RESEARCH REPORT

Institute of Transportation Studies | UNIVERSITY OF CALIFORNIA

Evaluate the Safety Effects of Adopting a Stop-as-Yield Law for Cyclists in California

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16. Abstract
The escalating number of injuries and fatalities among cyclists is a pressing safety concern. In the United States, communities are actively seeking strategies to boost cyclist safety, with some states implementing bike-specific policies, such as stop-as-yield laws, to support cyclists. Stop-as-yield laws allow cyclists to treat stop signs as yield signs. The laws are not yet widely implemented, and their potential safety impact is a subject of debate among transportation experts and advocates. This study investigates how stop-as-yield laws can positively or negatively affect safety and provides insights and guidelines for California policymakers and safety practitioners if the law passes in California. We collected cyclist data from five states that have enacted stop-as-yield laws—Idaho, Arkansas, Oregon, Washington and Delaware—and data from some of their contiguous states without such legislation. Using an observational before-after study with comparison groups at the state level, the research examined changes in cyclist crash frequencies after the laws were implemented. Additionally, a random-effects negative binomial regression model with panel data was employed to estimate a law's overall impact. The results did not indicate a significant change in cyclist crashes among the states with stop-as-yield laws.

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In response to the rising concern over cyclist injuries and fatalities, communities in the United States are actively exploring strategies to enhance cyclist safety. One approach gaining attention is the implementation of stop-as-yield laws, commonly known as “Idaho stop” laws. Originating in Idaho, these laws permit cyclists to treat stop signs as yield signs. Stop-as-yield laws, such as the Idaho Stop and Delaware Yield laws, address two concerns. First, they free up time in the courts by downgrading the violations to minor traffic offenses. Second, because many cyclists tend to behave in ways that maintain their energy and momentum, a stop-as-yield law can be considered a “bike-friendly” policy that can encourage people to use this environmentally friendly mode of transportation. However, little is known about the safety implications of stop-as-yield laws, particularly for a state with large urban areas like California.

This study investigates the potential impact of stop-as-yield laws on cyclist safety by comparing and analyzing cyclists’ crashes in states that have and have not enacted a stop-as-yield law. It also provides guidelines for the State of California in evaluating the safety implications should it consider such legislation.

To conduct the analysis, we collected cyclist data from states with enacted stop-as-yield laws (Arkansas, Delaware, Idaho, Oregon, and Washington) and from contiguous states without such laws (California, Louisiana, Maryland, Missouri, Pennsylvania, Tennessee, Texas, and Virginia). Using an observational before-after study with state-level comparison groups, the study examined changes in cyclist crash frequencies following the implementation of the stop-as-yield laws. Additionally, we used a random-effects negative binomial regression model with panel data to estimate the overall impact of these laws.

A literature review revealed a lack of consensus on the impact of a stop-as-yield law on safety and the degree to which it might influence overall safety outcomes. Similarly, the findings of this study align with this uncertainty, indicating no statistically significant change in cyclist crash rates in states with stop-as-yield laws. These results offer insights for California’s policymakers and safety practitioners when considering and investigating the safety implications of such laws, pre and post implementation. This study provides a comprehensive roadmap for evaluating the prospective legislation in California.

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Introduction

Cycling is considered an affordable and sustainable mode of travel and has demonstrated opportunities to mitigate traffic congestion, reduce air pollution, and complement public transportation in urban areas (*1*). At the individual level, cycling can increase physical activity and promote public health (*2*). However, a surge in injuries and fatalities among cyclists has emerged as a significant safety issue in recent years. For instance, in the United States, cyclist fatalities increased by 1.9 percent in 2021 and injuries by 7 percent, compared to 2020 (*3*). In 2020, about 26 percent of cyclist fatal crashes took place at intersections where the conflicts between cyclists and motorists present a high risk for crashes (*4*). Ensuring the safety of cyclists, who are considered vulnerable road users, is of utmost importance within the transportation system. This objective aligns with the Vision Zero Goal and the Safe System approach to eliminate traffic fatalities and serious injuries (*5*).

Throughout the United States, communities have been actively seeking strategies to enhance cyclist safety and alleviate confusion in situations that pose potential hazards and high risks. Several states have implemented bicycle safety laws to promote safety and safeguard all individuals using the roadways (*6*). To support cyclists, bike-specific policies have been introduced. The Idaho Stop Law, enacted in 1982, allows cyclists to treat stop signs as yield signs and red traffic lights as stop signs (Idaho Statutes § 49-720). Stop-as-yield laws address two concerns simultaneously. First, they free up time in the courts by downgrading these violations to minor traffic offenses. Second, because many cyclists tend to behave in ways that maintain their energy and momentum, a stop-as-yield law can be considered a "bike-friendly" policy that can encourage people to use this environmentally-friendly mode of transportation. Stopping discourages bicycling because it increases travel time, energy expenditure, discomfort, risk of collisions, and risk for strain and overuse injuries (*7*).

Currently, stop-as-yield laws are not yet widely implemented, and their potential safety impact is debated among transportation experts and advocates. One could argue that adopting a stop-as-yield law has the potential to make cyclist behavior more predictable for motorists, ensuring safer roads for everyone and making intersections flow more efficiently for all road users. Alternatively, one could argue that by normalizing an already common behavior, the law would have little effect on bicyclist behavior or safety, or it could increase the conflicts between cyclists and motorists at intersections and worsen safety. Nevertheless, the safety implications of stop-as-yield laws have not been extensively studied, leaving this matter largely unanswered.

This study investigates the potential positive or negative impact of a stop-as-yield law and identifies the research needs for evaluating the safety impacts if California should pass such a law. Table 1 lists the laws that have been implemented in the United States.

