CPBS
Center for Pedestrian and Bicyclist Safety

A Tier-1 University Transportation Center

Before and After Safety Evaluation of California's and San Diego's Active Transportation Projects

July 2024

A Report From the
Center for Pedestrian and Bicyclist Safety

Bruce Appleyard
San Diego State University

Megan Honey
San Diego State University

Nell Ahangarfabrik
San Diego State University

Mario Carbajal
San Diego State University

Wesley Cooksy
San Diego State University

Katie Crist
San Diego State University

Madison Swayne
San Diego State University

About the Center for Pedestrian and Bicyclist Safety (CPBS)

The Center for Pedestrian and Bicyclist Safety (CPBS) is a consortium of universities committed to eliminating pedestrian and bicyclist fatalities and injuries through cutting-edge research, workforce development, technology transfer, and education. Consortium members include: The University of New Mexico; San Diego State University; The University of California Berkeley; The University of Tennessee Knoxville; and The University of Wisconsin Milwaukee. More information can be found at: https://pedbikesafety.org

Disclaimer

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7. Author(s)
Bruce Appleyard https://orcid.org/0000-0003-2105-8079
Megan Honey https://orcid.org/0009-0007-8995-4079
Nell Ahangarfabrik https://orcid.org/0009-0006-0874-2457
Mario Carbajal https://orcid.org/0009-0001-9303-0254
Wesley Cooksy https://orcid.org/0009-0009-4401-8492
Katie Crist https://orcid.org/0000-0002-7549-8523
Madison Swayne https://orcid.org/0000-0003-0913-6716

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16. Abstract
Some regions have invested heavily in pedestrian and bike improvements, including sidewalks, protected cycle tracks, bike lanes and other infrastructure improvements to enhance the user experience and promote safety, yet many lack comprehensive research on both usage and safety associated with such investments, limiting our understanding of their effectiveness and impact of these improvements. Quasi-experimental longitudinal studies using pre/post data surrounding new project implementation are particularly lacking, often confounded by the lack of proper control sites, adequate data, and controlling for counts of exposure. While the implementation of such projects has received widespread support, there is a need to critically examine their benefits, including bike and pedestrian trips, safety, and the reduction of collision rates throughout the San Diego region. This project employed longitudinal analyses of bicycle counts and crashes around recently built bicycle projects in San Diego finding, for the most part, that the projects likely led to increased bicycle ridership. We then turned to conducting an analysis on how the projects affected safety outcomes through an exploration of different methods and approaches. We found that understanding the safety benefits of bicycle projects is a more complex undertaking. Future research could build on this study by applying control groups to more of the study sites, monitoring the post-construction safety conditions over a longer period of time, and introducing additional variables into the analysis, including before and after traffic volumes and speed limits. Nevertheless, considering all the current limitations of our study, our findings suggest that overall, bicycle projects encourage riding and likely improve safety and street livability.

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APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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Bruce Appleyard
City Planning Director & School of Public Affairs
San Diego State University

Megan Honey
School of Public Affairs
San Diego State University

Nell Ahangarfabrik
School of Public Affairs
San Diego State University

Mario Carbajal
School of Public Affairs
San Diego State University

Wesley Cooksy
School of Public Affairs
San Diego State University

Katie Crist
San Diego State University

Madison Swayne
School of Public Affairs
San Diego State University

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Acronyms, Abbreviations, and Symbols

CTC	California Transportation Commission
GHG	Greenhouse gas
SANDAG	San Diego Association of Governments
SWITRS	Statewide Integrated Traffic Records System
TIMS	Transportation Injury Mapping System

Abstract

Some regions have invested heavily in pedestrian and bike improvements, including sidewalks, protected cycle tracks, bike lanes and other infrastructure improvements to enhance the user experience and promote safety, yet many lack comprehensive research on both usage and safety associated with such investments, limiting our understanding of their effectiveness and impact of these improvements. Quasi-experimental longitudinal studies using pre/post data surrounding new project implementation are particularly lacking, often confounded by the lack of proper control sites, adequate data, and controlling for counts of exposure. While the implementation of such projects has received widespread support, there is a need to critically examine their benefits, including bike and pedestrian trips, safety, and the reduction of collision rates throughout the San Diego region. This project employed longitudinal analyses of bicycle counts and crashes around recently built bicycle projects in San Diego finding, for the most part, that the projects likely led to increased bicycle ridership. We then turned to conducting an analysis on how the projects affected safety outcomes through an exploration of different methods and approaches. We found that understanding the safety benefits of bicycle projects is a more complex undertaking. Future research could build on this study by applying control groups to more of the study sites, monitoring the post-construction safety conditions over a longer period of time, and introducing additional variables into the analysis, including before and after traffic volumes and speed limits. Nevertheless, considering all the current limitations of our study, our findings suggest that overall, bicycle projects encourage riding and likely improve safety and street livability.

Executive Summary

BACKGROUND

California, and the San Diego region in particular, have invested heavily in pedestrian and bike improvements, including sidewalks, protected cycle tracks, bike lanes and other infrastructure improvements to enhance the user experience and promote safety. While projects like these continue to be built, little comprehensive research on both usage and collision rates associated with investments in pedestrian and bicycle infrastructure exists. This limits our understanding of the effectiveness and impact of these improvements on safety and ridership.

These active transportation improvements have a wide range of benefits including reducing car dependence, which lessens carbon emissions and improved public health by encouraging active modes of transportation. Additionally, California has placed a major emphasis on improving equity in traditionally underserved communities that lack safe and easily accessible pedestrian and bicycle infrastructure. However, despite the efforts to improve infrastructure, collisions involving pedestrians and cyclists coupled with persistently low active travel mode share remain significant concerns.

One method to evaluate the effectiveness of these bicycle projects is to explore collision data from before and after the intervention occurred. These quasi-experimental longitudinal studies using pre/post data (in other words, before and after the intervention) surrounding new project implementation are particularly lacking, often confounded by the lack of proper control sites, adequate data, and controlling for counts of exposure. While the implementation of such projects has received widespread support, there is a need to critically examine their benefits, including bike and pedestrian trips, safety, and the reduction of collision rates throughout California and the San Diego region.

OBJECTIVES AND METHODS

Looking at locations with completed bicycle projects (including projects with Class 1, 4, and 5 upgrades), we conducted a series of longitudinal studies using pre/post data to overcome some of the aspects confounding most longitudinal studies of bicycle projects. In addition to analyzing collision data in the pre/post periods, we also included ridership data in our analysis; however, this data was only available at three of our study sites. Using a comprehensive framework for identifying control sites, we gathered collision data around these areas for comparison.

