Measuring the Impact of Complete Streets Projects on Bicyclist and Pedestrian Safety in Sacramento County, CA

Image Source: Broken Sidewalk

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Introduction

For decades, the United States' roadway system has been designed with one primary goal in mind: moving cars through space as quickly as possible. Over the course of the 20th century, transportation planners and traffic engineers lost sight of the multifaceted role that streets play in people's lives and, instead, focused on designing roads for cars rather than people. The result is a roadway system that does not meet the needs of all Americans and puts many of them in harm's way. In 2014, 32,675 people died in motor vehicle crashes and 5,813 of these crashes (17.8%) involved a pedestrian or bicyclist (National Highway Traffic Safety Administration, 2016).

Complete streets is a roadway design that aims to address the errors of the 20th century and make streets work for people once again. Complete streets allow users of all kinds, whether travelling by bike, car, public transit, walking, or wheeling, to safely use streets regardless of their age or ability. Streets allow individuals to get to work and to school, to access healthcare and other destinations, and to interact with civic life. Complete streets are intended to make these journeys comfortable, convenient, and safe for everyone by adding features like wide, buffered sidewalks, crosswalks, medians, and bike lanes. By incorporating these features, complete streets can decrease the risk of being involved in a crash for all street users.

This paper aims to quantify the impact of complete streets projects on pedestrian and bicyclist safety. By examining crashes before and after complete streets projects, this study will lead to a better understanding of the cumulative effect of complete streets projects on pedestrian and bicyclist safety. Using data provided by the Sacramento Department of Transportation, a subset of projects completed between 2011 and 2014 were selected and analyzed to determine the number of pedestrian and bicyclist crashes in the 24 months before and after these complete streets projects were constructed and calculate rates of crashes for bicyclists and pedestrians.

Literature Review

What are complete streets?

Complete streets are a design tool that reallocates street space to benefit users of different transportation modes. They allow users of all kinds, whether travelling by bike, car, public transit, walking, or wheeling, to safely use all streets regardless of their age or ability. People use streets to get to work or school, to access healthcare and other destinations, and to interact with civic life. Complete streets make these journeys comfortable, convenient, and safe for everyone.

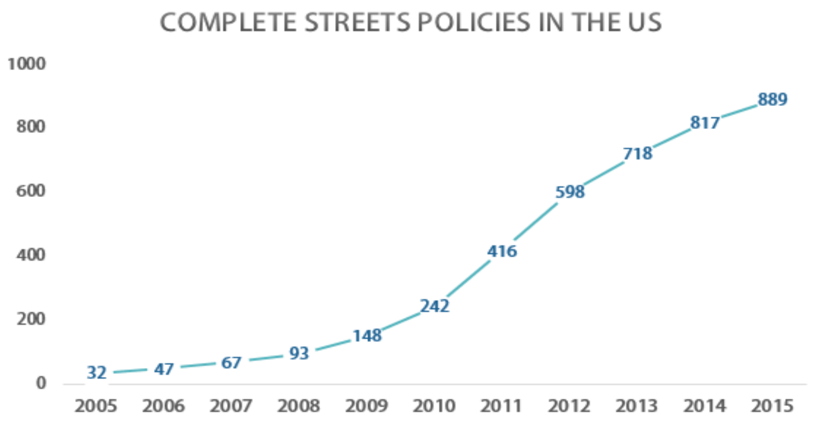
While all complete streets have similar goals, there is no list of required features complete streets must include. According to the National Complete Streets Coalition, though, complete streets projects often include: wider and improved sidewalks, bike lanes, curbcuts and ramps, crosswalks and pedestrian refuge islands, center left turn lanes, landscaping and street trees, and transit-only lanes and upgraded transit shelters (National Complete Streets Coalition, 2016).

As of April 2016, 889 states, regional governments, counties, and municipalities across the United States have adopted a complete streets policy (Smart Growth America, 2016). The concept of complete streets has gained momentum among a wide variety of groups, including grassroots organizations, community members, policy makers, and politicians, due to its wide array of benefits, relatively low costs, and ease of implementation.

The increase in complete streets policies has also been influenced by federal transportation policies and increased funding and support for walking and bicycling (Cradock et al., 2009). In 1992, the U.S. Department of Transportation Federal Highway Administration (2016) provided $22.9 million for pedestrian and bicycle facilities programs; in 2015, funding was $833.7 million (after peaking at $1.18 billion in 2009). Additionally, the Moving Ahead for