Table 1. States with a stop-as-yield law (modified from NHTSA 2022)

State Bill	Year Enacted	Stop-as-Yield	Red Signal as Stop Sign
Idaho (§ 49-720)	1982	Yes	Yes
Delaware (§ 4196A)	2017	Yes	No

State Bill	Year Enacted	Stop-as-Yield	Red Signal as Stop Sign
Arkansas (§ 27.51-1803)	2019	Yes	Yes
Oregon (§ 683.1)	2020	Yes	No
Washington (§ 46.61.190)	2020	Yes	No
North Dakota (§ 39-10.1-05.1)	2021	Yes	No
Oklahoma (§ 47.11-202.1)	2021	Yes	Yes
Utah (§ 41-6a-902 and § 41-6a-1105)	2021	Yes	Yes
Colorado (§ 42-4-1412)	2022	Yes	Yes

Literature Review

Stop-as-yield laws apply only to cyclist and driver behaviors at intersections. One study applied the Pedestrian and Bicycle Crash Analysis Tool (PBCAT) to present an overview of the prevalent bicycle crash types in the United States from 2014 to 2016. The study found that 36 percent of cyclist fatalities occurred at intersections (30 percent in urban areas and 6 percent in rural areas), and 60 percent were in non-intersections (38 percent in urban areas and 22 percent in rural areas). Cyclists failing to yield (midblock, yield-signalized, and sign-controlled) were 7.4 percent, 6.9 percent, and 6.8 percent of the fatal crash types, respectively, while motorists failing to yield (midblock, yield-signalized, and sign-controlled) were 1.1 percent, 0.9 percent, and 0.4 percent of the fatal crash types, respectively (*8*).

The Location-Movement Classification Method (LMCM) is an alternative method that reports the location and direction of the cyclist relative to the vehicle when the crash occurs, which can be helpful to better understand the conflict that preceded a crash between a driver and cyclist. One study applied the LMCM to crashes in Wisconsin between 2011 and 2013 and found consistent results with other statewide efforts regarding the distribution of fatal and injury crashes between the intersection and non-intersection locations. The study found that all-severity crashes are concentrated in intersections, but fatal crashes occurred mainly in non-intersection locations. In addition, 90 percent of motorists were more likely to be traveling straight in a fatal bicycle crash as compared to non-severe crashes (53 percent). Fatal bicycle crashes were also less likely to occur with cyclists traveling in the opposite direction of vehicle traffic (12 percent) than non-severe crashes (30 percent) (*9*).

Rolling-stop behavior at intersections is a common practice among cyclists. Sanctioning a rolling stop could potentially increase traffic conflicts, which are associated with higher rates of crashes (*10*). Drivers and cyclists need to make decisions regarding stopping or yielding at an intersection in a fraction of a second, which could negatively affect intersection safety. The probability of conflict is higher when the arrival time difference to the intersection between the driver and cyclist is lower (*11*), meaning there are circumstances in which it is not obvious who failed to yield between the cyclist and the driver when they arrive at the intersection at similar times. There is also evidence of the challenges of crash reporting due to unclear conditions, use of language, and structural preconceptions of traffic safety (*12*).

Piatkowski et al. (*13*) designed a study to identify behavioral norms among bicyclists in mixed-traffic conditions by asking individuals to score their behavior regarding obedience to traffic laws using a five-point Likert scale from “Never” to “Always.” Of the 17,851 respondents internationally, of which 14,341 respondents from the United States, 24 percent claim to not make complete stops at stop signs or not stop very well, and 76 percent claim to “complete well,” “fairly well,” or “extremely well” (*13*). An analysis of naturalistic GPS data for bicycles and e-bikes showed that about 80 percent of riders violate stop signs at speeds less than 6 km/h (3.7 mph)—characterized as a rolling stop—and about 20–30 percent of riders violate stop signs at high speeds above 12 km/h (7.5 mph) (*14*). A study of cyclist behavior at six intersections in Chicago found that only 4 percent of cyclists came to a complete stop at stop signs compared to 49 percent making a rolling stop (*15*).

Fajans & Curry (*16*) argue that there is a large difference in energy efficiency and speed between a cyclist who rolls through a stop sign and a cyclist who comes to a complete stop. Fully stopping every 300 feet can mean a 40 percent drop in average speed for the cyclist, compared to rolling at 5 mph without fully stopping, which means that frequent stopping can discourage cycling (*16*). Other environmental factors, such as weather, influence cyclists’ behavior and impact safety in intersections (*17*). For instance, a study found differences in cyclist behavior between sunny and cloudy days—on sunny days, riders are 1.8 times more likely to run through a red light, and on cloudy days, it is 1.2 times (*17*).

There is also evidence that cycling experience and road user adaptation can reduce the number of conflicts between cars and cyclists in intersections (*18 and 19*). An online survey of cyclists from multiple countries, including the United States, found that over time, cyclists develop the ability to predict if a driver is going to let them pass first in an intersection based on the car's perceived speed and acceleration(*18*). Another study found a long-term decrease in conflicts between drivers and cyclists in a Norwegian road-cycle path intersection, suggesting the adaptation of road users over time to their counterpart's behavior (*19*).

A few studies conducted in the United States that analyzed the effects of stop-as-yield laws found either some minor safety improvements or no significant change after the law was implemented (*20*, *21*, *and 22*). One study analyzed the yearly statewide traffic injuries and fatalities data from Idaho's Office of Highway and Traffic Safety from 1966 to 1992 (the Idaho Stop Law was implemented in 1982) and found that, after the law was adopted, bicyclist injuries from traffic crashes declined by 14.5 percent the following year. No change was observed regarding fatalities. The study also compared bicycle traffic injuries in Boise, Idaho, with Sacramento, California, and used the 2000 U.S. Census data to calculate an injury-to-bicycle-commuter ratio for each city, finding that Boise has a ratio of 30 percent to 60 percent lower than Sacramento. The study did not identify negative safety results associated with the adoption of the law (*20*).

