CPBS
Center for Pedestrian and Bicyclist Safety

A Tier-1 University Transportation Center

Understanding Pedestrian and Bicyclist Safety Trends in the Post-Pandemic Era

July 2024

A Report From the Center for Pedestrian and Bicyclist Safety

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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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16. Abstract

This comprehensive study investigates trends in pedestrian and bicyclist fatalities across the United States (U.S.) and fatalities and serious injuries (FSI) within California, especially before and after the COVID-19 pandemic. It particularly focuses on varying community settings, including urban, rural, disadvantaged, and non-disadvantaged areas. Utilizing multiple data sources, the study analyzes fatalities nationwide through the Fatality Analysis Reporting System (FARS) and FSI from the California Statewide Integrated Traffic Records System (SWITRS), enriched with socio-demographic data. Descriptive statistics were applied to the data to explore fatality trends across the U.S. and FSI trends across California. Additionally, a random-effects negative binomial regression model with panel data was employed to assess FSI in California, categorized by pre- and post-pandemic periods. This study illuminates significant shifts in pedestrian and bicyclist safety trends across the U.S. and California in the post-pandemic era. Nationwide, there was an 18.76% increase in pedestrian and bicyclist per capita fatality rates, with notable regional variations: urban areas saw a 21.02% increase, rural areas 7.29%, disadvantaged communities 20.02%, and non-disadvantaged communities 17.46%, highlighting a substantial increase in disadvantaged areas. In California, pedestrian and bicyclist crash data demonstrated a 6.74% rise in FSI rate, with 5.55% in disadvantaged communities and 8.00% in non-disadvantaged communities in the post-pandemic era. The analysis identifies significant disparities in safety outcomes influenced by various disadvantaged burden factors, with transportation and health disadvantages being the most impactful. These findings underscore the complexity of pedestrian and bicyclist safety in the post-pandemic era and highlight the necessity for targeted safety improvements tailored to regional characteristics to effectively address safety disparities and enhance the overall safety of vulnerable road users.

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SI* (MODERN METRIC) CONVERSION FACTORS

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

Understanding Pedestrian and Bicyclist Safety Trends in the Post-Pandemic Era

A Center for Pedestrian and Bicyclist Safety Research Report

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Acronyms, Abbreviations, and Symbols

CA	California
Caltrans	California Department of Transportation
ACS	American Community Survey
CEJST	Council on Environmental Quality's Climate and Economic Justice Screening Tool
CHP	California Highway Patrol
CPBS	Center for Pedestrian and Bicyclist Safety
DOT	Department of Transportation
FARS	Fatality Analysis Reporting System
FRED	Federal Reserve Economic Data
FSI	Fatal and Serious Injury
IRR	Incidence Rate Ratio
NHTSA	National Highway Traffic Safety Administration
Ped/Bike	Pedestrians and Bicyclists
SafeTREC	Safe Transportation Research and Education Center
SWITRS	Statewide Integrated Traffic Records System
U.S.	United States
VMT	Vehicle Miles Traveled

Abstract

This comprehensive study investigates trends in pedestrian and bicyclist fatalities across the United States (U.S.) and fatalities and serious injuries (FSI) within California, especially before and after the COVID-19 pandemic. It particularly focuses on varying community settings, including urban, rural, disadvantaged, and non-disadvantaged areas. Utilizing multiple data sources, the study analyzes fatalities nationwide through the Fatality Analysis Reporting System (FARS) and FSI from the California Statewide Integrated Traffic Records System (SWITRS), enriched with socio-demographic data. Descriptive statistics were applied to the data to explore fatality trends across the U.S. and FSI trends across California. Additionally, a random-effects negative binomial regression model with panel data was employed to assess FSI in California, categorized by pre- and post-pandemic periods. This study illuminates significant shifts in pedestrian and bicyclist safety trends across the U.S. and California in the post-pandemic era. Nationwide, there was an 18.76% increase in pedestrian and bicyclist per capita fatality rates, with notable regional variations: urban areas saw a 21.02% increase, rural areas 7.29%, disadvantaged communities 20.02%, and non-disadvantaged communities 17.46%. In California, pedestrian and bicyclist crash data demonstrated a 6.74% rise in FSI rate, with 5.55% in disadvantaged communities and 8.00% in non-disadvantaged communities in the post-pandemic era. Wilcoxon tests indicate that all rises are statistically significant. The analysis identifies significant disparities in safety outcomes influenced by various disadvantaged burden factors, with transportation and health disadvantages being the most impactful. These findings underscore the complexity of pedestrian and bicyclist safety in the post-pandemic era and highlight the necessity for targeted safety improvements tailored to regional characteristics to effectively address safety disparities and enhance the overall safety of vulnerable road users.

Executive Summary

The COVID-19 pandemic has significantly altered transportation patterns and road safety, with mixed effects on walking and bicycling and a notable decline in public transit and shared mobility ridership. This research investigates how these changes have influenced pedestrian and bicyclist safety, particularly in the context of the post-pandemic era. Our study focuses on understanding the trends and underlying factors contributing to the alarming rise in pedestrian and bicyclist fatalities, which increased by 18% and 12%, respectively, between 2019 and 2021. The COVID-19 pandemic further impacted transportation patterns, causing fluctuations in mobility and changes in travel patterns. The key research questions include: What are the impacts of transportation patterns and behavior shifts on pedestrian and bicyclist safety? How do these impacts vary across different community settings, including urban, rural, and disadvantaged communities? The study objectives are to investigate trends in pedestrian and bicyclist fatalities across U.S. and fatalities and serious injuries (FSI) within California, especially before and after the pandemic.

The study utilizes multiple data sources to analyze state-level fatalities in the United States through the Fatality Analysis Reporting System (FARS) and census tract-level FSI In California by the Statewide Integrated Traffic Records System (SWITRS). The crash data was enriched with population data collected from the U.S. Census Bureau as well as the Council on Environmental Quality's Climate and Economic Justice Screening Tool (CEJST). The CEJST tool was further used to identify disadvantaged communities nationwide and in California using eight categories of burdens: climate change, energy, health, housing, legacy pollution, transportation, water and wastewater, and workforce development. The pre- and post-pandemic timeframes utilized for this analysis were developed based on the St. Louis Federal Reserve national monthly Vehicle Miles Traveled (VMT) data covering 2018-2022.

The study period was segmented into two distinct phases to capture changes in pedestrian and bicyclist safety before and after the COVID-19 pandemic. The 'Before Pandemic' period, defined as a 26-month period spanning January 1, 2018, to February 29, 2020, showed stable VMT with typical seasonal variations. The 'After Pandemic' period was defined as another 26 months spanning another 26-month period spanning November 1, 2020, to December 31, 2022, and saw a gradual recovery in VMT as restrictions eased and travel patterns normalized, though not always reaching pre-pandemic levels.

Descriptive statistics were applied to FARS data to explore pedestrian and bicyclist fatality trends across the U.S. Additionally, fatalities were aggregated based on their locational characteristics within each state, i.e., urban, rural, disadvantaged, and non-disadvantaged communities. The per capita fatality rates before and after the pandemic were calculated for each state. The percentage change in fatality rates between the before and after pandemic periods was computed to understand national and regional trends. In California, fatal and serious pedestrian-bicyclist injuries were aggregated by census tracts and categorized as occurring before or after the pandemic. The compiled dataset was analyzed using a random effects negative binomial regression model with panel data to understand the trends in pedestrian bicycle injuries in the state.

This study illuminates significant shifts in pedestrian and bicyclist safety trends across the U.S. and California in the post-pandemic era. Nationwide, there was an 18.76% increase in pedestrian and bicyclist per capita fatality rates, with notable regional variations: urban areas saw a 21.02% increase, rural areas 7.29%, disadvantaged communities 20.02%, and non-disadvantaged communities 17.46%. In California, pedestrian and bicyclist crash data demonstrated a significant 6.74% rise in FSI rate, with 5.55% in disadvantaged communities and 8.00% in non-disadvantaged communities in the post-pandemic era. Wilcoxon tests indicate that all rises are statistically significant. Given the substantial variation in pedestrian and bicyclist safety outcomes observed across different regions, including urban, rural, and disadvantaged communities, it is crucial to implement targeted safety improvements and interventions tailored to each region's specific challenges and settings.

The modeling results highlight significant disparities in safety outcomes influenced by various disadvantaged burden factors, with transportation, health, and housing disadvantages being the most impactful. Also, the modeling results show a significant increase in FSI rates in California in the post-pandemic period. These findings underscore the complexity of pedestrian and bicyclist safety in the post-pandemic era and highlight the need for targeted interventions to address the disparities and enhance safety in high-risk zones.