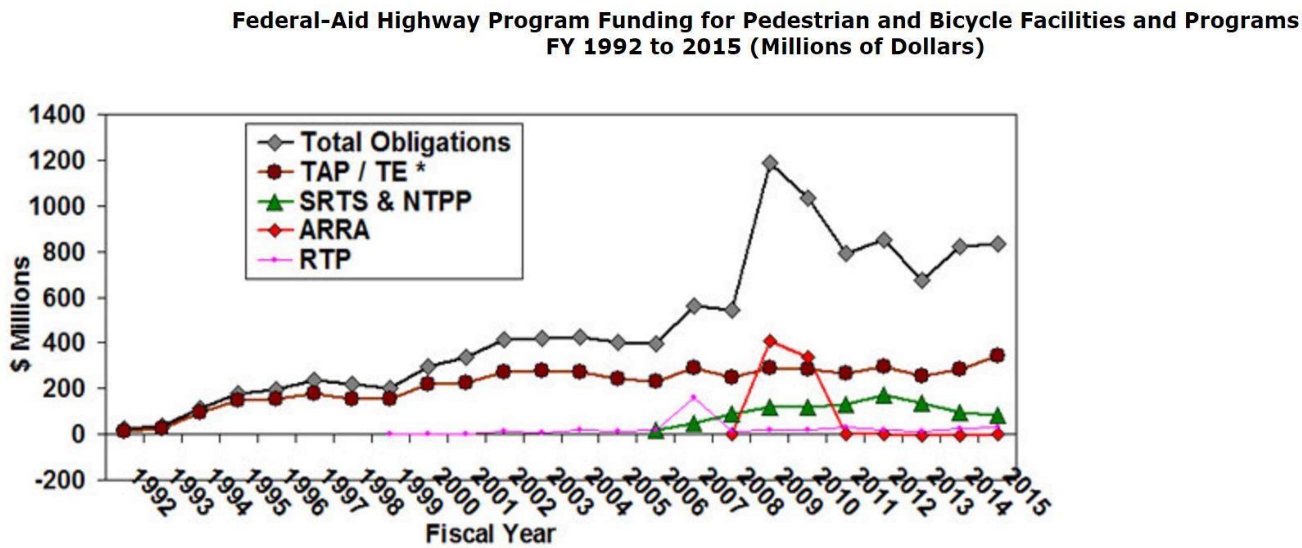
Progress in the 21st Century (MAP-21) bill passed in 2012 included a number of programs that encourage the use of design features of complete streets (e.g., Surface Transportation Program, Congestion Mitigation and Air Quality Improvement Program, Safe Routes to School, Recreational Trails, and others).

Figure 1. Increase in Complete Streets Policies in the U.S.



Data source: Smart Growth America, 2016.

Figure 2. Federal Pedestrian and Bicycle Funding 1992-2015[1]



Source: U.S. Department of Transportation Federal Highway Administration, 2016.

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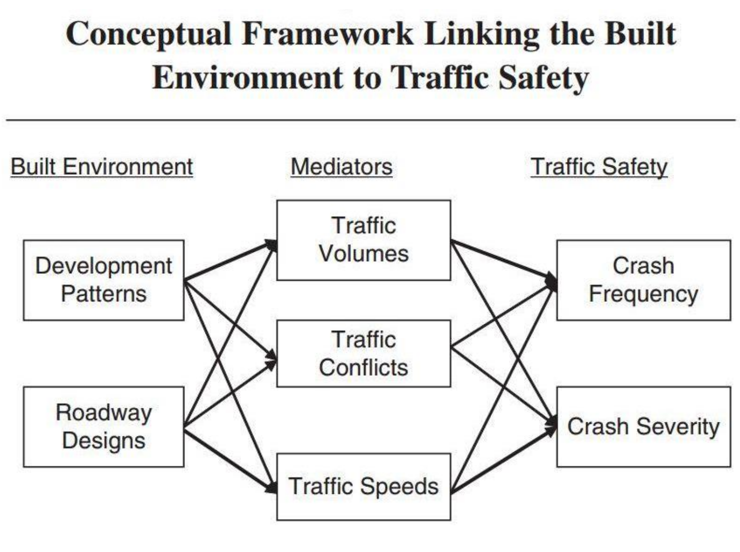
[1] TAP= Transportation Alternatives Program, TE= Transportation Enhancement Activities, SRTS= Safe Routes to School, NTPP= Nonmotorized Transportation Pilot Program, ARRA= American Recovery and Reinvestment Act, RTP= Recreational Trails Program

Safety Benefits of Complete Streets

Complete streets improve safety for pedestrians, bicyclist, and drivers alike. In their 2009 paper *The Built Environment and Traffic Safety,* Ewing and Dumbaugh develop a conceptual framework to link the built environment and traffic safety. Ewing and Dumbaugh's framework (see Figure 3) emphasizes that roadway design influences the number of crashes and the severity of crashes through the mediators of traffic volumes, traffic conflicts, and traffic speeds. Traffic volume is the primary determinant of the number of crashes, and traffic speed is the primary determinant of crash severity (Ewing and Dumbaugh 2009, p.348). Litman and Fitzroy (2005) found that vehicle miles traveled (VMT) and per capita traffic fatalities have a linear relationship: in urban areas, a 1% increase in VMT is associated with a 1% increase in traffic fatalities. Regarding speed as the primary determinant of crash severity, studies show that a pedestrian struck by a vehicle traveling 20 miles per hour or less has a 5% chance of being killed. If the vehicle is traveling 30 miles per hour the fatality rate increase to 45%, and at 40 miles per hour the fatality rate is 85% (UK Department of Transportation, 1987 and Trowbridge and McDonald, 2008).

Figure 3. Conceptual Framework Linking the Built Environment and Traffic Safety



Source: Ewing and Dumbaugh, 2009.

Traffic volumes tends to stay the same or decrease slightly after complete streets redesigns (Litman, 2015; Schlossberg, Rowell, Amos, and Sanford, 2013), so the mediator of traffic volumes will not be greatly affected by complete streets projects. Some complete street projects reduce speed limits, but, more typically, complete street projects communicate low travel speeds to drivers through design changes, for example by narrowing lane width. Narrower lanes can lead to decreases in vehicle operating speeds based on the simple premise that drivers feel comfortable driving faster when they have more space (Gattis and Watts, 1999). Other common elements of complete streets projects like landscaping and street furniture have also been found to reduce vehicular collisions as well as bicyclist and pedestrian injuries and fatalities (Dumbaugh, 2005).

Complete streets also reduce traffic conflicts by allocating space for different modes more equally and limiting interaction between users of different modes. Having bicyclists in bike lanes, pedestrians on sidewalks, and cars in travel lanes reduces the number of potential conflicts. Points where interaction between users of different modes occurs (e.g., intersections)

Figure 4. Example of Bike Box Installation

Source: National Association of City Transportation Officials.

are often given added emphasis through special treatments in complete streets projects (e.g., bike boxes and high intensity activated crosswalk (HAWK) signals for pedestrians). These treatments make all users more aware of one another and prepare them for actions such as merging, turning, and crossing.