Another study investigated the potential impacts of the Idaho Stop Law on bicycle crash severity. Using only crashes involving cyclists in which no party was intoxicated from 2007 to 2011, the study examined the difference in the ratio of bike crash severity between Boise, Idaho (practicing Idaho Stop Law), and Champaign/Urbana, Illinois (no stop law). The study found a statistically significant difference in the overall proportion of crashes that resulted in property damage or nonserious injuries. Still, no statistical difference was found in serious injuries or fatal crashes between Boise and Champaign/Urbana, and no statistical difference was found for any crash severity between the two cities in crashes that happened at stop-controlled intersections (*21*). Finally, according to the National Highway Traffic Safety Administration (NHTSA), in Delaware, the second state to implement a stop-as-yield law after Idaho(in 2017, traffic crashes involving cyclists at stop-controlled intersections fell by 23 percent in the 30 months after the Delaware Yield law passed, compared to the previous 30 months (*6 and 22*). There is no further information regarding the data sources, methodology, or rationale applied to measure the crash reductions reported in this fact sheet by NHTSA, so it is possible that other covariates might have influenced the reduction.

Table 2 shows the findings and methodological limitations of the studies described regarding the impacts of stop-as-yield laws in the United States.

Table 2. Findings and limitations of studies on the impacts of stop-as-yield laws

Study	Findings	Limitations
Meggs (2010)	• Bicyclist injuries from traffic crashes declined by 14.5 percent the year after the Idaho Stop Law was implemented, and no change was observed regarding fatalities. • Injury-to-bicycle-commuter ratio in Boise, Idaho (with Idaho Stop Law in place) is 30 percent to 60	• Not published in a peer-reviewed journal • Methods insufficiently described • The comparison between cities is not extensively explained • The results of the interviews are not sufficiently described

Study	Findings	Limitations
	percent lower than in Sacramento, California (without a stop law in place). ● Idaho local authorities, bicycle advocates, and individuals involved in the adoption of the law did not identify negative safety results associated with the adoption of the law.	
Whyte (2013)	● Statistically significant difference in the overall proportion of crashes that resulted in property damage or nonserious injuries between Boise and Champaign/Urbana. ● No statistical difference in serious injuries or fatal crashes between Boise and Champaign/Urbana. ● No statistical differences were found for any crash severity between the two cities in crashes that happened at stop signs.	● Small sampling size for a statistical significance test, especially when the crashes are disaggregated by severity and location, so the number of crashes in each category is reduced to smaller numbers
NHTSA (2022)	● In Delaware, traffic crashes involving cyclists at stop sign intersections fell by 23 percent in the 30 months after the Delaware Yield law passed, compared to the previous 30 months.	● The information about the impacts of the implementation of the law is limited ● No details regarding how and when the reported reductions of crashes involving cyclists in stop signs were measured

The literature about the implementation of stop-as-yield laws for cyclists is limited, and there is no consensus regarding the laws' potential implications. Hence, one main gap in the literature is the uncertainties about the safety impact of stop-as-yield laws. This study provides insights for policymakers and state legislature to better understand the research needs for evaluating the safety impacts of implementing a stop-as-yield law in California should it pass.

Methodology

This study consists of two steps, as described in Figure 1. First, we investigated the impact of stop-as-yield laws in different locations using observational before-after study with comparison groups. Second, we conducted a macro-level analysis of historical U.S. bicycle crashes and explored the potential contribution of stop-as-yield laws to the frequency and rate of cyclist crashes.