Introduction

The COVID-19 pandemic has profoundly impacted various aspects of society, including transportation patterns and road safety. While public transit usage and shared mobility ridership experienced significant declines during the pandemic, the impact on walking and bicycling was mixed (Monterde-i-Bort et al., 2022). The COVID-19 pandemic further impacted transportation patterns, causing vehicle miles traveled (VMT) fluctuations and mode choices (Grembek et al., 2022). Public transit usage and shared mobility ridership also experienced substantial drops during the early pandemic (Qi et al., 2023). However, the impact of the pandemic on walking and bicycling varied, with declines observed in commuting-related activities but increases observed in non-work-related activities (McElroy et al., 2022).

Pedestrian and bicyclist crashes and fatalities have been a longstanding traffic safety concern, with an alarming rise observed in recent years. According to the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA), pedestrian and bicyclist deaths accounted for 17% and 2.2%, of all traffic crash fatalities in the U.S. in 2021 respectively. Furthermore, between 2019 and 2021, pedestrian and bicyclist fatalities increased by 18% and 12% respectively (FARS, 2023; Stewart, 2023). These statistics highlight the pressing need to address pedestrian and bicyclist safety, particularly in the context of the post-pandemic era, where transportation patterns and behaviors may have undergone significant shifts. Understanding the trends and underlying factors contributing to pedestrian and bicyclist fatalities and serious injuries is crucial for developing targeted interventions and enhancing safety measures. Moreover, the impact of the pandemic on transportation and road safety has disproportionately affected disadvantaged communities. These communities often face greater challenges in terms of access to safe infrastructure, transportation options, and resources for addressing safety concerns (Patwary et al., 2024). Addressing equity in pedestrian and bicyclist safety is a critical aspect, and it aims to identify and mitigate disparities in traffic-related injuries and fatalities across different communities.

This study aims to provide a comprehensive analysis of trends in pedestrian and bicyclist fatalities and serious injuries in the post-pandemic era, with a particular focus on disadvantaged communities in California and the United States. By investigating the spatial patterns, underlying factors, and the relationship between crashes and community characteristics, the research seeks to inform targeted interventions and policy recommendations to enhance pedestrian and bicyclist safety and promote equitable access to safe transportation for vulnerable road users.

Data on pedestrian and bicyclist fatalities from 2018-2022 were sourced from NHTSA's Fatality Analysis Reporting System (FARS), while pedestrian and bicyclist fatality and serious injury data for California came from the Statewide Integrated Traffic Records System (SWITRS) maintained by the California Highway Patrol (CHP). The study period is divided into pre- and post-pandemic phases based on shifts in monthly VMT data. For the U.S., fatalities were categorized by state and location type (urban, rural, disadvantaged, and non-disadvantaged communities), with fatality rates calculated per 10,000 population. In California, pedestrian and bicyclist fatalities and serious injuries were analyzed by census tracts, incorporating equity and population data. The California data were analyzed using a random effects negative binomial regression model with panel data to uncover trends and investigate contributing factors.

The findings from this project will inform the development of evidence-based interventions and strategies to enhance pedestrian and bicyclist safety in the post-pandemic era. By identifying the underlying factors contributing to the observed trends, policymakers, transportation agencies, and urban and rural planners will be better equipped to design targeted measures that mitigate risks and improve safety for pedestrians and bicyclists.

Literature Review

Pedestrian and bicyclist safety is a critical issue that impacts the well-being of communities, the sustainability of transportation systems, and the overall quality of life in urban and rural areas alike. Despite significant advancements in vehicle safety technologies and infrastructure improvements, pedestrians and bicyclists remain among the most vulnerable road users, facing disproportionate risks of serious injury and fatality in crashes.

Pedestrian and bicyclist fatalities have seen significant changes over the past few decades in the U.S. Pedestrian fatalities peaked in the late 1960s and early 1970s, with over 8,000 deaths annually (Thoma, 2012). Since then, the numbers have generally trended downward until reaching a low point of 4,109 deaths in 2009. However, pedestrian fatalities have increased by around 80% since 2009, reaching 7,388 deaths in 2021 (FARS, 2023; IIHS, 2023). This recent increase is likely due to factors like more walking for economic and health reasons, higher vehicle miles traveled, and increased distractions for both drivers and pedestrians (FARS, 2023; IIHS, 2023).

Bicyclist fatalities followed a similar pattern, peaking in the 1970s before declining. The numbers remained relatively stable from the late 1990s through the 2000s (Thoma, 2012). In recent years, bicyclist deaths have increased, reaching 961 in 2021 (FARS, 2023; IIHS, 2023). This uptick coincides with the growing popularity of bicycling for transportation and recreation (IIHS, 2023).

The COVID-19 pandemic served as a catalyst for significant shifts in transportation patterns, with profound implications for pedestrian and bicyclist safety. During the pandemic, there was a significant drop in public transit ridership and overall vehicle miles traveled (Li et al., 2022). However, active transportation modes like walking and cycling surged in many areas due to avoiding crowded spaces and promoting outdoor recreation (Duren et al., 2023; Li et al., 2022). While total crash numbers decreased with lower traffic volumes, studies report an increase in reckless driving behaviors (speeding, impaired driving) and crash severity during the pandemic. This exposed pedestrians and bicyclists to higher risk despite reduced exposure. Some localities implemented policies like new bicycle lanes and street closures to promote active transportation and physical distancing (Duren et al., 2023; Li et al., 2022). These infrastructure and traffic calming measures were associated with increased bicycling during the pandemic (Duren et al., 2023).

A preliminary literature review suggests that the COVID-19 pandemic has had mixed effects on pedestrian and bicyclist safety with several underlying factors. While there was a decrease in overall traffic volumes (Liu & Stern, 2021), there were higher odds of speeding during (Patwary & Khattak, 2023; Shahlaee et al., 2022; Tucker & Marsh, 2021) and after the pandemic (Marshall et al., 2023), change in driving behavior (Dong et al., 2022), and driver intoxication (Adanu et al., 2021), leading to an increase in the severity of crashes (Gong et al., 2023). Several studies suggest that there have been changes in the types of crashes, with a higher proportion of single-vehicle crashes (Adanu et al., 2021) and crashes involving vulnerable road users (Patwary & Khattak, 2023).

Before the pandemic, pre-existing built environment factors and traffic characteristics played a major role in pedestrian and bicyclist safety (Dai & Dadashova, 2021). During the pandemic, changes in travel behavior, traffic patterns, and supportive policies influenced active transportation trends and associated safety impacts (Lee et al., 2023). A study revealed that COVID-19 has had lasting effects on specific crash types, such as fatal crashes and a shift in commuting patterns in the post-pandemic period. The study showed that fatal crashes in 2021 and 2022 compared to pre-pandemic levels have increased in Florida. This study suggests that the pandemic's impact on risky driving behavior and traffic safety is likely to continue long-term (Lee et al., 2023).

Studies showed that socio-demographic and geographical factors affect pedestrian and bicyclist safety. Areas with better walking/cycling infrastructure and more compact, mixed-use development tend to have lower pedestrian/bicyclist crash rates (Dai & Dadashova, 2021). Higher traffic volumes, speeds, and proportion of heavy vehicles are associated with increased pedestrian/bicyclist crash risk and severity (Dai & Dadashova, 2021; Duren et al., 2023). Specific traffic factors, such as the number of transit stops and turning vehicles at intersections, also elevate risk (Goughnour et al., 2022). Certain demographic groups like children, older adults, and low-income populations face higher pedestrian/bicyclist crash risks due to factors like greater exposure, road environments, and vehicle travel patterns in their communities (Dai & Dadashova, 2021). Additionally, pedestrian and bicyclist safety is a significant equity issue, with disadvantaged communities facing disproportionate risks and disparities. Numerous studies have found that low-income communities and communities of color experience higher rates of pedestrian and bicyclist crashes, injuries, and fatalities (Boldry et al., 2017; Sandt et al., 2016). For example, in counties where over 20% of households have incomes below the federal poverty line, the pedestrian fatality rate is over 80% higher than the national average (Sandt et al., 2016). These disparities are attributed to factors such as greater exposure to unsafe road conditions, higher traffic volumes and speeds, lack of pedestrian/bicycle infrastructure, and differences in emergency medical care access (Sandt et al., 2016). Disadvantaged communities often face a disproportionate burden of unsafe built environments that increase pedestrian and bicyclist risk (ITDP, 2023; Sandt et al., 2016). The legacy of discriminatory urban planning practices has resulted in the placement of dangerous roads and thoroughfares directly within many low-income and minority neighborhoods (ITDP, 2023). Studies also identified various barriers that limit active transportation options for disadvantaged groups, further exacerbating safety concerns. These barriers include lack of access to safe walking and bicycling facilities, personal safety concerns, lack of inclusive representation and community input in infrastructure planning, and association of bicycle facilities with gentrification in some areas (Sandt et al., 2016). A study showed that communities characterized by health, resilience, and transportation disadvantages tend to experience higher rates of fatal crashes (Patwary et al., 2024).