RESULTS

The results show that the addition of protected bicycle lanes had a positive effect on bicycle ridership. However, when we incorporated collision data into our pre/post analysis, the results were much less clear. With some projects yielding counterintuitive results in terms of safety (as measured by collisions), we then controlled for exposure. In the case of the 4th/5th avenue bikeway, the benefits are readily apparent, with bicycle counts increasing and collisions decreasing. However, we found that two of the study sites (30th Street and Landis Street) still had

higher total collision rates compared to the pre-construction period. We then introduced control sites for comparison, adjusting our approach to ensure we were making valid, apples to apples, comparisons. When we compared changes in collisions at our control sites to their corresponding treatment sites, the results were inconclusive.

CONCLUSIONS

Notably, our findings show that, for the most part, if you build it, people will ride, while understanding the before and after safety benefits of bicycle projects is a more complex undertaking requiring careful examination with a reasonable comparison between treatment and control sites, longer periods of data, and proper zones of analysis.

Nevertheless, considering all the current limitations of our study, we find that overall bicycle projects encourage riding and likely improve safety and street livability. Indeed, there is a need for further research as in some cases it is inconclusive as to the exact safety effects of the bicycle projects. Future research could build on this study by applying control groups to more of the study sites, monitoring the post-construction safety conditions over a longer period of time, and introducing additional variables into the analysis, including before and after traffic volumes and speed limits.

Introduction

California, and the San Diego region in particular, have invested heavily in pedestrian and bike improvements, including sidewalks, protected cycle tracks, bike lanes, protected intersections, and other infrastructure improvements to enhance the user experience and promote safety. These active transportation improvements have a wide range of benefits including reducing car dependence which lessens carbon emissions and improved public health by encouraging active modes of transportation. Additionally, California has placed a major emphasis on improving equity in traditionally underserved communities that lack safe and easily accessible pedestrian and bicycle infrastructure (*California Transportation Commission, 2022*).

However, despite the efforts to improve infrastructure, collisions involving pedestrians and cyclists coupled with persistently low active travel mode share remain significant concerns. The existing literature suggests that the presence and quality of bicycle infrastructure play a crucial role in improving perceived safety among riders and reducing collision rates (*Marshall & Ferenchak, 2019; Buehler and Pucher, 2020; Fosgerau et al, 2023; Reynolds et al., 2009; Kaths, 2022; Steinacker et al., 2022; Wysling & Purves, 2022*). In some cases, the implementation of bicycle infrastructure caused vehicle-bicycle collisions to increase, but researchers hypothesized that this increase occurred because more cyclists were present on streets with improved bicycle infrastructure (*Pedroso et al, 2016).*

California and the San Diego region lack comprehensive research on both usage and collision rates associated with investments in pedestrian and bicycle infrastructure, which limits our understanding of their effectiveness in reducing collisions and impact on increasing pedestrian and bicycle mode share. Quasi-experimental studies using pre/post data surrounding new project implementation are particularly lacking. While the implementation of such projects has received widespread support, there is a need to critically examine their benefits, including bike and pedestrian trips, safety, and the reduction of collision rates throughout California and the San Diego region.

Literature Review

Benefits of Pedestrian and Bicycle Infrastructure

Active transportation has been associated with a range of benefits such as improved public health outcomes, reduction of greenhouse gas (GHG) emissions, and reduced automobile dependency, which leads to less traffic (*Barajas et al., 2022*). Decreasing vehicle usage through increased walking and cycling and other non-motorized travel is crucial for meeting California's ambitious climate action goals—including reducing GHG emissions by 40% below 1990 Levels by 2030 (*California Air Resources Board, 2022*). According to the California Air Resources Board (CARB) inventory report on GHG emissions; the transportation sector remains the largest source of emissions—representing 37 percent of total statewide emissions (*CTC, 2022)*. While many factors influence emissions—such as fuel policies, vehicle fuel efficiency, and the increase of electric vehicles—increasing non-motorized travel through active transportation can play a pivotal role in reducing automobile dependence and meeting emissions targets (*CARB, 2022*). However, despite the wide-ranging benefits, rates of active transportation remain low (*McDonald and Aalborg, 2009; Pike and Handy, 2021*).

Public health outcomes have been shown to improve with increased active transportation—even when accounting for the possibility of increased injury and mortality from vehicular collisions or increased exposure to particulate matter (*Magrinyà et al., 2023*). Proximity to public transportation also increases active transportation because public transit involves active modes of transport to or from the transit node (*Mueller et al., 2015*). Increasing street connectivity has also been shown to increase walking and cycling (*Dill, 2004*). Research suggests that individuals who engage in physical activity through active transportation enjoy improved determinants of health (*Dill & Howe, 2017*).

Active transportation has the potential to increase personal well-being through several factors including increased sensory satisfaction, stronger place connection, potential increase in social interactions, and improved cognitive function from moderate exercise (*Wild & Woodward, 2020*). Efficient, easily accessible active transportation also has cost-saving potential in terms of savings associated with not needing a vehicle—including fuel costs, vehicle maintenance and fees, and parking fees. This has implications for increasing equity in lower-income communities typically lacking active transportation infrastructure (*Dill & Howe, 2017*).

Pedestrian and Cyclist Safety Concerns

Despite the environmental benefits of active transportation, the vast majority of Californians do not walk or bike as a form of travel. For example, in 2017, less than 2% of Californians biked to work, and less than 3% walked to work. (*Pike & Handy, 2021*). Many cite safety concerns as a reason for their preference towards vehicular travel (*Soto et al., 2022; Omura et al., 2019; Chaufan et al., 2012; Appleyard, 2003*). These safety concerns reflect an increase in pedestrian and bicycle fatalities, with pedestrian fatalities reaching levels not seen since the 1980s (*Governors Highway Safety Association, 2023*). This increase in fatalities may be attributable to inadequate transportation infrastructure, unsupportive of active travel modes (*Schneider et al., 2021, Schneider et al., 2010*). Therefore, increasing rates of active transportation requires investment in active transportation infrastructure improvements to enable more people to safely travel by bike or by foot. (*Aziz et al., 2012*).