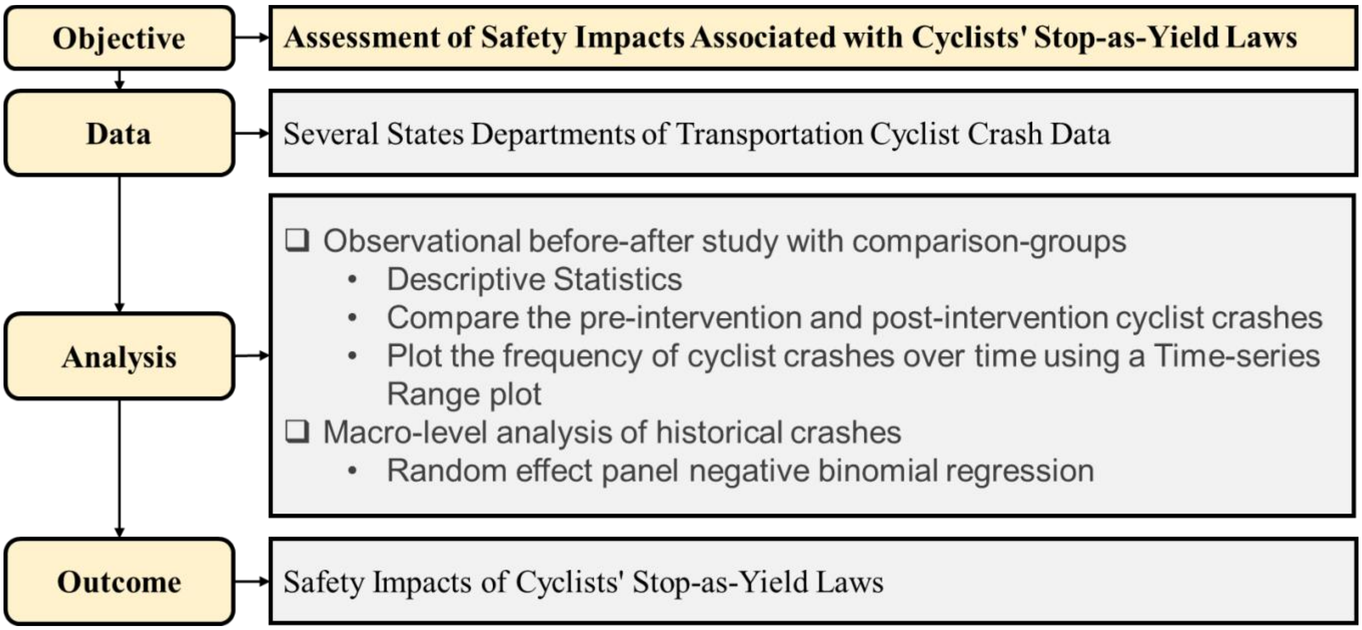

Figure 1. Study framework

Observational Before-and-After Study with Comparison Groups

An observational before-after study with comparison groups is designed to evaluate the impact of an intervention or treatment, i.e., stop-as-yield laws, on a specific outcome, i.e., cyclist crashes. In this study, data was collected before and after a state enacted a stop-as-yield law and for a comparison group that does not have a stop-as-yield law. The comparison group serves as a reference to assess the changes observed in the treatment group and helps to account for other factors that could influence the outcome. The following steps are undertaken to conduct this analysis.

- **Study design:** Determine the study period, and define the pre-intervention and post-intervention periods from the effective date of the stop-as-yield law in the selected states.
- **Comparison group selection:** Select the comparison group (i.e., state) based on the state where the stop-as-yield law was enacted and a neighboring/comparable state in which the law has not been established.

- **Data collection:** Collect two types of data: 1) Historical data on cyclist crashes during the pre-intervention and post-intervention periods; 2) Exposure data, such as population and/or the number of commuter bicyclists and vehicle miles traveled (urban/rural).
- **Data analysis:** Compare the pre-intervention and post-intervention bicycle crash frequencies or crash rates.
- **Visual inspection:** Plot the frequency or rate of crashes over time using a Time-series Range plot to help identify noticeable patterns, trends, or changes in the crash data over time.

Macro-Level Analysis of Historical Crashes

Temporal instability in crash data is discussed in the literature (*23*). Temporal instability suggests that the effect of explanatory variables varies over time due to many factors, such as changes in road user behavior. Another potential issue in the model is that some factors that cause road crashes are unknown or unobservable. Both temporal instability and unobserved heterogeneity would result in inefficient estimators, meaning that the estimated effects of explanatory variables (including the stop-as-yield laws indicator variable) can be inaccurate. To deal with this, random effect models have been used in the literature (*24–27*), enabling estimates to vary across observation time intervals. To that end, to conduct a comparative, macro-level analysis of cyclists' historical crashes to uncover the safety impacts of stop-as-yield laws and investigate the overall association between the laws and cyclist crash rate, a random-effects negative binomial regression model with panel data is estimated to account for unobserved heterogeneity across panels. This method is designed for analyzing count data (e.g., bicycle crash frequency) with overdispersion in a panel or longitudinal setting.

The panel data is a two-dimensional concept, where panel i=1, 2, .., *n* represents the states and time t=1, 2, ..., *n* represents the month. The model extends the negative binomial regression model to handle panel data, accounting for repeated measures or observations on the same individuals or groups over time. It accounts for individual-specific or group-specific heterogeneity and control for time-invariant variables. The random effect technique is used to control for the variations among entities when they have an impact on the dependent variable and the dispersion might vary across the groups or states for unidentified group-specific reasons (*28*). The general form and log likelihood of the model can be calculated using equations 1 and 2, respectively.

$$Pr\ Pr\ (Y_{it} = y_{it}, \delta_i) = \frac{\Gamma(\lambda_{it}+y_{it})}{\Gamma(\lambda_{it})\Gamma(y_{it}+1)} (\frac{1}{1+\delta_i})^{\lambda_{it}} (\frac{\delta_i}{1+\delta_i})^{y_{it}} \quad (1)$$

$$lnL = \sum_{i=1}^{n} \omega_i [ln\Gamma(r+s) + ln\Gamma\left(r + \sum_{k=1}^{n_i} \lambda_{ik}\right) + ln\Gamma\left(s + \sum_{k=1}^{n_i} y_{ik}\right) - ln\Gamma(r) - ln\Gamma(s) - ln\Gamma(r + s + \sum_{k=1}^{n_i} \lambda_{ik} + \sum_{k=1}^{n_i} y_{ik}) + \sum_{t=1}^{n_i} [ln\Gamma(\lambda_{it} + y_{it}) - ln\Gamma(\lambda_{it}) - ln\Gamma(y_{it} + 1)]]$$

(2)

Where y_{it} is the count for the tth observation in the ith group, δ_i is the dispersion parameter, $\lambda_{it} = exp\ (x_{it}\beta + offset_{it})$ and ω_i represents the weight for the ith group, and y_{it} is the count for tth observation in the ith group and $\sum_{t=1}^{n_i} y_{it}$ denotes the observed sum of the counts for the group. r and s are the dispersion parameters that are assumed to follow a Beta(r,s) distribution. See (*28 and 29*) for more information about the equation.

Data Description

The data used in this study were collected from U.S. Census journey-to-work data, the National Household Travel Survey, and state-level bicycle crash data from different states' departments of transportation. Multiple years of bicycle crash data, including all levels of severity (non-injury, injury, and fatal), were collected for four states that have passed the stop-as-yield laws (Arkansas, Delaware, Idaho, Oregon, and Washington) and some of their contiguous states (Louisiana, Maryland, Missouri, Pennsylvania, Tennessee, Texas, and Virginia) based on the availability of the data on an annual basis and/or monthly basis. Ideally, crash data would have been restricted to intersection injury crashes with a yielding violation, but this level of detail (even an intersection variable) was not available consistently across states. On a yearly basis, the data is aggregated over a one-year period. Likewise, on a monthly basis, the data is aggregated over a one-month period. Tables 3 and 4 summarize the descriptive statistics of the data on a yearly and monthly basis, respectively. The "stop-as-yield laws in place" variable represents 0 when and where the law is not practiced, and 1 when and where it is in effect.