Despite the extensive body of research on pedestrian and bicyclist safety, several gaps remain that warrant further investigation. Firstly, while the impacts of the COVID-19 pandemic on general traffic patterns and safety have been studied, there is limited understanding of the long-term effects on pedestrian and bicyclist safety, particularly in different community contexts such as disadvantaged areas. More granular analyses that consider the unique characteristics of individual communities, such as socio-demographic data and land use patterns, are needed to provide a more detailed understanding of the factors influencing pedestrian and bicyclist safety trends. Addressing these gaps will provide a more comprehensive and nuanced understanding of pedestrian and bicyclist safety, informing more effective and equitable transportation policies and interventions.

Data and Methodology

This study utilized various demographic, equity, and crash data sources to analyze pedestrian-bicyclist fatalities and serious injuries trends in the United States and California. The following sections provide details on the datasets, their sources, and some of the preprocessing steps involved. Some data sets were only used for the U.S. or California (CA) analysis, while some were used for both and are indicated as such.

Data

Crash Data

Data for crashes involving a pedestrian or bicyclist (ped/bike) were collected from two different crash data sources. For the United States analysis, only ped/bike fatalities were considered, while for the California analysis, ped/bike FSI were considered. Crashes were aggregated at a state level for the U.S. analysis and a county level for the California analysis.

FARS – U.S. Analysis

FARS is the nationwide traffic fatality records system maintained by the National Highway Traffic Safety Administration (NHTSA). For this analysis, ped/bike fatalities with valid latitude and longitude were analyzed. In order to determine if a fatal ped/bike crash occurred in a rural or urban environment, the crash level urban, rural flag, "RUR_URB", was used.

Data Periods considered:

"Pre-Pandemic" - January 1st, 2018 to February 29th, 2020 (26 months),

"Post-Pandemic" - November 1st, 2020 to December 31st, 2022 (26 months)

Data Source: 2018 - 2021 Final File, 2022 Annual Report File (ARF obtained April 2024)

Note: ARF data is considered provisional and should be interpreted as such.

SWITRS - CA Analysis
SWITRS is the crash database for California maintained by the California Highway Patrol (CHP). For this analysis, only ped/bike fatalities and serious injuries geo-located by UC Berkeley SafeTREC were analyzed.

Data Periods considered:
"Pre-Pandemic" - January 1st, 2018 to February 29th, 2020 (26 months),
"Post-Pandemic" - November 1st, 2020 to December 31st, 2022 (26 months)
Data Source: 2018 - 2021 Final, 2022 Provisional obtained in June 2024
Note: Provisional SWITRS data is subject to change and should be interpreted as such.

Demographic and Equity Data

Demographic and equity data were collected from two different sources. For the urban-rural section conducted as part of the national analysis, state-level population data was collected from the 2020 census. For the disadvantaged communities analysis, various state and census track-level equity indicators and population data were collected from the Environmental Quality's Climate and Economic Justice Screening Tool (CEJST).

Urban-Rural 2020 Population Data – U.S. Analysis
The total urban and rural populations of all 50 states and the District of Columbia were collected from the *State-level Urban and Rural Information for the 2020 Census and 2010 Census* dataset. This dataset was only used as part of the pre- and post-pandemic overall analysis and urban-rural analysis in the nationwide analysis section (CENSUS, 2010-2020).

CEJST Tool – U.S. and CA Analysis
The Council on Environmental Quality's Climate and Economic Justice Screening Tool (CEJST) was used to identify disadvantaged communities across all 50 states and DC along with all 58 counties in California. The dataset included census tract polygons with the Federal Information Processing Standard (FIPS) codes and binary scores for all eight categories of environmental and socioeconomic burdens. The eight categories of burdens consist of climate change, energy, health, housing, legacy pollution, transportation, water and wastewater, and workforce development (Table 1). Communities are considered disadvantaged if they meet either of the following criteria:

1. The communities are located in a census tract that meet the thresholds for at least one of the eight categories of burden.
2. The communities are located on land within the boundaries of Federally Recognized Tribes (CEJST, November 2022).

To identify relevant crashes nationally and in California occurring in disadvantaged and non-disadvantaged communities, the SN_C flag was used. The SN_C flag utilizes the definition of disadvantaged that is outlined above, with a value of 1 identifying a community as disadvantaged and a value of 0 indicating it as non-disadvantaged. Additionally, population estimates for disadvantaged communities and non-disadvantaged communities within a state and county respectively were derived from the CJEST population variable.

Table 1. CEJST categories of burdens definition (27)

Category	Environmental, climate, or other burdens	Socioeconomic burden
Climate change	1. Expected agriculture loss rate ≥ 90th percentile OR 2. Expected building loss rate ≥ 90th percentile OR 3. Expected population loss rate ≥ 90th percentile OR 4. Projected flood risk ≥ 90th percentile OR 5. Projected wildfire risk ≥ 90th percentile	Low income*
Energy	1. Energy cost ≥ 90th percentile OR 2. PM 2.5 in the air ≥ 90th percentile	Low income*
Health	1. Asthma ≥ 90th percentile OR 2. Diabetes ≥ 90th percentile OR 3. Heart disease ≥ 90th percentile OR 4. Low life expectancy ≥ 90th percentile	Low income*
Housing	1. Historic underinvestment = Yes 2. Housing cost ≥ 90th percentile OR 3. Lack of green space ≥ 90th percentile OR 4. Lack of indoor plumbing ≥ 90th percentile OR 5. Lead paint ≥ 90th percentile	Low income*
Legacy pollution	1. Abandoned mine land present = Yes OR 2. Formerly Used Defense Site (FUDS) present = Yes OR 3. Proximity to hazardous waste facilities ≥ 90th percentile OR 4. Proximity to Superfund or National Priorities List sites ≥ 90th percentile OR 5. Proximity to Risk Management Plan sites ≥ 90th percentile	Low income*
Transportation	1. Diesel particulate matter ≥ 90th percentile OR 2. Transportation barriers ≥ 90th percentile OR 3. Traffic proximity and volume ≥ 90th percentile	Low income*
Water and wastewater	1. Underground storage tanks and releases ≥ 90th percentile OR 2. Wastewater discharge ≥ 90th percentile	Low income*
Workforce development	1. Linguistic isolation ≥ 90th percentile OR 2. Low median income ≥ 90th percentile OR 3. Poverty ≥ 90th percentile OR 4. Unemployment ≥ 90th percentile	High school education < 10%

* Low Income = 65th percentile or above for census tracts that have people in households whose income is less than or equal to twice the federal poverty level, not including students enrolled in higher education.

Methods

This chapter outlines the methodological approaches employed in the study to analyze pedestrian-bicycle fatality trends in the U.S. and California, with a particular focus on the impact of the COVID-19 pandemic.

To analyze the impact of the COVID-19 pandemic on pedestrian and bicycle fatalities, the study period was divided into two distinct phases: before and after the pandemic. These periods were defined based on the observed patterns in the monthly VMT data for the United States, obtained from the Federal Reserve Economic Data (FRED) database (*25*). The monthly VMT data, seasonally adjusted, served as the primary indicator for identifying the transition points between the different phases. The dataset covered the period from January 2018 to December 2022, allowing for the analysis of VMT trends before and after the pandemic (Figure 1).