Safety in Numbers

Many papers have explored the "safety in numbers" theory amongst cyclists, which, as the name implies, suggests that as more cyclists use a route, drivers become more aware of them, and accidents drop. However, since an increased volume of cyclists means there is more opportunity for cyclists to get hit by cars, it is more helpful to measure bicycle safety by rates, as in the number of reported injuries or collisions divided by the number of cyclists. Without count data, researchers and practitioners only have raw counts of crash data. So, we might see in some cases that after an intervention such as a bicycle lane is added, total crashes may increase. Without count data, practitioners and researchers would be led to assume that the bicycle lane made safety worse, when in fact the rates of collisions have decreased (*Strauss et al. 2015; Ferster et al. 2021*).

Similar Studies

We reviewed available literature on similar before and after studies and found a lack of similar studies. A review of relevant literature by *Reynolds et al.* in 2009 found that there is a major lack of studies on transportation infrastructure and cyclist safety. The study analyzed various bibliographic databases and found 23 papers that met their criteria. While the review of literature revealed that specific purpose-built interventions did seem to increase cyclist safety, they found that there is a need to study a wider range of facilities and highlighted the difficulty in controlling for different exposure risks *(Reynolds et al., 2009)*. From these studies the authors found that, "Only one of the road/lane/path-related papers, were "before-after" studies that quantified the change in cyclist safety before and after some infrastructure-related intervention took place *(Reynolds et al., 2009)*." This highlighted the need for further research.

Common themes were identified that pose a challenge for similar studies such as ours, including the need for standardization in defining terms like "bike path", underreporting of incidents, and ensuring exposure risks are accurate for control and treatment sites. The before and after studies analyzed compared injuries before and after an intervention *(Reynolds et al., 2009)*. Our study chose to also include different control sites with similar roadway and place type characteristics. Overall, *Reynolds' et al. (2009)* literature review concluded that studies on the topic remain "remarkably sparse".

A more recent literature review of bicycle infrastructure safety research had similar findings. *DiGioia et al. (2017)* found that there is a serious need for further rigorous research on bicycle infrastructure safety effectiveness and identification of reliable data sources and exposure risk measures. The authors found that while there are numerous studies evaluating the safety impacts of bicycle treatments, there is a lack of accurate crash modification factors *(DiGioia et al., 2017)*. The authors identified 19 scientific peer-reviewed papers that provided meaningful results on bicycle treatments and found that, "bike lanes appear to be somewhat beneficial for safety, although results were mixed and most studies were not statistically significant *(DiGioia et al., p. 110, 2017)*."

DiGioa et al. (2017) found wide-ranging variability in design, depth, and controls. This literature review also found a lack of exposure data for bicycle ridership and identified the impact of time for treatments. Only one before and after study left a transition period after construction before collecting user data *(DiGioa et al., 2017)*. The review of literature also highlighted the "safety in numbers" phenomenon that seems to occur after increased awareness of cyclists occurs. Overall, this review of literature also found that there is limited research that quantifies the effectiveness of bicycle safety infrastructure measures. The study identified three major components needed for accurate studies: exposure data, roadway characteristic data, and crash data *(DiGioa et al., 2017)*. The authors also noted the need for well-defined infrastructure characteristics when selecting treatment and control sites.

Limitations of Before and After Studies of Bicycle Improvements

Before-and-after studies are essential for evaluating the impact of bicycle infrastructure improvements, but they face significant methodological, analytical, and practical limitations.

Methodological Limitations

1. Data Availability and Quality

Lack of Comprehensive Baseline Data: Many studies suffer from the absence of detailed and comprehensive baseline data. Without robust pre-intervention data, it becomes difficult to accurately measure the impact of the intervention (*Handy et al., 2014*).

Inconsistent and Incomplete Data Sources: The use of diverse data sources (e.g., manual counts, automated counters, surveys) can lead to inconsistencies and gaps in the data, complicating the comparison between pre- and post-intervention periods. (*Pucher, Dill, & Handy, 2010*). Near-misses or collisions that do not involve vehicles are rarely reported (Nelson et al, 2021; Das et al 2021).

Furthermore, as previous research has discussed, it is difficult to apply ridership data (which is usually available as a point, such as a permanent bicycle counter) to collision data in a larger area (such as a bicycle path that is several miles long). (*Nelson et al, 2021; Ferster et al, 2021; Jestico et al, 2016*).

2. Selection Bias

- Non-Random Site Selection: Bicycle improvements are often implemented in areas with existing high demand or political support, introducing selection bias. This makes it challenging to generalize findings to other contexts (*Winters et al., 2010*).

- Cyclist Self-Selection: Cyclists who choose to use new infrastructure might differ from those who do not, in terms of demographics, cycling habits, or attitudes. This self-selection bias can skew the results (*Heinen et al., 2010*).

3. Temporal Variability

- Seasonal and Weather Effects: Cycling activity varies significantly with seasons and weather conditions. Studies that do not adequately account for these variations risk attributing changes in cycling behavior to the intervention rather than to natural fluctuations (*Nosal & Miranda-Moreno, 2014*).

- Longitudinal Data Requirements: Long-term data collection is necessary to capture the full impact of infrastructure improvements, but maintaining such data collection efforts can be resource-intensive (*Fishman, Washington, & Haworth, 2013*).

Analytical Limitations

1. Control for Confounding Variables

- External Influences: Many external factors, such as economic conditions, fuel prices, and other concurrent urban development projects, can influence cycling behavior. Isolating the effect of the bicycle improvement from these confounders is challenging (*Buehler & Pucher, 2012*).

- Concurrent Interventions: Simultaneous implementation of other transportation or urban planning initiatives can confound the results, making it difficult to attribute observed changes solely to the bicycle improvement (*Dill & McNeil, 2013*).

2. Measurement of Impact

- Quantitative vs. Qualitative Outcomes: While quantitative measures (e.g., changes in cycling volume, accident rates) are commonly used, qualitative outcomes such as perceived safety and user satisfaction are equally important but harder to measure (*Aldred, 2013*).

- Lagged Effects: The impact of infrastructure improvements might not be immediately apparent, and behavioral changes can take time to manifest, necessitating extended follow-up studies (*Piatkowski et al., 2015*).

Practical and Logistical Limitations

1. Resource Constraints

- Funding and Human Resources: Comprehensive before-and-after studies require significant financial and human resources for data collection, analysis, and reporting. Limited funding can constrain the scope and quality of these evaluations (*Krizek et al., 2009*).

- Technological Challenges: Deploying and maintaining automated counters and other technological tools for data collection can be costly and require technical expertise (*Gatersleben & Appleton, 2007*).

2. Stakeholder Engagement

- Community Involvement: Effective data collection and study relevance depend on the engagement of local communities and stakeholders. However, securing cooperation and managing diverse interests can be challenging (*Pucher & Buehler, 2008*).