Table 3. Descriptive statistics of the data on a yearly basis (2015–21)*

Variable		Min/Frequency	Max/Percent	Mean	Standard Deviation
Total bicycle crashes		107	11115	1649	2632.03
Crash rate per 100,000 population		3.55	28.57	13.15	6.52
Stop-as-Yield laws in place	No	51	7286%	—	—
	Yes	19	27.14%	—	—

*Note: Annual data were collected for Arkansas, California, Delaware, Idaho, Louisiana, Maryland, Missouri, Oregon, Pennsylvania, Tennessee, Texas, Virginia, and Washington.

Table 4. Descriptive statistics of the data on a monthly basis (2015–21)*

Variable		Min/Frequency	Max/Percent	Mean	Standard Deviation
Total bicycle crashes		0	1108	137.400	222.162
Population		945,934	39,501,653	11,245,115	12,027,884
Crash rate per 100,000 population		0	4.262	1.096	0.732
COVID impact	Jan 2015–Feb 2020	555	76%	—	—
	March 2020–Dec 2020	81	11%	—	—
	Jan–Dec 2021	96	13%	—	—

Variable		Min/Frequency	Max/Percent	Mean	Standard Deviation
Season	Jan–March	210	25%	—	—
	April–June	210	25%	—	—
	July–Sep	210	25%	—	—
	Oct–Dec	210	25%	—	—
Stop-as-yield laws in place	No	634	75%	—	—
	Yes	206	25%	—	—

*Note: Monthly data were collected for Arkansas, California, Delaware, Idaho, Maryland, Oregon, Pennsylvania, Texas, Virginia, and Washington.

Results

Observational Before-After Study with Comparison Groups

Table 5 lists the annual bicycle crashes for the selected states shows the changes in yearly bicycle crashes before and after enacting a stop-as-yield law for Idaho, Delaware, Arkansas, Oregon, and Washington. The values in parenthesis indicate the percent change in crashes compared to the prior year.

Table 5. Total number of bicycle crashes per year for the selected states

State	2015	2016	2017	2018	2019	2020	2021
Idaho	288*	319 (10.8%)	223 (-30.1%)	303 (35.4%)	265 (-12.3%)	149 (-43.8%)	175 (17.5%)
Delaware	211	213 (+1%)	194 (-8.9%)	190 (-2.1%)	182 (-4.2%)	149 (-18%)	151 (1.3%)
Arkansas	130	142 (7.0%)	152 (29.6%)	107 (-29.6%)	108 (0.9%)	121 (12.0%)	134 (10.7%)
Oregon	960	847 (-11.8%)	764 (-9.8%)	826 (8.1%)	731 (-11.5%)	475 (-35%)	454 (-4.4%)
Washington	1671	1534 (-8.2%)	1292 (-15.8%)	1495 (15.7%)	1411 (-5.6%)	930 (-34%)	1010 (8.6%)
Louisiana	254	296 (16.5%)	303 (2.4%)	265 (-12.5%)	257 (3.2%)	231 (-10.1%)	219 (-5.2%)
Maryland	803	781 (2.7%)	730 (-6.53%)	639 (-12.5%)	722 (13.0%)	631 (-12.6%)	606 (4%)
Missouri	569	512 (-10%)	551 (7.6%)	497 (-9.8%)	444 (-10.7%)	433 (-2.5%)	384 (-11.3%)
Pennsylvania	1277	1306 (2.3%)	1144 (-12.4%)	964 (-15.6%)	1014 (5.1%)	819 (-19.2%)	761 (-7.1%)
Texas	2442	2605 (6.7%)	2664 (2.5%)	2425 (-9%)	2529 (4.3%)	2152 (-14.9%)	2249 (4.5%)
Virginia	682	626 (-8.2%)	664 (6.1%)	626 (-5.7%)	646 (3.2%)	554 (-14.2%)	536 (-3.2%)
Tennessee	456	418 (-8.3%)	435 (4.1%)	378 (-13.1%)	394 (4.2%)	370 (-6.1%)	321 (-13.2%)

State	2015	2016	2017	2018	2019	2020	2021
California	11115	10363 (-6.8%)	9910 (-4.4%)	9770 (-1.5%)	8948 (-8.4%)	6900 (-22.9%)	6532 (-5.33%)
Average of states with no law	—	(-1.8%)	(-2.4%)	(-7.8%)	(-0.8%)	(-12.8%)	(-5.6%)
Average of states with a law	—	(10.8%)	(-30.1%)	(16.7%)	(-8.2%)	(-23.8%)	(6.7%)
Average of all	—	(-0.8%)	(-4.5%)	(-4.0%)	(-1.9%)	(-17.0%)	(-0.9%)

*Numbers in red represent the periods in which the stop-as-yield law was enacted.

The percentage changes in total crashes during the periods of stop-as-yield laws in Delaware, Arkansas, Oregon, and Washington do not consistently demonstrate a different pattern relative to the average values of all the selected states or those without intervention through a stop-as-yield law. Likewise, as illustrated in Table 6, the t-test result indicates that the difference is not statistically significant between the means of the percent change in crash frequencies during the years when a stop-as-yield law was enacted and the years without such a law. Basically, the test does not provide sufficient evidence to reject the null hypothesis, indicating that the means are equal and there is no statistically significant difference.