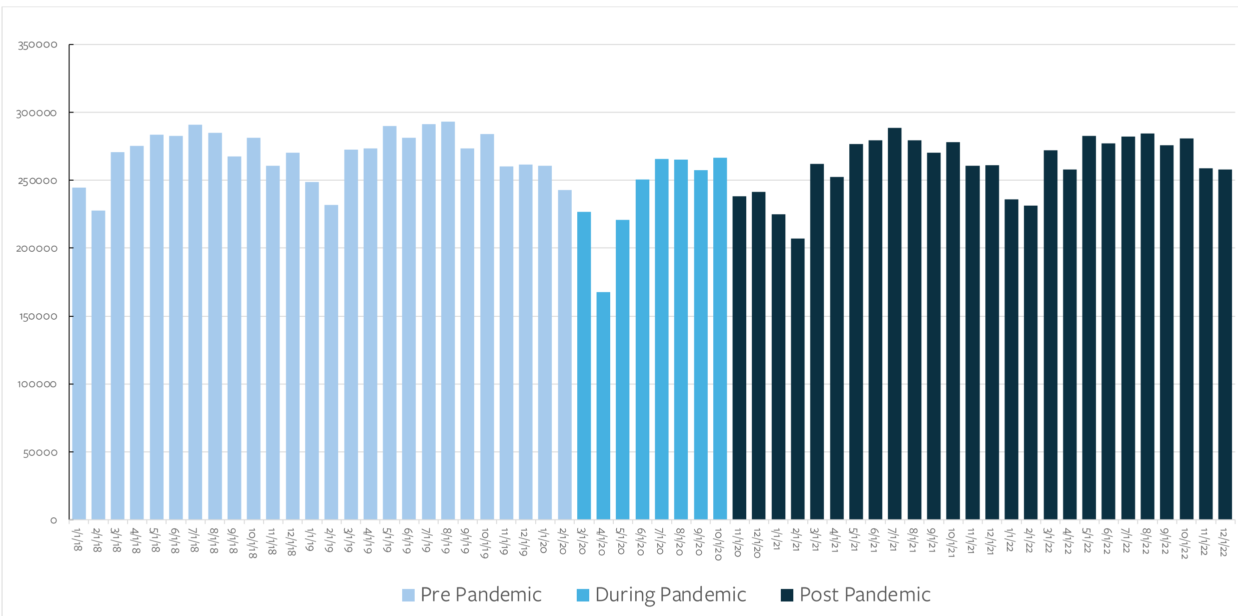

Figure 1. Seasonally adjusted monthly VMT in millions in the United States

The "Before Pandemic" period was defined as January 1, 2018, to February 29, 2020, spanning 26 months. The monthly VMT exhibited a relatively stable pattern during this time frame, with fluctuations reflecting typical seasonal variations. There was a significant drop in VMT starting in March 2020 and for the next several months, coinciding with the implementation of widespread lockdowns and travel restrictions in response to the COVID-19 pandemic. The "After Pandemic" period was defined as November 1, 2020 to December 31, 2022, spanning another 26 months. During this phase, VMT levels began to recover gradually, reflecting the easing of restrictions and a return to more normal travel patterns, although not necessarily reaching pre-pandemic levels in all regions. By segmenting the study period into two distinct phases, the analysis captured the potential changes in pedestrian and bicycle safety before and after the disruptions caused by the COVID-19 pandemic.

Pedestrian and bicyclist fatalities were aggregated by state and categorized as occurring before or after the pandemic, based on the defined time periods. Fatalities were further aggregated based on their locational characteristics within each state, i.e., urban, rural, or disadvantaged and non-disadvantaged communities. The fatality rates (per capita) before and after the pandemic were calculated for each state and region. The percentage change in fatality rates between the before and after pandemic periods was computed to understand national and state-level trends. The percentage change in fatality rates was calculated in two different ways using the following equations:

$$\%\text{Change in Fatality or FSI Rate} = \frac{\left(\left(\frac{All\ Fatalities\ or\ FSIs}{Total\ Population}\ post\text{-}pandemic \right) - \left(\frac{All\ Fatalities\ or\ FSIs}{Total\ Population}\ pre\text{-}pandemic \right) \right) * 100}{\left(\frac{All\ Fatalities\ or\ FSIs}{Total\ Population}\ pre\text{-}pandemic \right)} \quad (1)$$

$$\text{Average }\%\text{Change in Fatality or FSI Rate} = \frac{1}{No.\ of\ Regions} \sum_{i=Regions} \left(\frac{\left(\left(\frac{(Fatalities\ or\ FSIs)_i}{Population_i}\ post\text{-}pandemic \right) - \left(\frac{(Fatalities\ or\ FSIs)_i}{Population_i}\ pre\text{-}pandemic \right) \right) * 100}{\left(\frac{(Fatalities\ or\ FSIs)_i}{Population_i}\ pre\text{-}pandemic \right)} \right) \quad (2)$$

A paired Wilcoxon signed-rank test was conducted on the average percentage change in fatality or FSI rates to determine if the trends among the selected regions during the pre-pandemic and post-pandemic periods were statistically significant, particularly when the data did not follow a normal distribution.

The analysis of pedestrian-bicyclist FSI trends in California involved the following steps: i) fatal and serious pedestrian-bicycle injuries in California were aggregated by census tracts and categorized as occurring before and after the pandemic and ii) a paired Wilcoxon signed-rank test was conducted on the average percentage change in FSI rates to determine if the trends among the selected regions were statistically significant. The data used for the paired Wilcoxon test included 7993 of California's 8057 census tracts, as 64 cencus tracts were excluded from this analysis due to having a very low population or one of zero.

The compiled dataset was analyzed using a random effects negative binomial regression model with panel data to understand the trends in pedestrian bicycle injuries in the state. The existence of temporal instability in crash data is discussed in the literature (Mannering, 2018). Temporal instability suggests that the effect of explanatory variables varies over time, given many factors, such as changes in road user behavior over time. Another potential issue in the model stems from the fact that some of the 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 can be inaccurate. To deal with this, random effect models have been used in the literature (Guo et al., 2018; Islam et al., 2020; Mannering et al., 2016; Yan et al., 2021), enabling estimators to vary across observation-time intervals. To that end, to conduct a comparative analysis of pedestrian and bicyclist historical crashes before and after the COVID-19 period, a random-effects negative binomial regression model with panel data is estimated to account for unobserved heterogeneity across panels. This method is specifically designed for analyzing count data (e.g., crash data) with overdispersion in a panel or longitudinal setting. The panel data is a two-dimensional concept, where panel i=1, 2, .., n represents census tracts and time t=1, 2, …, n represents the periods before and after the pandemic. The model extends the negative binomial regression model to handle panel data, where repeated measures or observations on the same individuals or groups over time. It accounts for individual-specific or group-specific heterogeneity and controls 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/states for unidentified group-specific reasons (STATA18, 2023). The general form and log-likelihood of the model can be calculated using equations 3 and 4, respectively.

$$\Pr(Y_{it} = y_{it}, \delta_i) = \frac{\Gamma(\lambda_{it}+y_{it})}{\Gamma(\lambda_{it})\Gamma(y_{it}+1)}\left(\frac{1}{1+\delta_i}\right)^{\lambda_{it}}\left(\frac{\delta_i}{1+\delta_i}\right)^{y_{it}} \quad (3)$$

$$lnL = \sum_{i=1}^{n} \omega_i [ln\Gamma(\mathrm{r}+\mathrm{s}) + ln\Gamma\left(r + \sum_{k=1}^{n_i} \lambda_{ik}\right) + ln\Gamma\left(s + \sum_{k=1}^{n_i} y_{ik}\right) - ln\Gamma(\mathrm{r}) - ln\Gamma(\mathrm{s}) - ln\Gamma(\mathrm{r}+\mathrm{s}+\sum_{k=1}^{n_i}\lambda_{ik} + \sum_{k=1}^{n_i} y_{ik}) + \sum_{t=1}^{n_i}[ln\Gamma(\lambda_{it}+y_{it}) - ln\Gamma(\lambda_{it}) - ln\Gamma(y_{it}+1)]] \quad (4)$$

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 (Hausman et al., 1984; STATA18, 2023).

Results

This chapter presents the key findings from the analysis of pre- and post- Covid-19 pandemic pedestrian and bicyclist (ped/bike) fatality trends in the U.S. and ped/bike fatal and serious injury trends in California. As detailed in the methods section, the study period was divided into two distinct phases: before the pandemic and after the pandemic, with the analysis broken down at a state-by-state level nationally and county-by-county and census tract level for California. Further analysis was also conducted by breaking down results by rural and urban areas as well as disadvantaged and non–disadvantaged communities.

Pedestrian-Bicyclist Fatality Trends in the U.S.

Initial analysis of ped/bike fatalities revealed that the 10 states with the highest pre-pandemic ped/bike fatality per capita were in either the southern or western region of the United States (See Figure 2). New Mexico had the highest per capita rate followed by Florida, South Carolina, Louisiana and Delaware (see Table 2).

Post-pandemic, 7 out of the 10 states with the highest ped/bike fatality per capita were in the southern region, indicating a shift in where ped/bike fatalities occurred. (See Figure 3). New Mexico still had the highest per capita followed by Louisiana, Florida, Arizona and South Carolina (see Table 3). Hawaii and Nevada were no longer in the 10 states with highest per capita, with Georgia and Texas becoming the ninth and tenth, respectively.