- Political and Institutional Barriers: Changes in political priorities or administrative structures can disrupt ongoing studies and affect the implementation and evaluation of bicycle improvements (*Buehler & Pucher, 2011*).

Addressing these limitations outlined above requires careful study design, robust data collection and analysis methods, and sustained engagement with stakeholders. Despite these challenges, such studies remain a valuable tool for informing urban transportation policies and promoting cycling as a sustainable mode of transport.

Data, Methodology, and Frameworks

This project's primary outcomes will be to identify pedestrian, bicycle, and vehicle crashes, as well as bicycle counts around active transportation projects, and then articulate design and operation solutions captured in the form of a Technical Memo (which will later become a report). The Memo/Report will articulate the underlying mechanisms of these problems and solutions. The study's findings will play a key role in identifying areas of high risk for pedestrians and bicyclists, prompting the implementation of necessary safety measures to enhance pedestrian and bicycle safety conditions. Moreover, the study results are anticipated to highlight essential domains for future CPBS research over the coming five years, benefitting the broader safety research community.

A Comprehensive Framework for Evaluating Pedestrian and Cyclist Projects

Building on some of the insights from Donald Appleyard (1981), Bruce Appleyard and Donald Appleyard (2021), and Litman (2023), we present a framework and approach that we used in this and other similar studies for evaluating and prioritizing active transportation projects, drawing on insights from existing literature and best practices.

To effectively evaluate active transportation projects, it is essential to identify key parameters that capture their multifaceted impacts as shown in Figure 1. These parameters encompass both quantitative and qualitative aspects and include the following parameters.

Identifying Key Evaluation Parameters:

Active Transport Use & Mode Shift: Assessing the percentage change in the number of individuals using active transportation modes pre- and post-implementation of the project *(Aldred et al., 2019)*. Ideally this would include counts of bicyclists and pedestrians, but sometimes we need to rely on data from the census, such as the Journey to Work data.

Safety: Analyzing the impact of the project on the safety and accessibility of active transportation routes is key *(Pedroso et al, 2016)*. Therefore, we should evaluate registered collisions and records of injury severity and fatalities.

Auto dominance/dependence: Evaluating the amount of traffic, congestion and the reductions in greenhouse gas emissions, air pollution, and noise pollution due to decreased reliance on motorized transport *(Maizlish et al., 2019).*

Social Equity: Assessing whether the project addresses the needs and interests of all socio-economic groups and promotes inclusivity *(Chang et al., 2021)*. In California, looking specifically as to whether these projects are in disadvantaged communities *(SB 35 Disadvantaged Communities)*.

Needs 1: Land use, Trip Generation and Attraction. We also need to see if there are areas that will generate or attract walking or bicycling trips, such as schools, shops, or jobs.

Needs 2: Street Design & Livability. We also need to understand that even if a street has no registered collisions, it could still be a dangerous street worthy of getting funding for infrastructure to improve safety and livability. Things that we can measure here include:

- Street width
- Speed & volumes
- Number of lanes

Needs 3: Existing facilities. When prioritizing projects for funding, we also may want to look at existing facilities to see where the places with deficits are located. Knowledge about the location of sidewalks and bicycle lanes may be hard to come by, but information on intersection density may provide a good proxy for these other facilities.

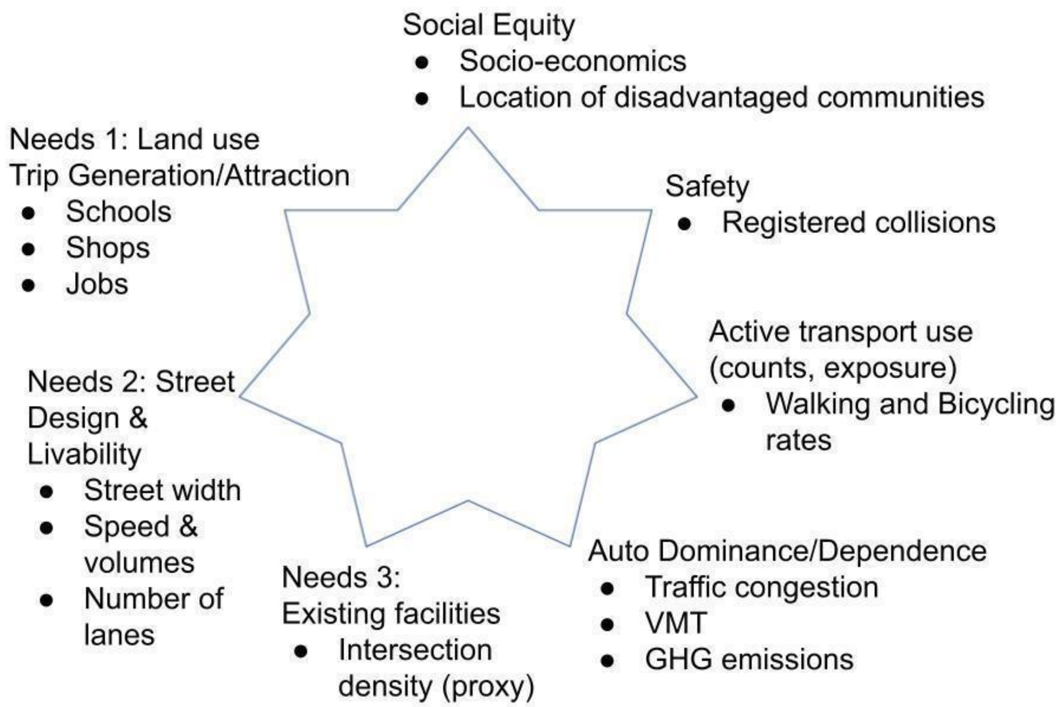

Figure 1. A comprehensive framework for evaluating ATP projects

Data

Collisions

We downloaded collision data from the California Statewide Integrated Traffic Records System (SWITRS) through UC Berkeley's Transportation Injury Mapping System (TIMS) website. (It should be noted that the 2022 and 2023 data in SWITRS is provisional and subject to change). Using the x and y coordinates provided in the UC Berkeley dataset, collisions were mapped as points in ArcGIS Pro.

Bikeways

To map San Diego's bicycle network, we used the Bikeways shapefile from the SanGIS/SANDAG GIS Data Warehouse.

Bicycle Counts

Bicycle count data was obtained from SANDAG's Open Data portal. We used the version of the data from the 2023 State of the Commute report, which provides results for eight counters from 2014-2023. For each counter, the dataset includes a total annual count as well as average bicycle counts per day. In a process referred to as quality assurance/quality control (QAQC), SANDAG adjusts the raw counts to account for periods of time in which the counters were broken or the sensors routinely missed bicyclists (*SANDAG, 2024*).