Table 6. Two-sample t-test on the percent change in crash frequencies

T-Test Two Sample Assuming Unequal Variances	Group 1: Years when stop-as-yield laws were enacted	Group 2: Years without stop-as-yield laws
Mean	-0.055	0.047
Variance	0.048	0.008
P(T<=t) one-tail (α=0.05)	0.445	
P(T<=t) two-tail (α=0.05)	0.890	
Hypothesized Mean Difference	0	

Likewise, to reinforce and exemplify the preceding results, the trends in Figures 2 and 3 illustrate the time-series range plot of monthly bicycle crashes for Delaware and Arkansas, respectively. Considering the Delaware time-series range plot (Figure 2), we can see a short-term fluctuation each year representing a monthly or seasonal variability in crash frequencies. The red lines represent the duration that the stop-as-yield laws were in place. We can see a reduction in total bicycle crash frequencies during this period compared to the before-intervention period. The purple lines demonstrate the COVID-19 period, during which we can see another drop in bicycle crash frequencies. However, it is difficult to distinguish between the interaction of the stop-as-yield laws and the COVID-19 pandemic.

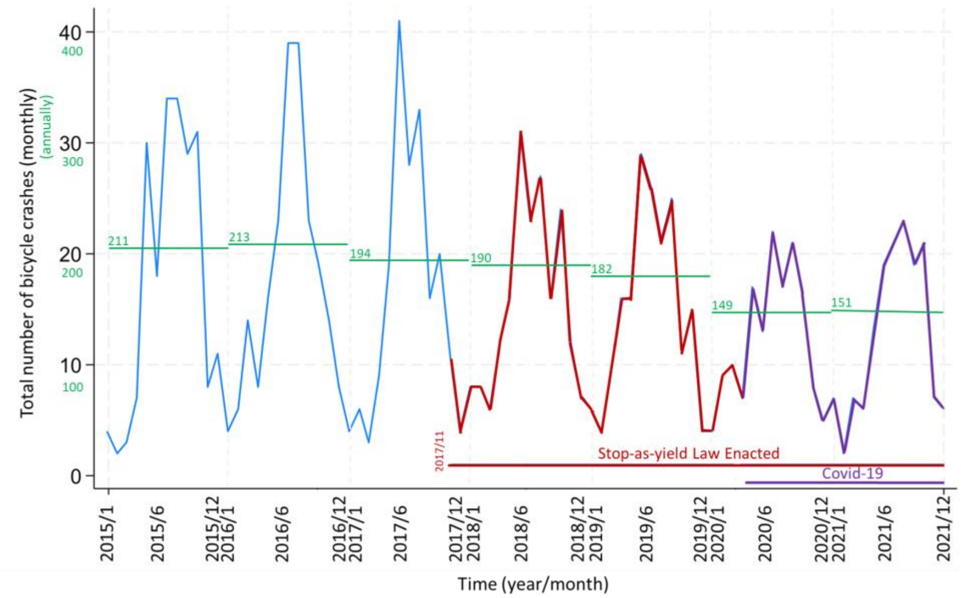

Figure 2. Delaware time-series range plot of monthly bicycle crashes

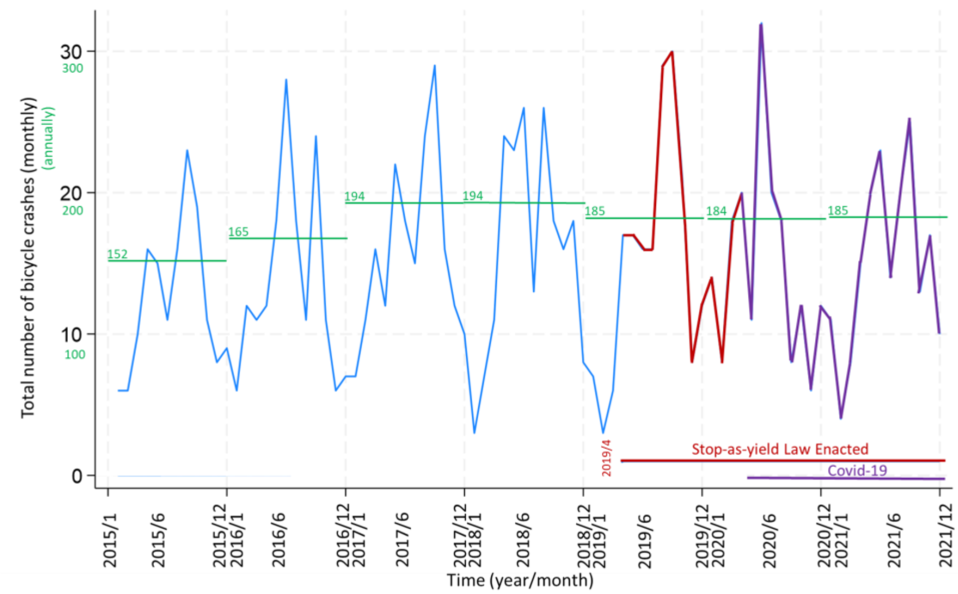

Figure 3. Arkansas time-series range plot of monthly bicycle crashes

Macro-Level Analysis of Historical Crashes

This study also conducts a macro-level analysis of historical bicycle crashes in the United States and explores the potential contribution of stop-as-yield laws to the frequency of cyclist crashes. A random-effects negative binomial regression model with panel data is estimated to investigate the overall association between the stop-as-yield laws and bicycle crash rate. This model uses the states' population as the exposure variable. The model was estimated on a monthly data basis. Table 7 presents the modeling results. The likelihood-ratio test compares the panel model with the pooled model (a negative binomial model with constant dispersion). It indicates that the panel model is significantly different from the pooled model. The Wald Chi-squared test also demonstrates that the overall model is statistically significant.