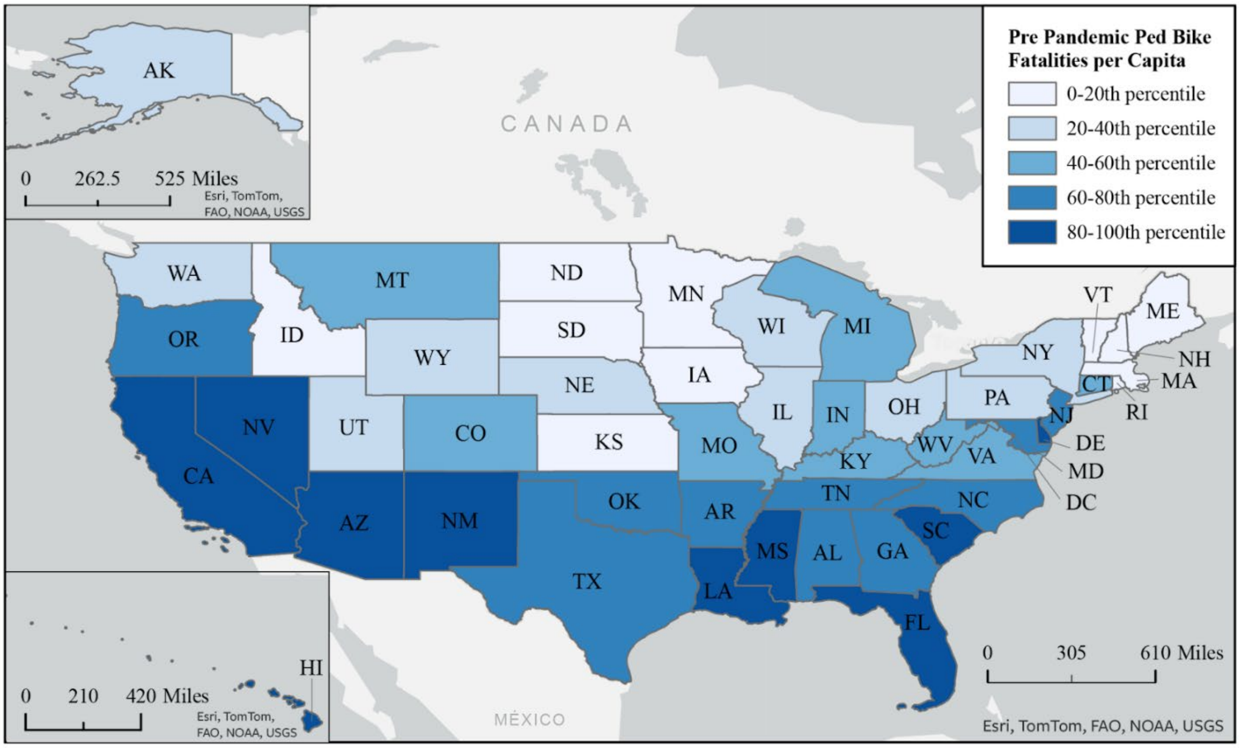

Figure 2. Ped/Bike Fatalities per Capita in the U.S. - Pre-Pandemic

Table 2. Top 10 States with the highest Ped-Bike Fatalities per Capita - Pre-Pandemic

State	Pre-Pandemic Ped/Bike Fatalities	Pre-Pandemic Ped/Bike Fatalities per 10,000 Population
New Mexico	203	0.959
Florida	1900	0.882
South Carolina	399	0.780
Louisiana	358	0.769
Delaware	75	0.758
Arizona	521	0.729
California	2510	0.635
Hawaii	91	0.625
Mississippi	183	0.618
Nevada	178	0.573

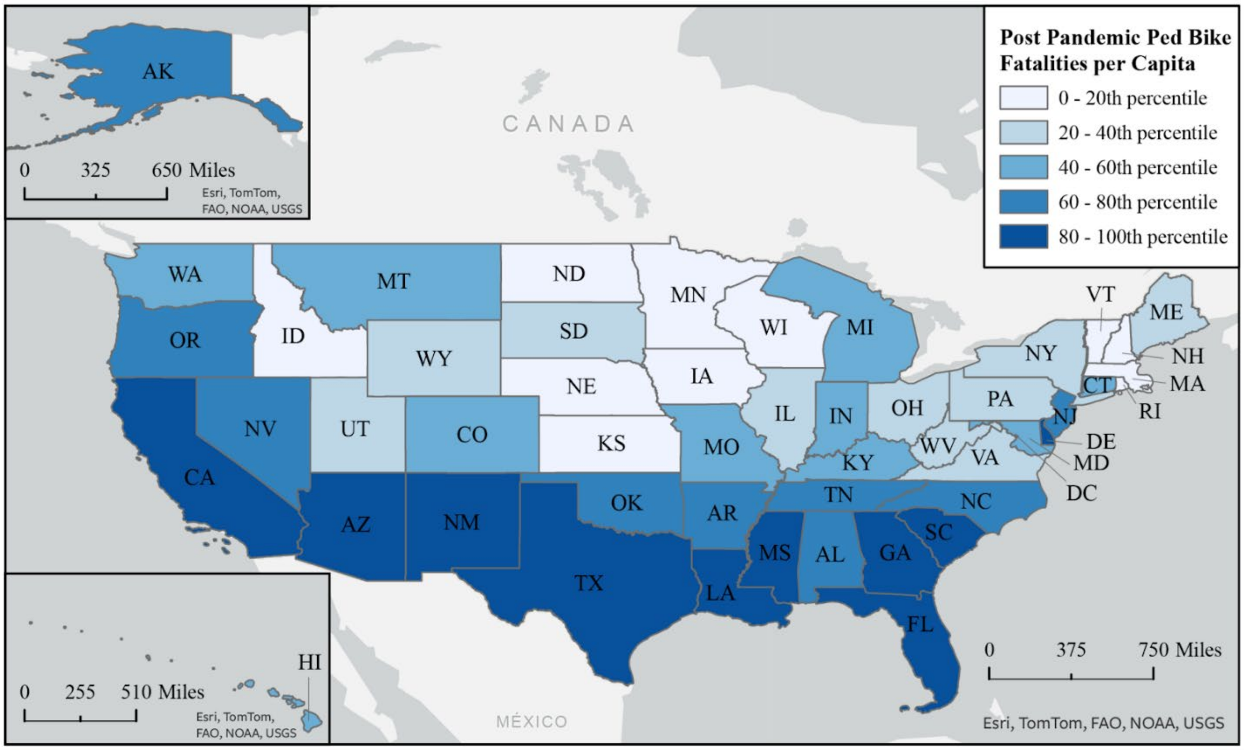

Figure 3. Ped/Bike Fatalities per Capita in the U.S. - Post-Pandemic

Table 3. Top 10 States with the highest Ped-Bike Fatalities per Capita - Post-Pandemic

State	Post-Pandemic Ped/Bike Fatalities	Post-Pandemic Ped/Bike Fatalities per 10,000 Population
New Mexico	223	1.053
Louisiana	476	1.022
Florida	2181	1.013
Arizona	671	0.938
South Carolina	446	0.871
Mississippi	225	0.760
Delaware	75	0.758
California	2857	0.723
Georgia	757	0.707
Texas	1940	0.666

Pedestrian-Bicyclist Fatality Trends in Rural and Urban Areas in the U.S.

The analysis of ped/bike fatalities revealed a nationwide increase in fatality rates after the pandemic compared to before the pandemic. Nationally, the ped/bike fatality per 10,000 inhabitants increased by 18.76% (see Table 4) in the after-pandemic period when compared to the before-pandemic period. In urban areas across the U.S., the ped/bike fatality per 10,000 inhabitants rose by 21.02 % (see Table 5) over the same period, while the rate in rural areas rose by 7.29 % (see Table 6). Tables 4-6 present the results of the paired Wilcoxon-tests conducted on ped/bike fatality rates across the U.S., urban areas, and rural areas, respectively, and show statistically significant rises in the average state-level fatality rates.

The overall national increase in ped/bike fatality rates masked significant variations among different regions and states across the United States. Vermont saw the largest increase across all states, with a rise of 88%, while Hawaii saw a decrease of 25%. Figures 4, 5, 6, and 7 compare total, urban and rural percentage changes for pre- and post-pandemic ped/bike fatality rates across the four U.S. regions, Northeast, Midwest, West, and the South.

Table 4. Paired Wilcoxon-test Analysis of Ped/Bike Fatality Rates across the U.S.