Selection of Bikeways

We conducted a before and after analysis of collisions on several bikeways in San Diego County that had recently received significant improvements. These bikeways included:

- City of San Diego
  - 30th Street (Adams Ave to Juniper)
  - 4th Avenue (Washington St to B St)
  - 5th Avenue (Washington St to B St)
  - Meade Ave (Fairmount Ave to Park Ave)
  - Landis Street (Chamoune Ave to Alabama St)
  - Rose Creek (Bay Ho to Pacific Beach)
- National City
  - Bayshore Bikeway (Vesta St to W 19th St)
- Encinitas
  - Coastal Rail Trail (Chesterfield to F St)

Table 1. Data sources available

Bikeways	Collision Data	Ridership Data	Paired with a Control Site?
30th St	Yes	Yes	Yes
4th/5th Ave	Yes	Yes	Yes
Meade Ave	Yes	No	No
Landis St	Yes	Yes	No
Rose Creek	Yes	No	No
Bayshore Bikeway (National City Segment)	Yes	No	No
Coastal Rail Trail (Encinitas)	Yes	No	No

Several factors were considered when choosing projects to evaluate within San Diego County. Since one of our goals was to adjust for bicycle exposure, we first focused on sites that had functional bicycle counters operated by SANDAG (30th St, 4th/5th Ave, and Landis St). Unfortunately, the remaining five treatment sites did not have counters available. Table 1 shows the available data at each treatment site. Additionally, we wanted to highlight more recent projects; all of these projects were completed between 2018 and 2022. We also wanted to focus on projects with a high impact; those that were along busy corridors and had a high volume of bicycle ridership. Figure 2 shows a map of chosen treatment sites.

Figure 2. Bikeway study sites

Methods

Before and After Analysis: Ridership

We first explored bicycle ridership trends at these study sites using the average daily bike counts provided by SANDAG's counters. Bicycle counters were available at three of our study sites: 30th Street, 4th/5th Avenue, and Landis Street. Then, we compared study site trends to the average bike counts for all eight of SANDAG's bicycle counters.

Before and After Analysis: Collisions

We first mapped bicycle lanes using SANDAG's Bikeways shapefile. Then, we conducted a select-by-location query for collisions in the SWITRS dataset that were within 100 feet of each study location. Since many bikeways intersect major freeways, we excluded freeway collisions.

Since our study locations were relatively small, resulting in a low number of bicycle collisions throughout the study period, we chose to expand our dataset to include vehicle, bicycle, and pedestrian collisions. This broader focus allowed us to also analyze whether the construction of bikeways also affected road safety for vehicles. Several of our study sites (including Landis Street and Meade Avenue) contained other traffic calming measures, such as roundabouts and speed bumps, that are focused on reducing vehicle collisions. Additionally, previous research has found that bicycle infrastructure can create safer conditions for vehicles and pedestrians as well as cyclists (*Marshall and Ferenchak, 2019*).

For each bikeway, we set a before and after period of one calendar year. This length of time was chosen because for three of our study locations, we had less than two years of data available. Calendar years (January-December) were chosen in order to create a comparable analysis with SANDAG's average annual bicycle ridership numbers, which are only provided by calendar year.

Each "post-test" period included the first calendar year after the project was completed. For example, a project completed in August 2021 would use the 2022 calendar year as the post-test. Each "pre-test" period extended from the calendar year prior to the start of construction. For example, a project where construction began in April 2018 would use the 2017 calendar year as the pre-test. We excluded the construction phase from our safety and bicycle count analysis to account for road closures, lower levels of traffic, and lower levels of cyclists. Information on when the bikeways were completed and construction periods were obtained primarily through press releases and notices on SANDAG's website; however, in some cases, when this information was not available, we relied on local news sources. The construction dates and before/after periods for each bikeway are shown in table

Table 2. Description of study sites

Bikeway	Previous Bicycle Class	Upgraded Bicycle Class	Build Date	Construction Start	Pre-Test Calendar Year	Post-Test Calendar Year
30th Street	None	Separated Bikeway (4)	8/1/2021	6/1/2021	2020	2022
4th Ave	Class 3	Separated Bikeway (4)	2/25/2022	Summer 2020	2019	2023
5th Ave	Class 2	Separated Bikeway (4)	2/25/2022	Summer 2020	2019	2023
Bayshore Bikeway (National City Segment)	Class 2	Multi-Use Path (1)	2/17/2018	12/1/2016	2015	2019
Meade Ave	None	Bike Boulevard (5)	3/19/2022	12/12/2019	2018	2023
Rose Creek	None	Multi-Use Path (1)	5/26/2021	1/1/2018	2017	2022
Coastal Rail Trail (Encinitas)	None	Multi-Use Path (1)	5/1/2019	4/30/2018	2017	2020
Landis St	None	Bike Boulevard (5)	4/23/2022	12/12/2019	2018	2023

Before and After Analysis (Adjusted for Ridership)

Bicycle count data from SANDAG was available for three sites in our dataset: 30th Street, 4th/5th Avenue, and Landis Street. We calculated adjusted collisions simply by dividing the number of collisions in a year within 100 feet of each bicycle lane by the average daily bicycle counts for each street. (Since there is only one counter for both 4th and 5th avenue, we combined the collisions from each street and divided by the average bike count).

Before and After Study Using Control Sites

A control site is a stretch of road that in as many ways as possible should reflect the same conditions as what the treatment site had beforehand. The control sites chosen were determined by both equivalent place typology characteristics and a length of road that sufficiently covered the same length as the treatment site's project.

When selecting control sites for comparison with sites treated with bicycle infrastructure, several key criteria were considered to ensure the validity and reliability of the comparison to treated sites based on existing literature (*Reynolds et al., 2009; Taciuk & Davidson, 2018; Ahmed et al., 2022; Freemark et al., 2022*). These criteria are selected to minimize confounding variables and ensure that the differences observed are due to the bicycle infrastructure intervention and not other factors.

When choosing Control Sites for the study, the following sub-categories of variables were taken into consideration.

Urban Context: Urban Context refers to the physical geography of the area in question and can include variables such as similar demographics (including but not limited to population density, age, and income levels). Urban Context also takes into account the physical lay of the land: that is identical land use around both the treatment and control roads. And finally, Control Sites should be selected based on similar levels and patterns of pedestrian, bicycle, and automobile traffic. As a proxy for urban context, we used a place typology dataset to find comparable control sites.