Street users, whether bicyclists, pedestrians, transit users, or drivers, understand the safety benefits of clearly designating space for all users. A study examining perceived comfort while driving and bicycling on various roadways conducted by Sanders (2016), found that all road users, whether non-bicycling drivers, bicycling drivers, or non-driving bicyclists, prefer bicycle treatments that clearly indicate when and where to expect bicyclists (e.g., barrier-separated bike lanes, lanes on streets without parallel parking) as opposed to roadway designs with shared space between bicyclists and motorists (e.g., sharrows or no treatment).

A number of studies have evaluated the safety impact of pedestrian modifications that are often part of complete streets projects, such as crosswalks, raised medians, and sidewalks. One common element of complete streets projects is re-painting and upgrading of crosswalks. Numerous studies (Dulaski, 2006; Huang et. al., 2001; Knoblauch, Nitzburg, and Seifert, 2001) have found that crosswalks are associated with higher pedestrian usage and decreased traffic speed approaching the crosswalk. Additionally, in a study of all pedestrian crashes in the state of New Jersey between 2007 and 2009, Hanson, Noland, and Brown (2013) found that the majority of crashes (65%) occurred in areas without crosswalks. Hanson, Noland, and Brown (2013) also used a binomial logit model to examine factors influencing whether pedestrians involved in crashes were injured or killed and found that the presence of sidewalks and buffers were associated with improved survival rates (95% confidence level). Other studies have found that crashes involving pedestrians are more likely to occur on streets without sidewalks (Knoblauch, Nitzburg, and Seifert, 2001).

The implications of roadway design on motor vehicle collisions with bicyclists has received less attention in the literature than vehicular and pedestrian collisions; however, multiple studies have shown that streets with bike lanes are safer for bicyclists than streets without any bike facilities (Moritz, 1998; Reynolds, Harris, Teschke, Cripton, and Winters, 2009). Injury rate, collision frequency, and crash rates are all lower on streets with bike lanes versus streets without any facilities (Moritz, 1998; Reynolds et al., 2009). Similarly, a study of cycle tracks in Montreal, Canada found that bicyclists riding in the cycle track had a 28% lower risk of injury compared to bicyclists on reference streets without any bike facilities (Lusk et al., 2011). These findings suggest that complete streets, which typically include bike facilities (though the type of facility may differ), are safer for bicyclists than streets without any bike facilities.

Table 1. Bike Facilities and Relative Danger[2]

TABLE 2 Relative Danger Associated with Various Bicycle Facilities

FACILITY TYPE	FRACTION OF COMMUTING KM	FRACTION OF CRASHES	RELATIVE DANGER +
Major street *	35.4%	44.6%	1.26
Minor street *	31.0%	32.1%	1.04
Bike lane/route #	18.4%	9.2%	0.50
Bike path	14.4%	9.6%	0.67
Other &	0.8%	4.4%	5.30
TOTALS	100.0%	100.0%	

NOTES: + - Fraction of crashes/fraction of commuting km.
* - No specific bike facilities provided.
# - Bike lane and bike routes combined.
& - Most frequently sidewalks.

Source: Moritz, 1998.

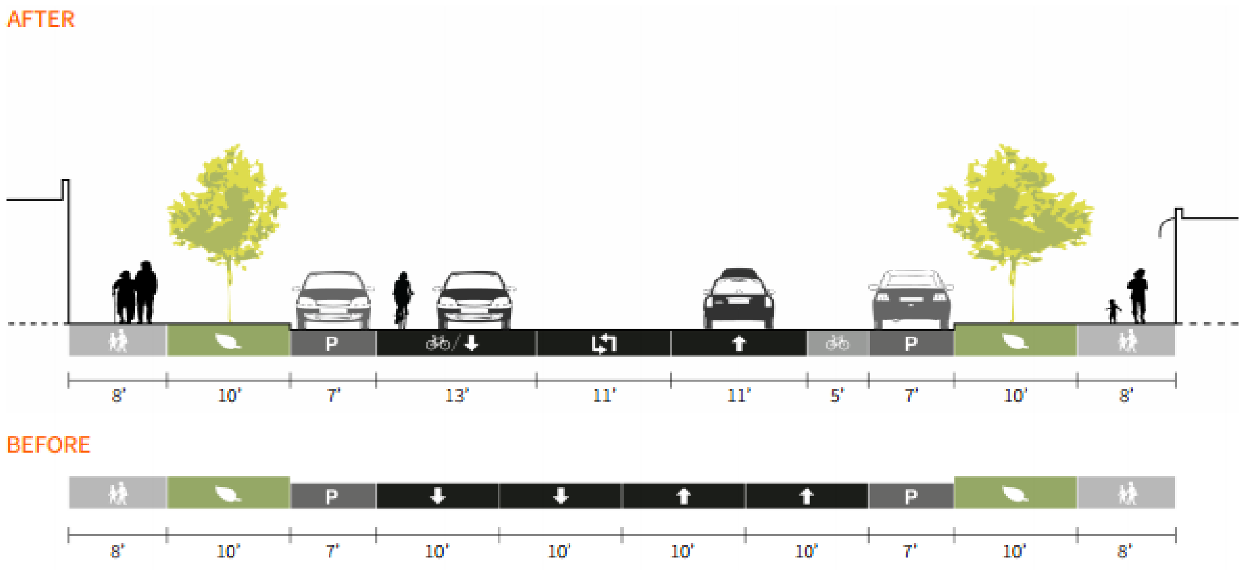
In addition to specific design features, complete streets improve bicycle and pedestrian safety through the theory of “safety in numbers.” Jacobsen’s (2003) paper on the topic examines five different data sets (from California, Denmark, Holland, the United Kingdom, and

