crosswalk	5,853	15%	518	12%
21456(b)	Failure to obey pedestrian signal	2,821	7%	324	7%
21956(a)	Outside of residential/business districts, pedestrians must walk close to left-hand edge of roadway	1,922	5%	269	6%
21453(d)	Unless directed to by pedestrian signal, pedestrians must obey red traffic signals	1,098	3%	114	3%
21950(a)	Failure to yield right-of-way to pedestrian in marked or unmarked crosswalk	412	1%	30	1%
21461.5	Pedestrians must obey regulatory signage	316	1%	114	3%

Table 4 Primary Driver Violations in Pedestrian Crashes, 2005-2014

		Statewide		State Highways	
Violation	Description	Number	Percent	Number	Percent
21950(a)	Failure to yield right-of-way to pedestrian in marked or unmarked crosswalk	38,379	76%	2,982	70%
21453(a)	Did not stop before reaching marked limit line	1,945	4%	188	4%
23152(a)	Driving under the influence	1,857	4%	424	10%
21804(a)	Failure to yield when entering or crossing highway	1,025	2%	60	1%
21801(a)	Failure to yield when making left/U-turn	936	2%	30	1%
22450(a)	Did not stop at a stop sign before entering an intersection	793	2%	30	1%
21950(c)	Failure to exercise due care and reduce speed when approaching a pedestrian within a crosswalk	711	1%	50	1%

Both on- and off-state highways, the majority of violations committed by pedestrians resulting in pedestrian crashes are pedestrians failing to yield outside of marked or unmarked crosswalks. The most common

[18] The percentages listed in these tables represent conditional probabilities – that is, these percentages are the share of pedestrian crashes on state highways where the pedestrian was at fault where each violation was found to be the Primary Collision Factor.

driver violation in pedestrian crashes is failure to yield right-of-way to pedestrians in marked or unmarked crosswalks,

Table 5 Primary Bicyclist Violations in Bicycle Crashes, 2005-2014

		Statewide		State Highways	
Violation	**Description**	Number	Percent	Number	Percent
21650.1	Wrong way bicycling	19,790	39%	1,887	42%
21804(a)	Failure to yield when entering or crossing highway	7,512	15%	509	11%
21202(a)	Bicyclist did not ride as close as practical to the right-hand curb or edge of roadway	5,554	11%	538	12%
21453(a)	Did not stop before reaching marked limit line	4,933	10%	595	13%
22450(a)	Did not stop at a stop sign before entering an intersection	2,825	6%	52	1%
21200.5	Bicycling under the influence	1,721	3%	226	5%
21802(a)	Failure to stop at stop sign	1,582	3%	127	3%
21658(a)	Improper lane changing	978	2%	100	2%

Table 6 Primary Driver Violations in Bicycle Crashes, 2005-2014

		Statewide		State Highways	
Violation	**Description**	Number	Percent	Number	Percent
21801(a)	Failure to yield when making left/U-turns	6,514	29%	482	23%
21804(a)	Failure to yield when entering or crossing highway	3,193	14%	224	11%
21802(a)	Failure to stop at stop sign	2,811	12%	201	10%
21453(a)	Did not stop before reaching marked limit line	1,843	8%	226	11%
22450(a)	Did not stop at a stop sign before entering an intersection	1,365	6%	58	3%
21950(a)	Failure to yield right-of-way to pedestrian in marked or unmarked crosswalk	1,352	6%	157	8%
21453(b)	Failure to yield to pedestrians in crosswalk when making right-turn on red	805	4%	151	7%
21658(a)	Improper lane changing	771	3%	107	5%
21451(a)	Failure to yield right-of-way to other traffic in intersection, including to pedestrians in crosswalk	701	3%	99	5%
23152(a)	Driving under the influence	498	2%	60	3%

For bicycle crashes, the main violations are more distributed across violation types than for pedestrian crashes. Bicyclists three most common violations statewide are bicycling the wrong way, failure to yield when entering/crossing highway, and not riding as close as is practicable to the right edge of the roadway. For drivers at fault in bicycle crashes, the most common violation codes statewide were failing to yield when making left/U-turns, failure to yield when entering/crossing highway, and failure to stop at stop sign.

6. Corridor Analysis

Corridors are analyzed separately for pedestrians and bicyclists on a per-mile basis for the numbered routes in each county. Corridors are defined separately by county to help control for the substantial variation that can exist along a single numbered highway. Routes are filtered out as outliers if they are shorter than 0.1 mile or have fewer than 5 crashes. The top 15 highest collision frequency corridors are shown for pedestrian crashes in Table 5 and for bicycle crashes in Table 6.

These results do not control for exposure. The majority of corridors with above average collisions for both pedestrians and bicyclists are surface highways in urban areas, suggesting that these are locations of high pedestrian and bicyclist exposure, not necessarily high risk locations. To properly evaluate how risk varies between these corridors a spatially resolved exposure measure, such as pedestrian and bicycle counts on the corridor, is needed.

Table 7 Pedestrian Corridors with Above Average Collisions, 2005-2014

County	Route	Mileage	Crashes	Crashes Per Mile
Alameda	**123**	10.4	109	10.5
Los Angeles	**19**	5.8	48	8.3
San Francisco	**101**	24.3	200	8.2
Orange	**39**	40.0	306	7.7
Alameda	**185**	20.3	143	7.1
Contra Costa	**123**	4.4	31	7.1
Orange	**72**	1.0	7	7.0
Alameda	**112**	3.6	25	7.0
Solano	**29**	11.9	83	7.0
San Francisco	**1**	14.2	95	6.7
San Mateo	**82**	50.3	325	6.5
San Bernardino	**66**	6.5	38	5.8
Santa Clara	**82**	33.3	188	5.7
Kern	**204**	9.6	54	5.6
San Diego	**282**	1.3	7	5.5

Table 8 Bicyclist Corridors with Above Average Collisions, 2005-2014

County	Route	Mileage	Crashes	Crashes Per Mile
Orange	**39**	40.0	401	10.0
Santa Clara	**82**	33.3	321	9.6
San Diego	**282**	1.3	12	9.4
Alameda	**123**	10.4	97	9.4
Orange	**1**	52.8	430	8.1
Los Angeles	**66**	6.4	44	6.8
Los Angeles	**19**	5.8	33	5.7
Contra Costa	**123**	4.4	24	5.5
San Mateo	**82**	50.3	243	4.8
Los Angeles	**72**	13.5	64	4.7
Alameda	**13**	19.4	78	4.0
San Bernardino	**66**	6.5	26	4.0
San Francisco	**101**	24.3	95	3.9
Alameda	**185**	20.3	73	3.6
Los Angeles	**1**	123.2	423	3.4