Baseline Similarity: These are the criteria that specifically refer to bicycle usage on the treatment and control roads. When determining a control site, the level of bicycle usage should be as similar as possible to what it was for the treatment site prior to the latter's project being constructed. Equally important, the level of bicycle safety and bicycle traffic stress in the control site must be equivalent to that of the treatment site in the before conditions.

Infrastructure: This refers to the physical design of the roads which–in the case of the treatment site–the bike project was applied to. The control site road should have a very similar physical design as that which the treatment site road had in the before condition, including but not limited to: same number of lanes across, and connectivity to the wider transportation network.

Environmental: Control site environmental factors such as terrain and typical weather patterns should match those of the treatment site. For instance, a treatment site that is in a coastal area with mostly flat terrain should be compared against a control site in a coastal area with mostly flat roads. In these conditions, things like air temperature, fog presence, sunlight exposure, and levelness of the terrain are more likely to match.

Socioeconomic: Control sites should be selected based on similar types of business activity in the locality of the treatment site. They should also be selected based on the proximity of public services and amenities (e.g. schools, parks, and shopping areas) to the treatment sites. The place typology data was also used as a proxy for socioeconomic factors.

Temporal Factors: Control sites should only record casualties (injuries and fatalities) that take place in the same time period as that being established for the treatment site's analysis. In the below chart case, that time frame was one year before the treatment was applied, then one year afterwards.

Accessibility & Mobility: Access to public transit is a crucial driving factor in bicycle usage. As such, control sites should be selected based on a similar quantity of and proximity to public transportation services. The provision of parking is also an influential factor. Control sites should also be selected based on the size of parking lots surrounding both they and treatment site and how much parking is immediately available there.

Behavioral & Cultural: Local attitudes towards bicycling, relating to or independent thereof, the above seven variables are central to the choice of using a bicycle. Additionally, the quantity and type of bicycle-supporting infrastructure that is typically provided in the general region of study must also be taken into account. In this case, the region of San Diego County is a largely car-centric area that typically provides, at best, Class II Unprotected Bike Lanes on many of its major roads.

By ensuring that control sites match treated sites on these criteria, researchers can more confidently attribute differences in outcomes (e.g., changes in cycling rates, safety improvements) to the bicycle infrastructure intervention itself. This careful selection helps to isolate the impact of the infrastructure and provides more robust and generalizable findings.

Based on these variables, we established control sites for two of our treatment sites: 4th/5th Avenue and 30th Street. Table 3 provides an overview of the control sites, and Figure 3 provides a map of control sites.

Table 3. Description of control sites

Control Site Area	Bikeway Class	Cross Streets	Comparable Treatment Site	Pre-Test Calendar Year	Post-Test Calendar Year
Sherman Heights - Imperial Avenue	Separated Bikeway (4)	19th Street to 33rd Street	4th & 5th Avenues	2019	2023
Golden Hill - Broadway	Bike Route (3) / No bike lane	19th Street to 30th Street	4th & 5th Avenues	2019	2023
Kensington/Normal Heights - Adams Avenue	Bike Route (3)	Edgeware Road to 19th Street	30th Street	2020	2022

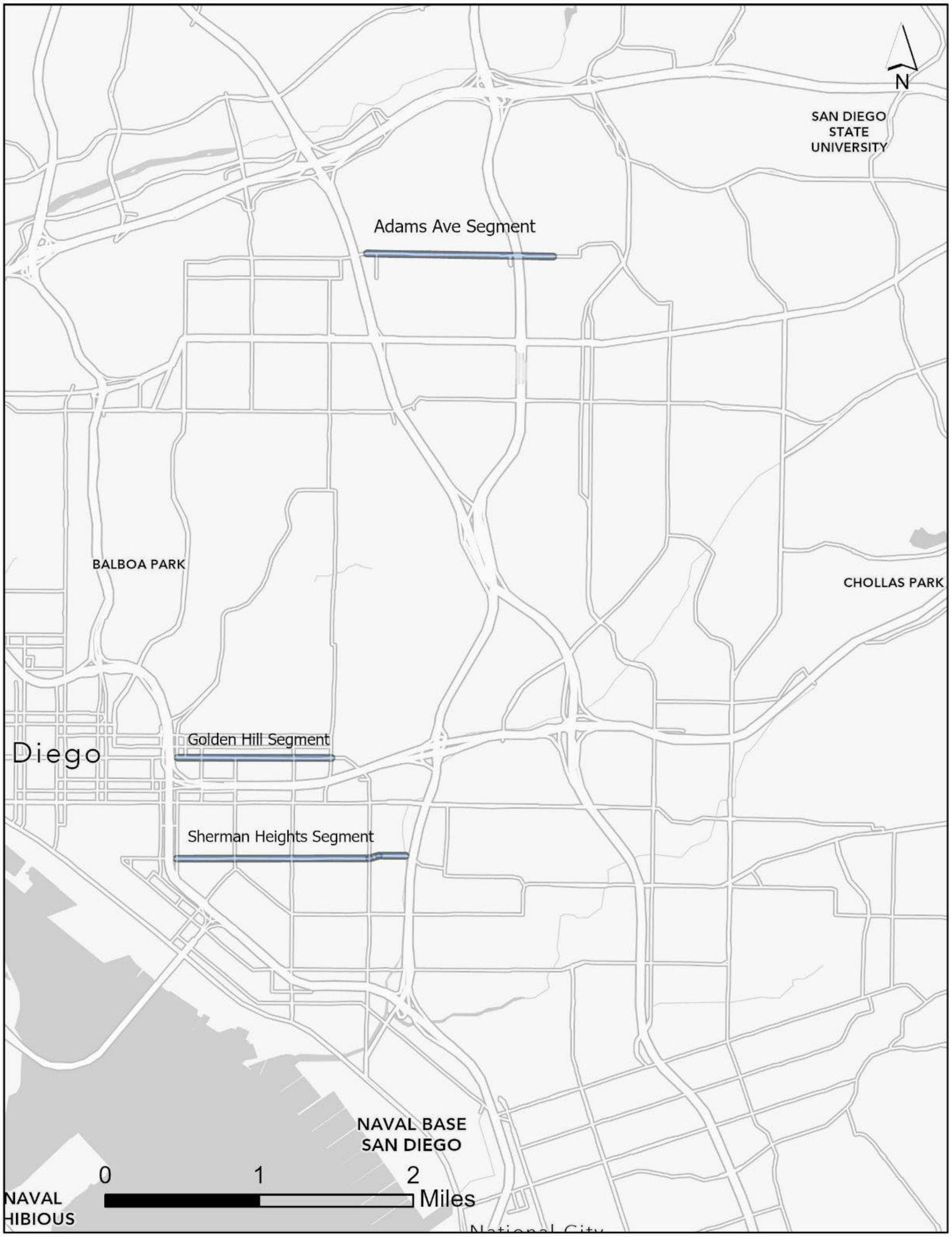

Figure 3. Map of control sites

Results

Before and After Analysis: Ridership

Bicycle counters were available at three of our treatment sites: 30th Street, 4th/5th Avenue, and Landis Street. Using the average annual bike counts provided, we calculated the percent change in ridership for each year. As shown in figure 4, we compared the changes in ridership at our study sites with the overall change in ridership for all of SANDAG's eight counters.