[2] Major street= arterial or connector, Minor street= local road, Bike lane/ route= either a designated state bicycle route or road with a designated lane for bicyclists, bicycle path= an off-road, separated path for bicyclists.

other European countries) and finds that, in each case, the risk of collisions between motor vehicles and pedestrians and bicyclists decreases as more people walk or bicycle. Since complete streets projects encourage more people to walk and bicycle (Litman, 2011), complete streets can increase the phenomenon of “safety in numbers” and improve safety for pedestrians and bicyclists. “Safety in numbers” may improve safety in several ways: increasing awareness and anticipation of bicyclists and pedestrians being present in streets, creating more recognition of “typical” pedestrian and bicycle behavior, and increasing lobbying power of bicyclists and pedestrians to enact policies that prioritize their safety. The New York City Department of Transportation (NYCDOT) even lists the idea of safety in numbers as one of its main strategies for improving the safety of its streets and one of its main reasons for implementing complete streets projects (New York City Department of Transportation, 2013).

While many studies have examined the univariate impacts of common elements of complete street projects on pedestrian and bicyclist safety, fewer studies have attempted to measure the cumulative impact of complete streets projects on safety. One such study was conducted by the Seattle Department of Transportation (SDOT, 2010) along the Stone Way N. corridor. In July 2007, SDOT repaved a 1.2-mile segment of Stone Way N. and made the following improvements: converted four lanes to two lanes plus a center turn lane, added a bike lane on the uphill side of the street, added sharrows to a wider lane on the downhill side of the street, and added and/or upgraded crosswalks to meet new safety standards. Comparing the 28 months before and after the improvements, SDOT (2010) found that total collisions decreased by 14%, pedestrian collisions decreased 80% (from 5 to 1), and bicycle collisions remained the same (though an increase in cycling led to a decrease in collision rate).

Figure 5. Stone Way N. in Seattle Before and After Complete Street Redesign



Source: Schlossberg et al., 2013

The New York City Department of Transportation (NYCDOT) conducted a thorough review of its complete streets program in 2013, which included an analysis of the number of crashes with injuries before and after 38 complete streets projects. Although this analysis did not separate out pedestrian and bicycle collisions from motor vehicle collisions, NYCDOT found that the number of crashes with injuries was lower after the complete streets redesign for all 38 projects, varying from a 12% to 88% reduction (NYCDOT, 2013).

Complete Streets in California

California has been one of the leading states in encouraging and requiring the implementation of complete streets. California passed a statewide Complete Streets Act in 2008 requiring cities and counties to revise the circulation elements of their comprehensive plans to advance a, "balanced, multimodal transportation network that meets the needs of all users of streets, roads, and highways, defined to include motorists, pedestrians, bicyclists, children, persons with disabilities, seniors, movers of commercial goods, and users of public transportation, in a manner that is suitable to the rural, suburban, or urban context of the general plan" (California Assembly Bill 1358, 2008). At the time, only 93 jurisdictions in the country had adopted a complete streets policy, and only five other states had enacted statewide policies. As of June 2016, 106 cities, counties, and regions in California have adopted complete streets policies (National Complete Streets Coalition, 2016).

The California Department of Transportation (CALTRANS) has also forwarded the adoption and implementation of complete streets across the state. After the Complete Streets Act of 2008, CALTRANS issued Deputy Directive 64-R1 directing the organization to implement complete streets and requiring a Complete Streets Implementation Action Plan (CSIAP). As part of the CSIAP, CALTRANS has developed complete streets training programs, updated statewide standards to include complete streets principles, and created guidance for cities and counties.

The City of Sacramento's first foray into complete streets occurred in 2004 when the city adopted a new set of pedestrian-friendly street design standards that forwarded complete streets principles. Two years later, Sacramento amended its general plan to include the new standards, which were also included in the city's pedestrian master plan. One of the mobility goals in Sacramento's 2035 General Plan is to "plan, design, operate and maintain all streets and roadways to accommodate and promote safe and convenient travel for all users – pedestrians, bicyclists, transit riders, and persons of all abilities, as well as freight and motor vehicle drivers" (City of Sacramento, 2015, p. 2-194).

Methodology

First, in order to assess the impact of complete streets projects on bicycle and pedestrian safety in Sacramento, CA it was necessary to identify complete streets projects that have been constructed within Sacramento County. The Sacramento Department of Transportation (SACDOT) releases an updated project master list detailing projects that are in the planning phase, under construction, or recently completed every other month. A review of SACDOT's project master lists from 2009-2016 identified nine complete streets projects that were completed between September 2011 and August 2014 (see Table 2 below). After identifying complete streets projects, data on pedestrian and bicyclist crashes was collected from the California Statewide Integrated Traffic Records System (SWITRS), "a database that serves as a means to collect and process data gathered from a collision scene" (California Highway Patrol, 2008).