Location	Victim	Before Pandemic		After Pandemic		Percentage Change
		Fatalities	Fatalities per 10,000 Population	Fatalities	Fatalities per 10,000 Population	
United States	Pedestrian	13755	0.415	16264	0.491	18.24%
	Bicycle	1816	0.055	2228	0.067	22.69%
	Ped and Bike	15571	0.470	18492	0.558	18.76%
Average of all States and D.C.	Pedestrian		0.367		0.437	18.93% P-value = 0.000
	Bicycle		0.045		0.056	24.64% P-value = 0.001
	Ped and Bike		0.412		0.493	19.56% P-value = 0.000

Table 5. Paired Wilcoxon-test Analysis of Ped/Bike Fatality Rates across Urban Areas in the U.S.

Location	Victim	Before Pandemic		After Pandemic		Percentage Change
		Fatalities	Fatalities per 10,000 Population	Fatalities	Fatalities per 10,000 Population	
United States	Pedestrian	11372	0.429	13649	0.515	20.02%
	Bicycle	1450	0.055	1868	0.070	28.83%
	Ped and Bike	12822	0.484	15517	0.585	21.02%
Average of all States and D.C.	Pedestrian		0.376		0.462	22.76% P-value = 0.000
	Bicycle		0.044		0.060	35.76% P-value = 0.000
	Ped and Bike		0.421		0.522	24.13% P-value = 0.000

Table 6. Paired Wilcoxon-test Analysis of Ped/Bike Fatality Rates across Rural Areas in the U.S.

Location	Victim	Before Pandemic		After Pandemic		Percentage Change
		Fatalities	Fatalities per 10,000 Population	Fatalities	Fatalities per 10,000 Population	
United States	Pedestrian	2315	0.349	2518	0.380	8.77%
	Bicycle	361	0.054	353	0.053	-2.22%
	Ped and Bike	2676	0.404	2871	0.433	7.29%
Average of all States and D.C.	Pedestrian		0.336		0.369	9.76% P-value = 0.019
	Bicycle		0.048		0.049	1.20% P-value = 0.800
	Ped and Bike		0.384		0.418	8.69% P-value = 0.036

Northeast Region

Vermont (+89%), followed by Maine (+68%), New Hampshire (+36%), Massachusetts (+24%), and New Jersey (+14%) saw the largest increase in overall ped/bike fatality rates (see Figure 4). In urban ped/bike fatality rates, all three top states saw an over 50 percent increase, with Vermont, Maine, and New Hampshire seeing a 166, 57 and 50 percent increase respectively. For rural ped/bike fatality rates, Massachusetts (+100%) saw the largest increase followed by Vermont (+80%), Maine (+64%), New Jersey (+63%) and New Hampshire (+13%). Only Rhode Island saw a decrease in total (-5%) and urban (+12%) ped/bike fatalities with no change in rural ped/bike fatalities.

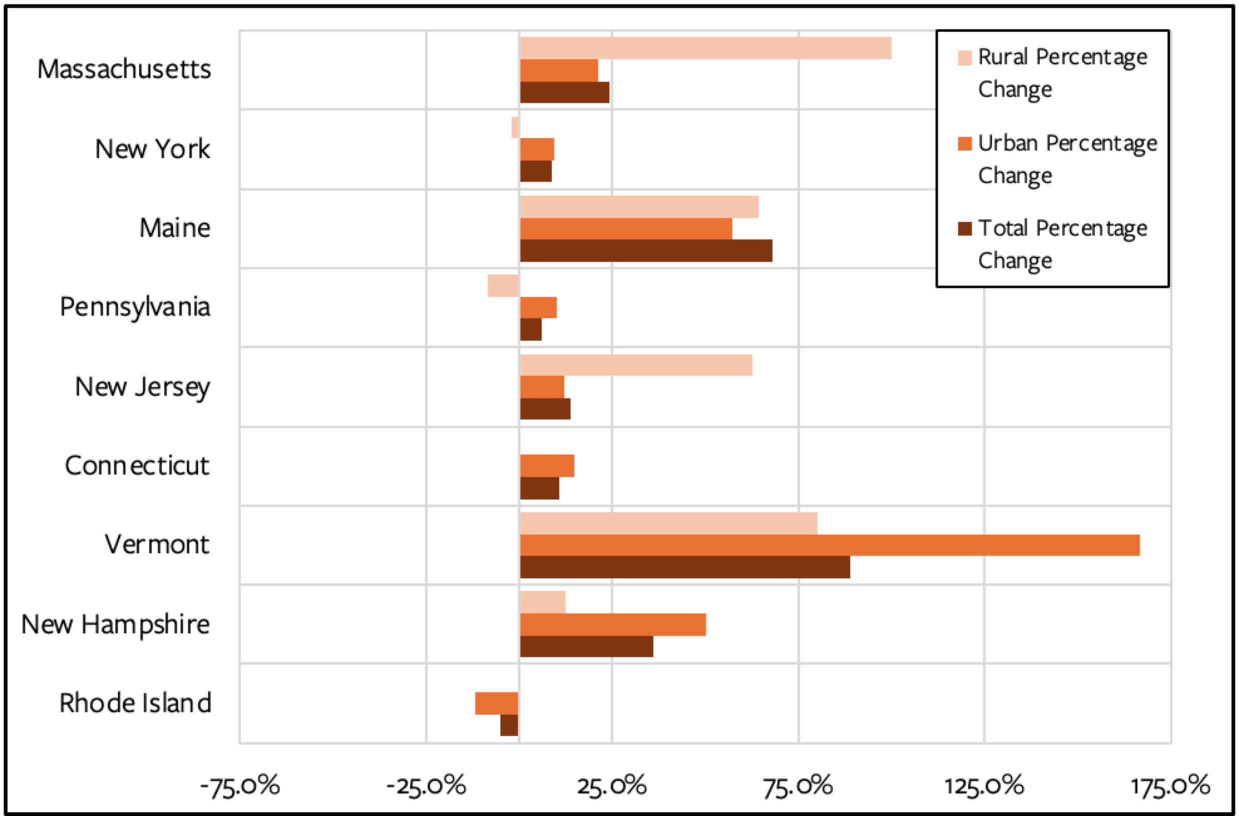

Figure 4. Per Capita Percentage Change Pre- and Post-Pandemic in Total, Urban and Rural Ped/Bike Fatalities - Northeast Region

Midwest Region

South Dakota (+52%), followed by Kansas (+40%), North Dakota (+40%), Michigan (+29%), and Illinois (+26%) saw the largest increase in overall ped/bike fatality rates (see Figure 5). While South Dakota saw an increase in ped/bike fatalities rates across the board (total, urban, and rural rates), Kansas saw an increase in total (+40%) and urban (+71%) per capita but a decrease in rural (-9%). Iowa and Ohio followed a similar pattern with an increase in total (+3%, +22%) and urban (+16%, +30%) but a decrease in rural (-20%, -3%). Nebraska was the only state that saw a decrease in total (-17%) and urban (-24%) per capita.