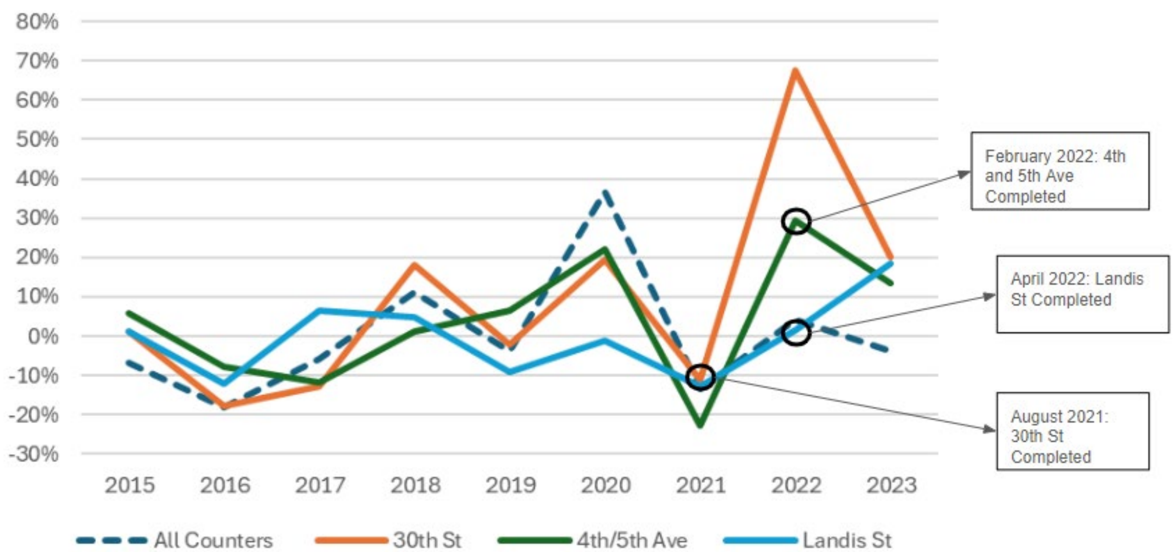

Figure 4. Year over year changes in average bicycle counts

In the case of 30th Street, we see a sharp increase in ridership between 2021 and 2022, which is when the separated bikeway was completed. Along 4th and 5th Avenue, bicycle counts rose in 2022, coinciding with when construction was completed for a separated bikeway. Along Landis Street, ridership increased slightly in 2022 and 2023. When we look at trends for all of SANDAG's counters, we see a sharp increase in ridership during 2020, coinciding with the COVID-19 pandemic. Growth in bicycle ridership at all bicycle counter sites is lower than the growth of ridership at new bicycle facilities, which were completed between 2021 and 2023.

After analyzing trends from a 10-year period, we specifically looked at bicycle ridership in the years directly before and after construction to review the percent change in counts. Since bicycle ridership counts are adjusted and aggregated by calendar year, our pre-test period for each site included the last full calendar year before construction, while the post-test period for each site included the first full calendar year after the project was completed.

Table 4. Ridership at study sites before and after construction

Bikeway	Before Conditions		After Conditions		Percent Change
	Pre-Test Year	Average Bike Counts	Post-Test Year	Average Bike Counts	
30th Street	2020	160	2022	238	49%
4th and 5th Ave	2019	177	2023	245	38%
Landis St	2018	88	2023	83	-6%

In table 4, we see significant increases in ridership along 30th Street and 4th/5th Avenue, with a slight drop in ridership along Landis Street.

Building on this analysis of before and after bicycle counts, we then conduct an exploratory analysis of collisions.

Before and After Analysis: Collisions

Since bicycle collisions alone are relatively low for each segment, we analyzed total collisions (vehicle, pedestrian, and bicycle) along each study site.

Table 5. Total collisions in before and after analysis

Bikeway	Before Conditions		After Conditions		Percent Change
	Pre-Test Year	Total Collisions	Post-Test Year	Total Collisions	
30th St	2020	9	2022	18	100%
4th Ave & 5th Ave	2019	46	2023	27	-41%
Bayshore Bikeway (National City)	2015	1	2019	7	600%
Meade Ave	2018	14	2023	16	14%
Rose Creek	2017	3	2022	0	-100%
Coastal Rail Trail (Encinitas)	2017	5	2020	2	-60%
Landis St	2018	5	2023	6	20%

When evaluating all collisions (vehicle, pedestrian, and bicycle), we see mixed results, as demonstrated in table 5. Four of the study sites (30th Street, Bayshore Bikeway, Meade Avenue, and Landis Street) saw an increase in total collisions after the project was completed. However, in some cases, the number of collisions was too small to accurately calculate percent change. For example, Bayshore Bikeway only had 1 collision in the pre-test period, resulting in a large percentage increase in the post-test period. The remaining study sites (4th/5th Avenue, Rose Creek, and the Coastal Rail Trail) saw a decrease in total collisions. 4th/5th Avenue, which both had relatively high numbers of collisions, saw significant decreases.

Table 6. Bicycle and pedestrian collisions in before and after analysis

Bikeway	Before Conditions		After Conditions		Percent Change
	Pre-Test Year	Bicycle / Pedestrian Collisions	Post-Test Year	Bicycle / Pedestrian Collisions	
30th St	2020	3	2022	2	-33%
4th Ave & 5th Ave	2019	15	2023	11	-27%
Bayshore Bikeway (National City)	2015	0	2019	0	N/A
Meade Ave	2018	3	2023	5	67%
Rose Creek	2017	0	2022	0	N/A
Coastal Rail Trail (Encinitas)	2017	1	2020	1	0%
Landis St	2018	2	2023	2	0%

While the numbers for pedestrian and bicycle collisions were low, we decided to report them in order to see how many collisions came from active modes of transportation. Table 6 shows only bicycle and pedestrian collisions from the dataset. While a few treatments sites show a drop in pedestrian and bicycle collisions, the numbers are very low, making the percent changes extremely sensitive. For example, the 30th Street bikeway shows a 33% drop in collisions between the pre-test and post-test period; however, this was a drop from 3 collisions to 2 collisions. In two cases, no pedestrian or bicycle collisions were reported in the pre-test period, making it impossible to calculate percent change.