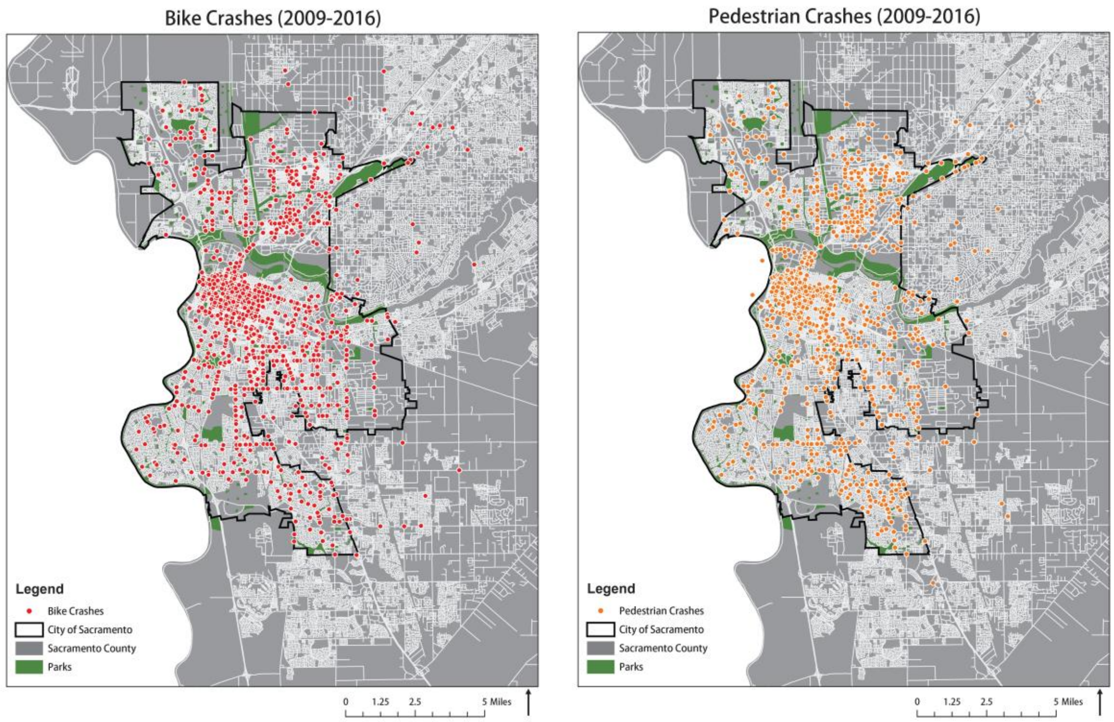
Both the complete streets projects and bicycle and pedestrian crash data were added into a geographic information system (GIS) via ESRI's ArcMap 10.3. The GIS also included: boundary files for the both the City and County of Sacramento, Sacramento County street centerlines, parks, and Census Block Group boundaries. Then, using the Summarize Within tool in ArcMap, all of the crashes that occurred on the selected complete streets in the 24 months before construction began and the 24 months after construction was completed were identified.

While the data on the absolute number of crashes on the selected complete streets provides useful information, calculating the crash rate (e.g., number of crashes per 100,000 miles walked/biked) is a more useful measure, as it incorporates and adjusts for the amount of walking and biking that is occurring. For example, it is possible that some complete streets may see an increase in the absolute number of pedestrian or cyclist crashes, but this increase in crashes may be a result of greater numbers of pedestrians and cyclist using the street due to the improved amenities and environment. Accurate counts of the number of pedestrians and bicyclists using a street are difficult to obtain, though (Salon, 2016). In order to measure the number of pedestrians and cyclists traveling on the complete streets (and therefore obtain crash rates) the author originally attempted to use GIS to estimate the pedestrian volume at every intersection in Sacramento County, following the Model of Pedestrian Demand from Kelly Clifton at Portland State University; however, this method was unsuccessful due to issues with the pedestrian assignment extension.

Table 2. Complete Streets Projects in Sacramento County, CA (2011-2014)

Project Name	Elements	Construction Start Date	Construction Completion Date
Franklin Boulevard	Sidewalks w/ landscape buffer, signal work, street lights, bike lane	Apr-14	Aug-14
El Camino Avenue	Sidewalks, street crossings, obstacle removal, signal upgrades	April-13	Dec-13
Marconi Avenue	Sidewalks, stripe bike lane, bus stops, improve median and signals	Apr-13	Aug-13
Freedom Park Drive	Sidewalks, bike lanes, streetscape, landscape	May-11	Oct-12
Orange Grove Avenue	Sidewalks, bike lanes	Mar-13	Aug-13
Fair Oaks Boulevard	Modify signal, landscaping, sidewalks	April-12	September-12
Arden Way	Sidewalk, stripe bike lane, lighting, signal	Jun-11	Nov-11
Dudley Boulevard	Landscape, sidewalk, lights	May-11	Sep-11
Auburn Boulevard	Sidewalks, landscaping, bike lanes, street monuments	September-11	August-12

Figure 6. Bicycle and Pedestrian Crashes in Sacramento County, CA (2009-2016)



Instead, the 2010-2012 California Household Travel Survey was analyzed to derive daily estimates of walking and biking for all census block groups within Sacramento County. Having calculated estimates of the daily miles walked and biked within each census block group, these estimates were scaled to the street-level by dividing the daily walking and biking estimates by the total mileage of roads in the block group. The result was a metric of the total miles walked/bike per mile of road for every block group in Sacramento County. For the selected complete streets projects, the total miles/biked per mile of road for the relevant block group were combined with the number of pedestrian and bicyclists crashes during the study period to obtain the crash rate metric: the number of pedestrian/bicyclists crashes per 100,000 miles walked/biked.

Because complete streets projects are not uniform and contain different design elements, they do not all provide the same benefits in terms of improving bicyclist and pedestrian safety (Schlossberg, Rowell, Amos, and Sanford, 2013). Having obtained crash rates before and after construction was completed on the selected complete streets projects, the last step in the analysis was to determine the impact of different design configurations (e.g., the "completeness" of the complete street) on pedestrian and bicyclist safety. In order to determine the "completeness" of the selected complete streets projects (and because of the lack of any standard grading system), a grading system that weighs the design elements of each individual project and the totality of the street redesign was developed. Each complete street project was scored on whether it included: upgraded sidewalk facilities (yes=1, 0=no), bike facilities (yes=1, 0=no), pedestrian crossings and amenities (yes=1, 0=no), and streetscape/landscape elements (yes=1, 0=no). In addition, each project was given a score of one or zero based on how appealing it would be to walk/cycle on. This subjective measure was included because aesthetics -- the attractiveness of the environment-- are associated with increased levels of walking and biking (Saelens and Handy, 2008). The scoring for how appealing the street is to walk or bicycle on was based on images from Google Street View, specifically focusing on how well-maintained the street and streetscape elements were, perceived pedestrian and bicyclist comfort, cleanliness, and orderliness. Considering all the scoring elements, the most "complete" street would receive a score of six, while an "incomplete" street would receive a score of zero.