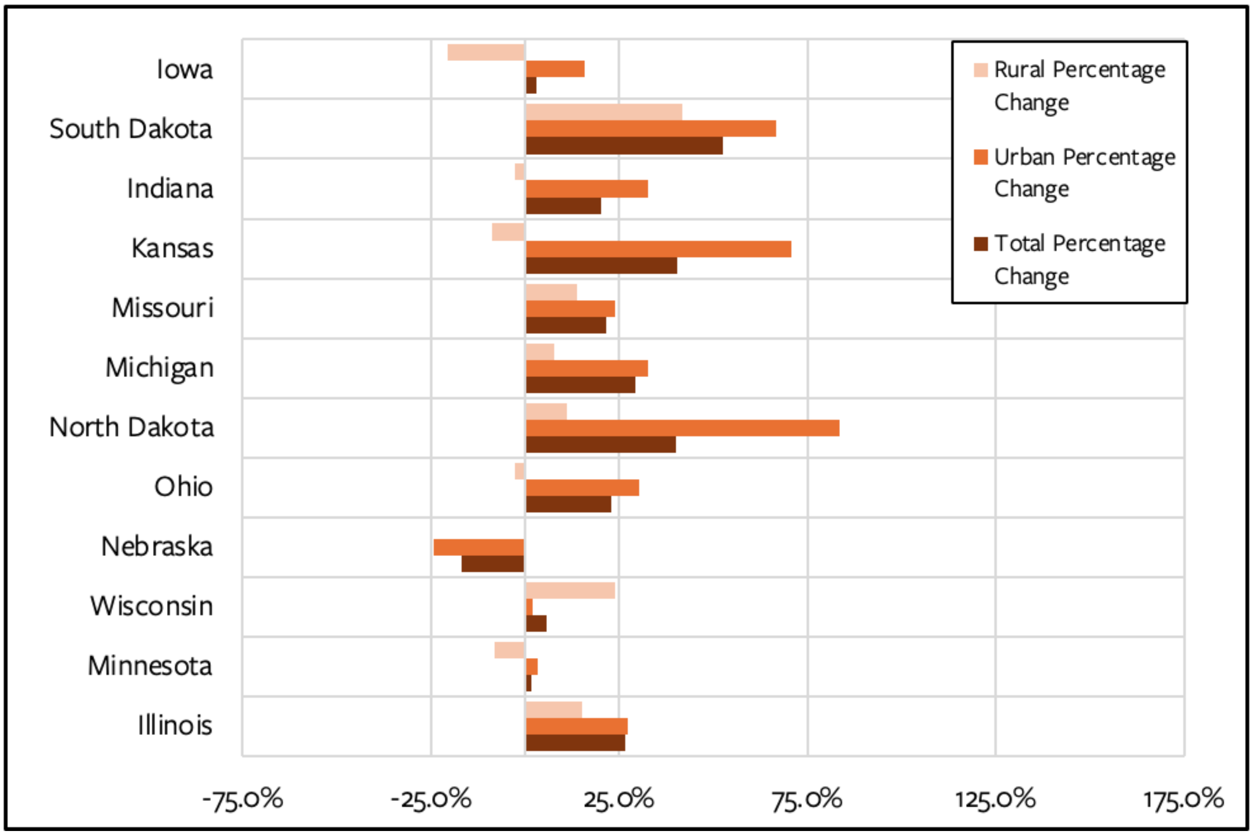

Figure 5. Per Capita Percentage Change Pre- and Post-Pandemic in Total, Urban and Rural Ped/Bike Fatalities - Midwest Region

South Region

Washington D.C. (+41%), followed by Tennessee (+41%), Arkansas (+39%), Louisiana (+33%), and Oklahoma (+30%) saw the largest increase in overall ped/bike fatality rates (see Figure 6). All states except Delaware (-13%) saw an increase in urban ped/bike fatality rates ranging from 5 percent in Maryland to 59 percent in South Carolina. Seven states saw a decrease in rural ped/bike fatality rates, including Maryland (-55%), South Carolina (-33%), Virginia (-27%), Florida (-20%), Alabama (-15%), West Virginia (-14%), and Tennessee (-5%). Georgia (94%) saw the largest increase in rural ped/bike fatality rates, followed by Delaware (+73%) and Texas (41%).

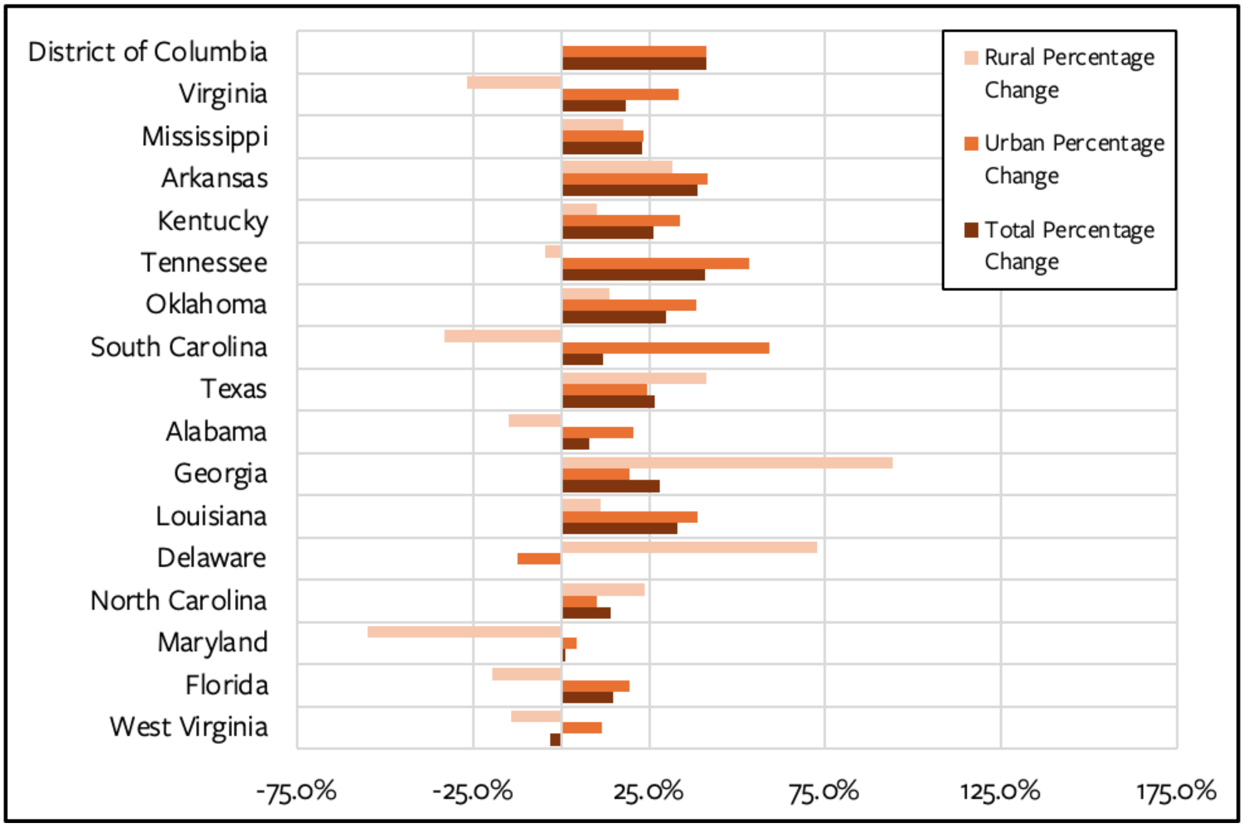

Figure 6. Per Capita Percentage Change Pre- and Post-Pandemic in Total, Urban and Rural Ped/Bike Fatalities - South Region

Note: D.C.'s population is urban only.

West Region

Alaska (+54%), followed by Washington (+32%), Utah (+30%), Oregon (+29%), and Arizona (+29%) saw the largest increase in overall ped/bike fatality rates (see Figure 7). All states except Hawaii (-15%) and New Mexico (-5%) saw an increase in urban ped/bike fatality rates ranging from 140 percent in Wyoming to 11 percent in Nevada. 4 states saw a decrease in rural ped/bike fatality rates, including Hawaii (-87%), Wyoming (-31%), Utah (-18%), and California (-4%). The states with the highest increases in rural ped/bike fatality rates were Colorado (127%), New Mexico (62%), Washington (60%), Nevada (53%) and Oregon (52%).