The modeling results indicate that different periods of COVID-19 (2020 and 2021) have a negative association with the bicycle crash rate, which is consistent with (*30*). This trend aligns with pedal-cyclist injury data from the National Highway Traffic Safety Administration (*3*). Also, the expected bicycle crash rate increases during spring and summer compared to winter and fall in the United States.

The modeling results also reveal that the stop-as-yield law variable does not exhibit a statistically significant association with bicyclist crashes. In other words, the analysis provides insufficient evidence to conclude that implementing a stop-as-yield law significantly impacts bicyclist safety. Likewise, the literature has no consensus regarding whether a stop-as-yield law would affect safety positively or negatively. One could argue that adopting a stop-as-yield law has the potential to enhance the predictability of cyclist behavior for motorists, resulting in safer roads for all users and a more efficient flow of traffic at intersections. Alternatively, one could argue that by normalizing an already common behavior, the laws would have little effect or adverse effect on bicyclist behavior or safety. Stopping and starting at intersections can be challenging for cyclists, but yielding instead of stopping can potentially increase the risk of being hit by vehicles that do not notice or respect cyclists. One of the main concerns of the stop-as-yield laws is that they can cause confusion among road users. Motorists might not anticipate the actions of cyclists who are not following traditional stop sign procedures, potentially leading to more conflicts and crashes. In addition, because it could take drivers some time to grow accustomed to the stop-as-yield laws and learn to take safe courses of action accordingly, an increased number of crashes might be observed during this transition period.

Table 7. Random effect panel negative binomial regression (Y: Bicycle crash rate)

Variable		Coefficient	Z-value	P-value	Incidence-rate ratio
Stop-as-yield law	No (base)	—	—	—	—
	Yes	0.082	1.44	0.151	1.085
COVID-19 period	No (base)	—	—	—	—
	March-December 2020	-0.370	-11.15	0.000	0.691
	2021	-3.320	-10.61	0.000	0.726
Season	January-March (base)	—	—	—	—
	April-June	0.461	16.39	0.000	1.585

Variable		Coefficient	Z-value	P-value	Incidence-rate ratio
	July-September	0.591	21.55	0.000	1.806
	October-December	0.295	10.15	0.000	1.343
Constant	-	-13.770	-22.38	0.000	—
Exposure	Population	1	—	—	1
Ln (r)		1.542			
Ln (s)		3.381			
Number of observations		840			
Number of groups		10			
Log-likelihood-full		-3775.510			
AIC		7569.020			
BIC		7611.621			
Wald chi2		658.28			
Prob > chi2		0.000			
Likelihood ratio test: panel vs. pooled models		1204.97			
Prob >= chibar2		0.000			

This study is not without limitations. First, while macro-level analysis of historical crashes can provide insights into the problem, more careful research designs are required to fully capture the safety impacts of a stop-as-yield law. It is essential to note that the safety impact of stop-as-yield laws can vary depending on local traffic patterns, infrastructure, and the behavior of road users. The estimated safety impact of the stop-as-yield laws derives from a small sample size (only five states have stop-as-yield laws) and a short period of the enactment of the laws at a macro level. Therefore, it is not generalizable and could change over time when more data is collected for a longer period. Second, although the COVID-19 impact on bicyclist crashes is captured by adding the variable in the model, the interaction between COVID-19 and the laws' implementation still makes distinguishing between the impacts challenging. Therefore, in future studies, excluding the COVID period from the analysis is recommended when sufficient data is available. Moreover, given that stop-as-yield laws specifically impact conflicts between bicyclists and vehicles at stop-controlled intersections, it is strongly advised to take into account bicycle crash data specifically for such locations. Nevertheless, the challenge lies in the availability of this information across all states' datasets. An additional challenge in bicycle crash data pertains to the underreporting of crashes involving bicycles within state departments of transportation. Inconsistencies in the collection and recording of crashes results in an incomplete portrayal of the scope and characteristics of these occurrences.

Research Needs and Future Work

This section focuses on identifying the research needs and possible approaches for evaluating the safety impacts of implementing a stop-as-yield law in California. The possibility of enacting a stop-as-yield law in California in the near future would provide the opportunity for conducting a robust before-and-after safety assessment. This section identifies the data requirements for such research, including data period and analysis methods, and describes three approaches.

Macro-Level Analysis of Historical Crashes

The proposed methodology in this study—the random effect panel negative binomial regression—is a robust technique to conduct a macro-level analysis of historical bicycle crashes and explore the potential contribution of stop-as-yield laws to the frequency of cyclist crashes. This analysis can be repeated in the future by including the California data after implementing a stop-as-yield law. Because regression models can be used to control for other factors by including relevant covariates as independent variables, including more variables in the model can account for their potential influence on the outcome and isolate the effect of the stop-as-yield law in California. It is recommended to collect data for potential confounding variables that need to be controlled, such as traffic volume exposure, bicycle and road infrastructure, weather conditions, economic conditions, cyclist exposures, population, and bicycle commuters. The findings of the current study were derived from small sample size and for a short period of the enactment of the laws, so it is recommended to collect more data for a longer period in the future. It is also recommended to exclude the COVID-19 time from the data when more data duration is available to help differentiate the COVID-19 impact and the impact of stop-as-yield laws. Analyzing historical cyclist crash data over a long period allows the identification of long-term trends, such as changes in crash rates and the long-term impact of the stop-as-yield law intervention at a macro level. Because a macro-level analysis can overlook specific details or characteristics of individual crashes and might not capture nuanced factors, such as demographic factors, driver behavior, weather conditions, or roadway conditions, collecting more variables can alleviate this issue. However, data consistency and availability are challenges in data collection from different states.