Analysis Results

Table 3 below shows the crashes involving a bicyclist and/or pedestrian in the 24 months prior to the construction start date and 24 months after construction was completed. The majority of the complete streets projects (six out of nine) did not experience any crashes within the time period. For the three projects that did experience crashes, the raw numbers seem to indicate mixed results in improving bicyclist and pedestrian safety.

Table 3. Raw Crash Numbers for Complete Streets Projects

Project Name	Crashes in 24 Months Prior to Construction	Crashes in 24 Months After Construction
Franklin Boulevard	3 (1 ped, 2 bike)	7 (3 ped, 4 bike)
El Camino Avenue	2 (1 ped, 1 bike)	2 (1 ped, 1 bike)
Marconi Avenue	-	-
Freedom Park Drive	-	-
Orange Grove Avenue	-	-
Fair Oaks Boulevard	-	-
Arden Way	-	-
Dudley Boulevard	-	-
Auburn Boulevard	1 (ped)	1 (ped)

It was surprising that most the complete streets projects did not experience any crashes within the two years before and after construction. This may partially be due to location; most of the projects are located outside of the central city, which is where both pedestrian and bicyclist crashes are concentrated. It is also possible that the complete streets projects without accidents may have been located in areas with lower levels of walking and biking.

After examining all of the relevant factors, though, the main reason for the absence of crashes on most projects appears to be that the projects without any crashes only cover short segments of roadway (see Table 4 below). Several of these projects are singular stages of larger complete streets redesigns that are in progress. Table 4 below shows the average daily miles walked/biked per mile of road for the Census Block Group(s) surrounding the selected projects adjusted for the length of the project. The three projects that experienced crashes (Franklin Boulevard, El Camino Avenue, and Auburn Boulevard) are the longest projects, ranging from 1.96 to 3.5 miles. Comparatively, the projects that did not experience any crashes were between .5 and 1.01 miles. Because Franklin Boulevard, El Camino Avenue, and Auburn Boulevard are longer (in combination with other factors) they experienced much higher bicycle and pedestrian volumes, meaning there was greater exposure and risk of crashes.