Before and After Analysis (Adjusted for Ridership)

We then combined our approach to review collisions adjusted for ridership, which we calculated as the number of collisions divided by the average bike counts for the pre-construction and post-construction periods.

When normalizing total collisions (vehicle, pedestrian, and bicycle) by average bicycle ridership, we see safety improvement along 4th and 5th Avenue, as shown in table 7. This was the only case in the dataset in which total collisions decreased while bicycle ridership increased.

Control Sites

We then evaluated collisions along our control sites. Ridership data was not available for these sites.

As shown in table 8, the Adams Ave segment (the control site for 30th Street) saw a decrease in total collisions in the post-test period, while the collisions along 30th Street actually increased in the post-test period. Along the Sherman Heights segment, the percent decrease in collisions is lower in the post-test compared to the treatment site. Along the Golden Hill segment, collisions increased, while they decreased in the treatment site.

Table 7. Total collisions adjusted for ridership

Bikeway	Before Conditions			After Conditions			Percent Change
	Average Bike Counts	Collisions	Collisions / Exposure	Average Bike Counts	Collisions	Collisions / Exposure	
30th St	160	9	0.056	238	18	0.076	34%
4th and 5th Ave	177	46	0.260	245	27	0.110	-58%
Landis St	88	5	0.057	83	6	0.072	27%

Table 8. Total collisions at control sites

Control Site	Comparable Treatment Site	Before Conditions		After Conditions		Percent Change Total Collisions	
		Pre-Test Calendar Year	Total Collisions	Post-Test Calendar Year	Total Collisions	Control	Treatment
Adams Ave Segment	30th St	2020	13	2022	3	-77%	100%
Sherman Heights Segment	4th/5th Ave	2019	16	2023	14	-13%	-41%
Golden Hill Segment	4th/5th Ave	2019	4	2023	7	75%	-41%

Discussion

Notably, our results show that the addition of protected bicycle lanes has a positive effect on bicycle ridership. Average bicycle counts increased in the post-construction period for two major routes: 30th street (which saw a 49% increase) and 4th/5th Avenue (which saw a 38% increase). This is an encouraging finding, as it demonstrates that these infrastructure improvements have increased the number of cyclists on the road.

Considering the limitations on our methods, our results showed that bicycle lanes had varied effects on road safety. In our study sites, we found that in some cases, total collisions decreased in the post-construction period, while in other cases, total collisions increased. Bicycle lanes along 4th and 5th Avenue seem to be particularly effective in reducing total collisions, both when looking at raw numbers and when adjusting for bicycle ridership.

When we compared the results of the pre/post-test in our treatment sites to our control sites, our results were inconclusive. The two of the control sites for 4th & 5th Avenues showed a higher percent increase in collisions compared to the corresponding treatment, further pointing to the success of the control sites in reducing collisions. The other control site for 30th Street, however, showed a lower percent increase in collisions compared to the corresponding treatment.

Limitations to Study

There were several limitations to our study. First, we had less than two years of collision data available in the post-construction period for several of these sites. Additionally, the bicycle counter data from SANDAG only records ridership at a single point, while the collision data that we are using covers the entire bicycle route. As previous research has discussed, it is difficult to compare ridership data from a single point with collision data over an entire bicycle path (*Nelson et al, 2021; Ferster et al, 2021; Jestico et al, 2016*). While the collision data gathered from TIMS is the most comprehensive, accessible, and accurate source for traffic safety data in California, the 2022 and 2023 collisions within the dataset are considered preliminary data and are subject to change. This is an important consideration because many of our post-construction safety analyses spanned these years. This dataset also only includes collisions in which there was an injury reported, therefore omitting vehicle crashes that are considered "property damage only," such as fender benders (*UC Berkeley, 2024*). Additionally, some of the pre-test and post-test periods coincided with the COVID pandemic, which drastically altered transportation patterns. Lastly, the safety analyses included a relatively small number of collisions, resulting in percent changes that were highly sensitive. For example, in some cases, we saw a 100% decrease in bicycle collisions, but that change was simply from 3 collisions in the pre-construction period to 0 collisions in the post-construction period.

Recommendations for Future Research

To develop a longer period for post-construction, we recommend continuing to monitor these sites in order to develop a more robust analysis. We also plan to expand on our methodology to introduce more control sites into the analysis, ideally pairing each treatment site with a control site for a more robust collision analysis. Another option to control for variation in ridership is to look at overall ridership in similar place type contexts throughout San Diego. In order to increase the number of collisions in our dataset, particularly for vehicle-vehicle collisions, we could run the same analysis using data directly from SWITRS, as this would include non-injury incidents. Lastly, we plan to introduce other variables into our safety analysis, including traffic volumes and speed limits, which may help explain collision trends.

Conclusions and Recommendations

Notably our findings support the idea that if you build it, people will ride, with average bicycle counts increasing in the post-construction period for two major routes: 30th street (which saw a 49% increase) and 4th/5th Avenue (which saw a 38% increase).

We also find that looking at the effects of bicycle projects on overall safety is a more complicated undertaking than expected. We found that, in some cases, total collisions decreased in the post-test period, while in other cases, total collisions increased. Bicycle lanes along 4th and 5th Avenue seem to be particularly effective in reducing total collisions, both when looking at raw numbers and when adjusting for bicycle ridership.

In sum, our findings show that, for the most part, if you build it, people will ride, but that understanding the before and after safety benefits of bicycle projects is a more complex undertaking requiring careful examination with a reasonable comparison between treatment and control sites, longer periods of data, and proper zones of analysis.

Nevertheless, considering all the current limitations of our study, we find that overall bicycle projects encourage riding and likely improve safety and street livability. Indeed, there is a need for further research as in some cases it is inconclusive as to the exact safety effects of the bicycle projects. Future research could build on this study by applying control groups to more of the study sites, monitoring the post-construction safety conditions over a longer period of time, and introducing additional variables into the analysis, including before and after traffic volumes and speed limits.

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