Macro-Level Observational Before-After Study in California

Before-after studies, used to evaluate the safety impacts of road treatments and policy interventions (*31*), require data collection for the periods before and after the change. In this regard, the data at the state level in California for vehicle-cyclist crashes at stop–controlled intersections should be collected for a sufficient duration before the stop-as-yield law is passed and after. Additionally, controlling for other factors in before-after studies is crucial to account for potential confounding variables and ensure that the observed changes can be attributed to the stop-as-yield law. A stop-as-yield law applies only to cyclist behaviors at stop-controlled intersections, so the crash data analysis should focus on the types of crashes that the law might have influenced. Studies have shown that there are different types of cyclist crashes at intersections (*8 and 32*) that could be affected differently by a stop-as-yield law. There is generally not sufficient information in crash databases to filter the crashes adequately, but there are crash typologies that can help. The Pedestrian and Bicycle Crash Analysis Tool (PBCAT) codes bicycle crashes by crash types that describe the events and maneuvers that lead to the crash (e.g., motorist overtaking cyclist, bicyclist failed to yield, etc.). For instance, motorists overtaking bicyclists is the most frequent crash type among fatal bicycle crashes in the United States, with 28 percent of the total fatal crashes (*8*). Collecting data for bicycle crashes and coding them by crash types using PBCAT in California is recommended. Also, this analysis can be done at different crash severity levels (i.e., no injury, visible injury, serious injury, and fatal injury) to investigate the safety impact of the stop-as-yield law.

Micro-Level Observational Before-After Study in California

Because macro-level analysis can overlook specific details or characteristics of individual crashes, it might not capture nuanced factors at a micro level, such as driver behavior, bicyclist behavior, vehicle-specific characteristics, or roadway conditions, which are crucial for a comprehensive understanding of crash causation. Also, it is possible that a stop-as-yield law has different effects in different communities or states due to the differences in environment, driving and cycling behavior, culture, infrastructure, etc.

To conduct this analysis in California after implementing a stop-as-yield law, the study can first focus on identifying hotspots of bicyclist crashes at stop-controlled intersections. Then, the key variables to measure and evaluate bicyclist safety should be determined, including those related to bicyclist safety, such as crash frequency, severity, crash type, cyclist and driving behavior and violations, and traffic and cyclist exposure. The data should be collected for a sufficient duration of time before and after implementation. In addition, because it can take drivers and cyclists some time to grow accustomed to a stop-as-yield law and learn to take safe courses of action accordingly, it is recommended to define a long enough study period.

Lastly, a descriptive analysis can be conducted to understand trends in bicyclist safety before and after the implementation of the stop-as-yield law in California. Many appropriate statistical tests can be used to assess the significance of the observed differences, including 1) a paired t-test to compare the means of the same locations before and after the implementation of the law; 2) a Chi-squared test to compare and test whether the distribution of bicyclists' crash severity (e.g., minor, severe, fatal) differs significantly between the before and after intervention; and 3) analysis of covariance to determine if there are statistically significant differences in group means after adjusting for potential confounding variables.

Conducting a micro-level analysis can provide more detailed insights into specific California locations and communities by considering the local context, which can vary significantly between different locations. However, combining both micro- and macro-level approaches can provide a comprehensive understanding of the potential safety impacts of the stop-as-yield law, with micro-level studies offering in-depth insights and macro-level studies offering broader implications.

Conclusions

The surge in injuries and fatalities among cyclists has emerged as a significant safety issue in recent years. Throughout the United States, communities have been seeking strategies to enhance cyclist safety and alleviate confusion in situations that pose potential hazards and high risks. Some states have implemented bike-specific policies, such as a stop-as-yield law, to support cyclists. Generally, the law allows cyclists to treat stop signs as yield signs. However, there are uncertainties about the safety impact of stop-as-yield laws, and there is no consensus regarding the laws' potential implications.

This study investigated the potential impact of a stop-as-yield law on bicyclist safety by collecting bicyclist data from the five states that have enacted a stop-as-yield law—Arkansas, Delaware, Idaho, Oregon, and Washington—and for some of their contiguous states that have no stop-as-yield law in place. The results from the observational before-after study with comparison groups at the state level indicate no significant change in cyclist crashes among the states with a stop-as-yield law compared to the average number of cyclist crashes for the states without a stop-as-yield laws.

This study also conducted a time-series, cross-section analysis (a random-effects negative binomial regression model with panel data) of cyclist-involved crashes to capture the effect of influencing factors on cyclists involved in crashes. The model investigated the safety impacts of stop-as-yield laws and the overall association between the stop-as-yield laws and cyclist crash rate. The modeling results indicate that different periods of COVID-19 had a negative association with the bicycle crash rate, and the expected bicycle crash rate increased during spring and summer compared to winter and fall. By controlling for these variables, the model shows no statistically significant association between the stop-as-yield laws and bicyclist crashes. In other words, the analysis provides insufficient evidence to conclude that implementing a stop-as-yield law significantly impacts bicyclist safety. Likewise, the literature has no consensus regarding whether a stop-as-yield law would affect safety positively or negatively.

This study has identified several areas for potential future research, such as considering more control variables, such as economic, environmental, cultural, driving, and cycling behavioral factors of the studied communities, although this information is subject to the data availability of the selected states. Another area for future studies is to investigate the impact of the stop-as-yield laws in more specific locations, such as stop sign–controlled intersections in urban, rural, and suburban areas. Narrowing down the study level (states vs. metropolitan areas or neighborhoods) and considering more control variables can potentially isolate the impact of the stop-as-yield laws on cyclist crash frequency and rate. This study also identifies the research needs and furnishes a roadmap for evaluating the safety impacts of implementing a stop-as-yield law in California.

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