Figure 7. Location of Selected Complete Streets Projects

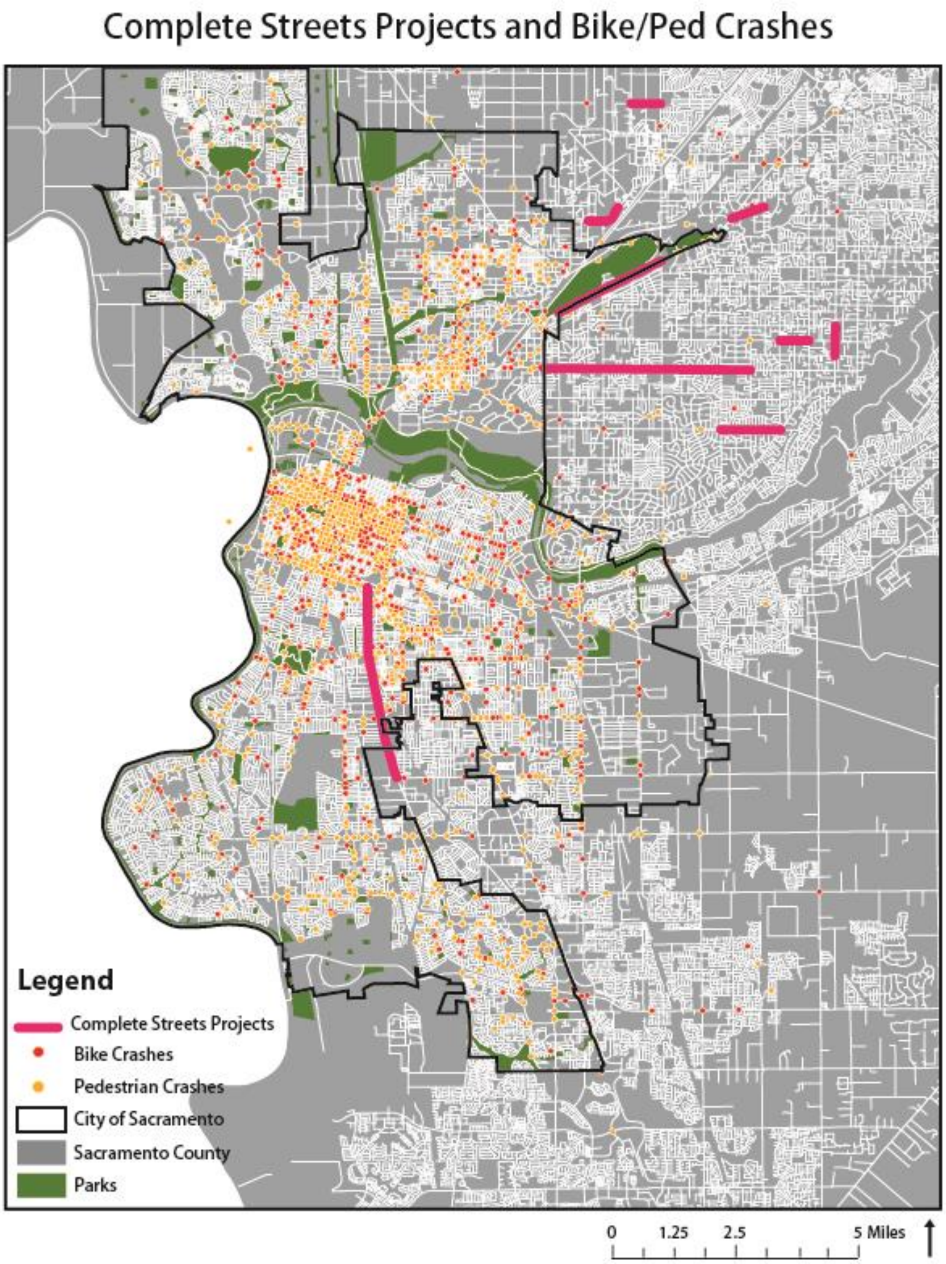


Table 4. Estimates of Miles Walked/Biked per Day on Complete Streets Projects

Project Name	Length (miles)	Walking Miles per Day	Biking Miles per Day
Franklin Boulevard	3.29	133.25	304.65
El Camino Avenue	3.5	105.47	215.13
Marconi Avenue	0.5	32.00	41.33
Freedom Park Drive	0.5	3.67	22.67
Orange Grove Avenue	.59	5.90	12.98
Fair Oaks Boulevard	0.5	9.25	34.00
Arden Way	1.01	6.73	34.34
Dudley Boulevard	.63	0.00	1.89
Auburn Boulevard	1.96	72.13	125.05

Franklin Boulevard saw three crashes (one involving a pedestrian and two involving cyclists) in the 24 months before the complete street redesign and seven crashes (three involving pedestrians and four involving cyclists) in the 24 months after construction. On El Camino Avenue, there were two crashes (one involving a pedestrian and one involving a cyclists) in the 24 months prior to the complete streets upgrades, and two crashes (one involving a pedestrian and one involving a cyclist) in the 24 months after construction. Auburn Boulevard also saw one pedestrian crash in the 24 months before construction and one pedestrian crash in the 24 months after construction.

None of the complete streets projects saw a reduction in the raw number of crashes involving pedestrians and cyclists after the upgrades were constructed. Two of the projects (El Camino Avenue and Auburn Boulevard) had the same number of crashes in the 24 months before and after construction. Crashes on Franklin Boulevard more than doubled from three to seven. As stated before, though, these numbers may be skewed by the fact that more people may be walking and bicycling on both streets following the upgrades. In order to obtain a more accurate picture of bicycle and pedestrian safety for these three projects, it was necessary to calculate a crash rate metric that considers the number of people walking and cycling on the respective streets.

In order to determine the impact of the complete street redesigns on bicycle and pedestrian crash rates, the difference in the volume of walking/biking before and after the projects are constructed must be calculated. The best way to obtain this data would be to conduct bicycle and pedestrian counts before and after construction; however, this important step is not always completed and, if it is, data is not always publicly available. The author surveyed the literature to determine the “normal” increase in bicycle and pedestrian activity after a complete street is constructed. After surveying the literature, no instances reporting the change in pedestrian volume before and after complete street redesigns were identified, which is unsurprising considering that automatic pedestrian counts require more expensive technology (e.g., infrared counters). Several studies did report the change in bicycling before and after construction, though, which varied from a low of a 20% increase to a high of a 325% increase. The highest and lowest values were excluded to obtain an average increase in cycling of 89%. This average increase was then applied to the three projects that experienced crashes during the study period to obtain before and after crash rates (see Table 5 below).

Table 5. Bicycle and Pedestrian Crash Rates (with adjusted bicyclist/pedestrian volumes)

	24 Months Before Construction		24 Months After Construction	
Project Name	**Ped Crashes/ 100,000 Miles Walked**	**Bike Crashes/ 100,000 Miles Biked**	**Ped Crashes/ 100,000 Miles Walked**	**Bike Crashes/ 100,000 Miles Biked**
Franklin Boulevard	1.03	0.90	1.63	0.95
El Camino Avenue	1.30	0.64	0.69	0.34
Auburn Boulevard	1.90	0.00	1.00	0.00

The same number of crashes occurred on both El Camino Avenue and Auburn Boulevard before and after construction, so it is not surprising that when an increase in people walking and biking is assumed there is a significant drop in crash rates. Obviously, the magnitude of this decrease will depend on the assumed increase in walking and biking, but it seems clear that both of these complete streets projects have had a positive impact on bicycle and pedestrian safety. For Franklin Boulevard, though, even when a large increase in walking and biking is assumed, crash rates still increase for pedestrians and bicyclists.

Why might the complete streets upgrades on Franklin Boulevard not improve bicycle and pedestrian safety while the changes to Auburn Boulevard and El Camino Avenue led to improvements? As mentioned previously, all complete streets projects are not alike, as the dimensions of the right of way have a major impact determining what components can fit within the street. In order to quantify these differences, the author developed a scoring system to rank the "completeness" of the complete streets projects. Table 6 below shows the scores for the three projects that experienced crashes during the study period.

Table 6. Complete Streets Grades for Relevant Projects[3]

Project Name	Sidewalk	Bike Lane	Crosswalks and Pedestrian Amenities	Streetscape/ Landscape	Visual Score	Overall Score
Franklin Boulevard	0.5	0.5	1	1	0	3
El Camino Avenue	1	0.5	1	1	1	4.5
Auburn Boulevard	1	0.5	0	1	1	3.5

As Table 6 shows, Franklin Boulevard received the lowest score of the three projects that experienced crashes. In examining the projects using Google Street View, the upgrades along Franklin Boulevard are discontinuous, for example the bike lane appears and disappears

[3] Half points represent unprotected bike lanes or discontinuous sidewalk upgrades.

along the three-mile stretch of road. This may be due to the relative length of the project (3.29 miles) and cost of constructing improvement along the entire distance; however, having features like bike lanes and sidewalk buffers appear and disappear may be dangerous for bicyclists and pedestrians. Intermittent bike lanes, in particular, can be dangerous for two reasons: bicyclists must switch from feeling “safe” in a separated lane to riding with traffic and the act of merging from a bike lane into a shared lane creates a potential conflict. Cars also have to be aware of bikes exiting and entering the roadway and, without proper signage, may not be aware of cyclists entering the roadway. As previously mentioned, studies show that all road users, whether driving a car or riding a bicycle, prefer clearly designated spaces for each mode (Sanders, 2016).

Figure 8. Images of Franklin Boulevard (above) and El Camino Avenue (below)

Source: Google Streetview

Considering the discontinuous nature of the improvements along Franklin Boulevard, it is not surprising that the bicyclist and pedestrian crash rates increased after construction. Transportation departments would be well served to prioritize continuity of upgrades and improvements along complete streets projects to avoid increasing the risks for the very people the project is intended to benefit.

Discussion and Recommendations

After conducting the analysis, three major points stood out as deserving further attention: the lack of data on bicyclist and pedestrian volumes, the need to ensure all bicycle and pedestrian features are continuous, and the lack of a standardized grading system for all complete streets projects.

One of the major findings of this paper is that there is a significant lack of data on where and how many people are walking and biking on our streets (Salon, 2016). This lack of data hampers researchers' ability to analyze the bicycle and pedestrian safety environment and the impact of interventions like complete streets. In order to deal with the lack of available data, this paper analyzed the 2010-2012 California Household Travel Survey and derived estimates of bicycle and pedestrian activity at the level of individual streets in Sacramento County, California. The author then reviewed the literature on complete streets projects to find an average increase in bicycle and pedestrian activity (89%) and applied this to the three complete streets projects that experienced crashes during the study period. The result was a crash rate metric (number of bicycle/pedestrian crashes per 100,000 miles walked/biked) that was sensitive to the change in bicycle and pedestrian volume resulting from the complete street redesigns. While the results obtained using this methodology are valuable, a number of estimates and assumptions had to be made due to the lack of data. The National Complete Streets Coalition lists data on bicyclist and pedestrian volumes as a potential performance measure for complete streets in its implementation guide, Taking Action on Complete Streets. Going forward, it is recommended that bicycle and pedestrian counts should be conducted before and after construction for all complete streets projects to gauge the impact of the complete streets projects on the number of people walking and biking. This data should be made publicly available in a shared, central portal for complete streets projects as well.

Another finding of this paper is the potential danger of intermittent complete streets improvements. Of the three projects that experienced crashes during the study period, only one saw an increase in the raw number of bicycle and pedestrian crashes and bicycle and pedestrian crash rates: Franklin Boulevard. In examining the improvements along Franklin Boulevard, it was clear that many of the facilities (e.g., bike lanes and sidewalk buffers) were not present along the entire complete street. It is the author's belief that the intermittent nature of the improvements increased crash risks for bicyclists and pedestrians. Discontinuous pedestrian and bicycle facilities force cyclists and pedestrians to transition from safe, comfortable conditions to less comfortable, potentially dangerous situations with little or no warning. Discontinuous bicycle facilities, in particular, may force cyclists to merge from a separated riding environment into a shared environment with traffic. These interactions are very dangerous for cyclists.

Lastly, there is currently no standardized grading system for complete streets projects around the country. The facilities and design elements included in complete streets projects varies from site to site; thus, every complete street differs slightly from others. While it would be impractical and counterproductive to recommend mandatory elements and configurations for complete streets, instituting a standardized grading system would allow for easier comparisons between projects.

Conclusion

Complete streets allow users of all kinds, whether travelling by bike, car, public transit, walking, or wheeling, to safely use our streets regardless of their age or ability. This paper aimed to quantify the impact of complete streets projects on pedestrian and bicyclist safety. By examining crashes before and after complete streets projects, this study aimed to better understand the cumulative effect of complete streets projects on pedestrian and bicyclist safety. Using data provided by the Sacramento Department of Transportation, a subset of projects completed between 2011 and 2014 were selected and analyzed to determine the number of pedestrian and bicyclist crashes in the 24 months before and after complete streets projects were completed.

In the course of this analysis, several issues arose, most notedly a lack of data regarding bicycle and pedestrian volumes. In order to work around this issue, estimates of the number of people walking and biking for every mile of street in Sacramento County, California were calculated using data from the 2010-2012 California Household Travel Survey. Using these estimates of bicyclist and pedestrian volumes, the number of bicyclist/pedestrian crashes per 100,000 miles walked/biked were calculated for three complete streets projects in Sacramento County, California. The impact on bicyclist and pedestrian safety from these projects was mixed: two complete streets led to reduced bicyclist and pedestrian crash rates and one saw an increase in crash rates after construction. The major difference between the projects that positively impacted bicyclist and pedestrian safety and the one project with a negative impact was the continuity of the complete streets upgrades. Along Franklin Boulevard, the project which saw an increase in crash rates, the complete streets upgrades are discontinuous, with bike lanes and sidewalk buffers disappearing at several segments along the street.

Following this analysis, three main recommendations became apparent: data collection regarding bicyclist and pedestrian volumes should be a crucial element of all complete streets projects, a standardized grading system for complete streets projects should be developed, and, for planners and engineers designing complete streets, continuity of all elements should be a priority. Implementing these recommendations will help to fulfill the promise complete streets hold for creating safe streets for bicyclists, pedestrians, and all users.

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