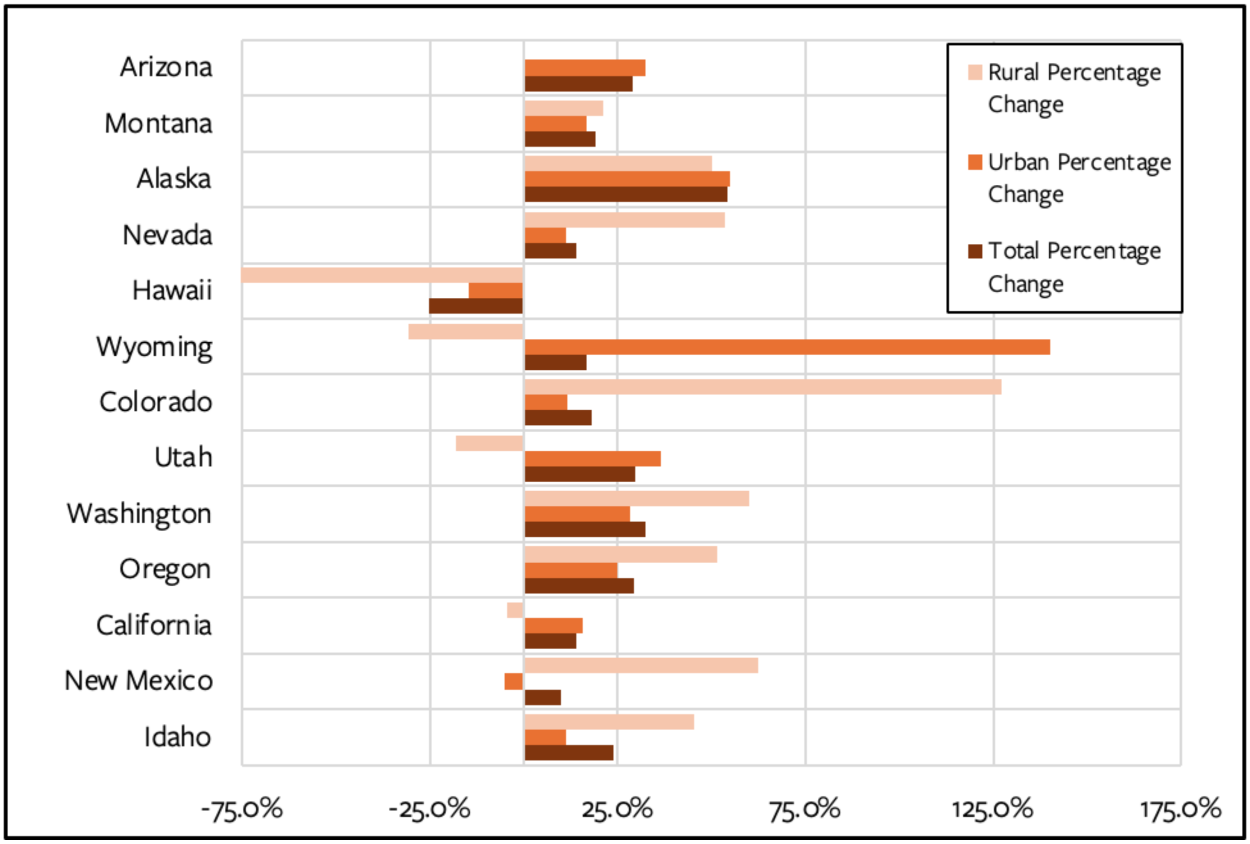

Figure 7. Per Capita Percentage Change Pre- and Post-Pandemic in Total, Urban and Rural Ped/Bike Fatalities - West Region

Pedestrian-Bicyclist Fatality Trends in Disadvantaged and Non-disadvantaged Communities in the U.S.

The analysis of pedestrian-bicyclist fatalities revealed a nationwide increase in fatality rates after the pandemic compared to before the pandemic in disadvantaged and non-disadvantaged communities in the United States. Nationally, the ped/bike fatality per 10,000 inhabitants increased by about 20.02% (see Table 7) in disadvantaged communities and 17.46% (see Table 8) in non-disadvantaged communities after-pandemic period when compared to the before-pandemic period. Table 7 and Table 8 also present the results of the paired Wilcoxon-tests conducted on the average ped/bike fatality rates across the U.S. and show a statistically significant rise in disadvantaged communities and in non-disadvantaged communities.

Table 7. Paired Wilcoxon-test Analysis of Ped/Bike Fatalities across Disadvantaged Communities in the U.S.

Location	Victim	Before Pandemic		After Pandemic		Percentage Change
		Fatalities	Fatalities per 10,000 Population	Fatalities	Fatalities per 10,000 Population	
United States	Pedestrian	6914	0.652	8243	0.778	19.22%
	Bicycle	832	0.079	1054	0.099	26.68%
	Ped and Bike	7746	0.731	9297	0.877	20.02%
Average of all States and D.C.	Pedestrian		0.535		0.689	28.74% P-value = 0.000
	Bicycle		0.050		0.078	55.25% P-value = 0.001
	Ped and Bike		0.586		0.767	31.01% P-value = 0.000

Table 8. Paired Wilcoxon-test Analysis of Ped/Bike Fatalities across Non-Disadvantaged Communities in the U.S.

Location	Victim	Before Pandemic		After Pandemic		Percentage Change
		Fatalities	Fatalities per 10,000 Population	Fatalities	Fatalities per 10,000 Population	
United States	Pedestrian	6844	0.313	8021	0.367	17.20%
	Bicycle	984	0.045	1174	0.054	19.31%
	Ped and Bike	7828	0.358	9195	0.421	17.46%
Average of all States and D.C.	Pedestrian		0.296		0.345	16.54% P-value = 0.000
	Bicycle		0.042		0.049	15.27% P-value = 0.001
	Ped and Bike		0.338		0.393	16.38% P-value = 0.000

The following presents the regional variations of the percentage change in the fatality rates in disadvantaged and non-disadvantaged communities in the U.S.

Northeast Region

Maine (+175%) saw the largest increase in ped/bike fatality rates in disadvantaged census tracts, followed by Massachusetts (+41%), New Jersey (+39%), Pennsylvania (+19%) and Rhode Island (+11%) (See Figure 8). Only one state saw a decrease in ped/bike fatality rates in disadvantaged census tracts, with New York seeing a slight decrease of 5 percent.

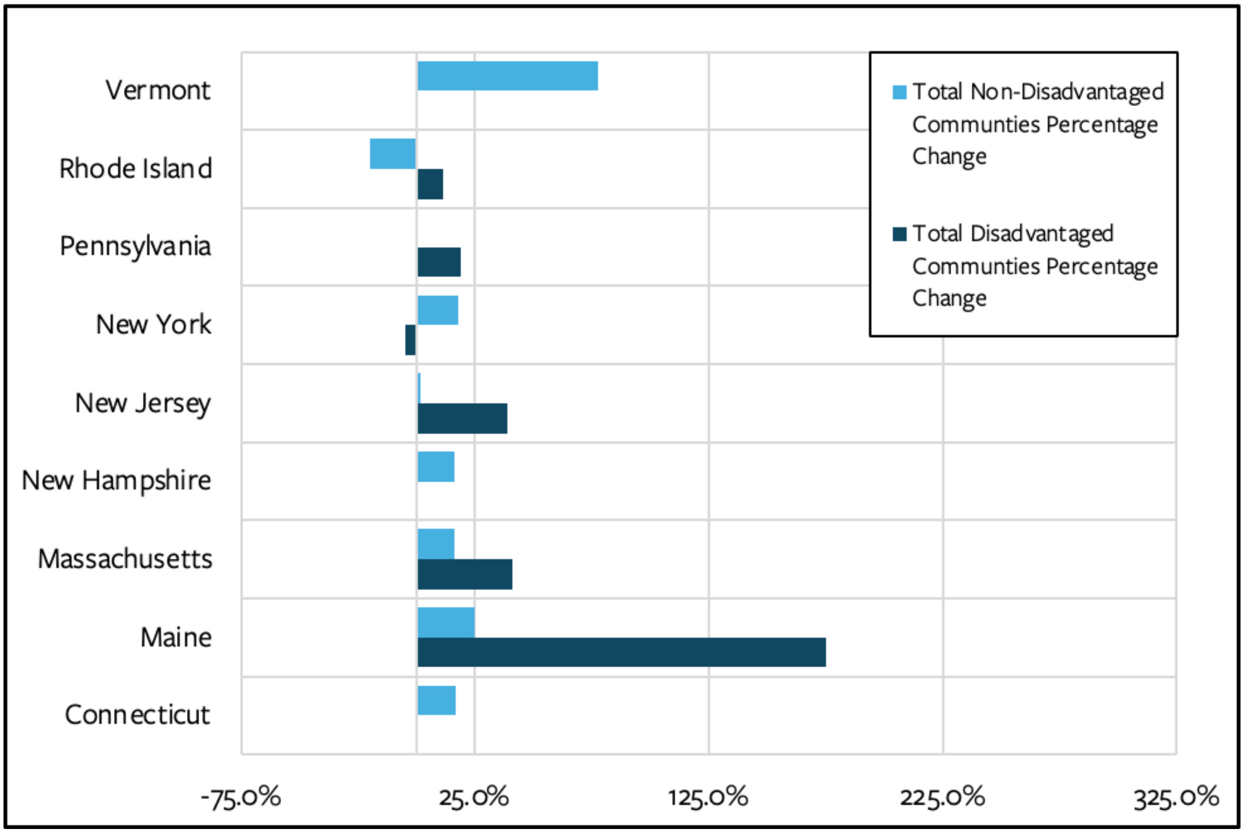

Figure 8. Per Capita Percentage Change Pre- and Post-Pandemic in Disadvantaged and Non-Disadvantaged Communities Ped/Bike Fatalities - Northeast Region

Midwest Region

North Dakota (+300%) saw the largest increase in ped/bike fatality rates in disadvantaged census tracts, followed by Minnesota (+77%), Kansas (+56%), South Dakota (+54%) and Ohio (+46%) (see Figure 9). All states saw an increase in ped/bike fatality rates in disadvantaged census tracts, while only 8 states saw an increase in ped/bike fatality rates in non-disadvantaged census tracts.

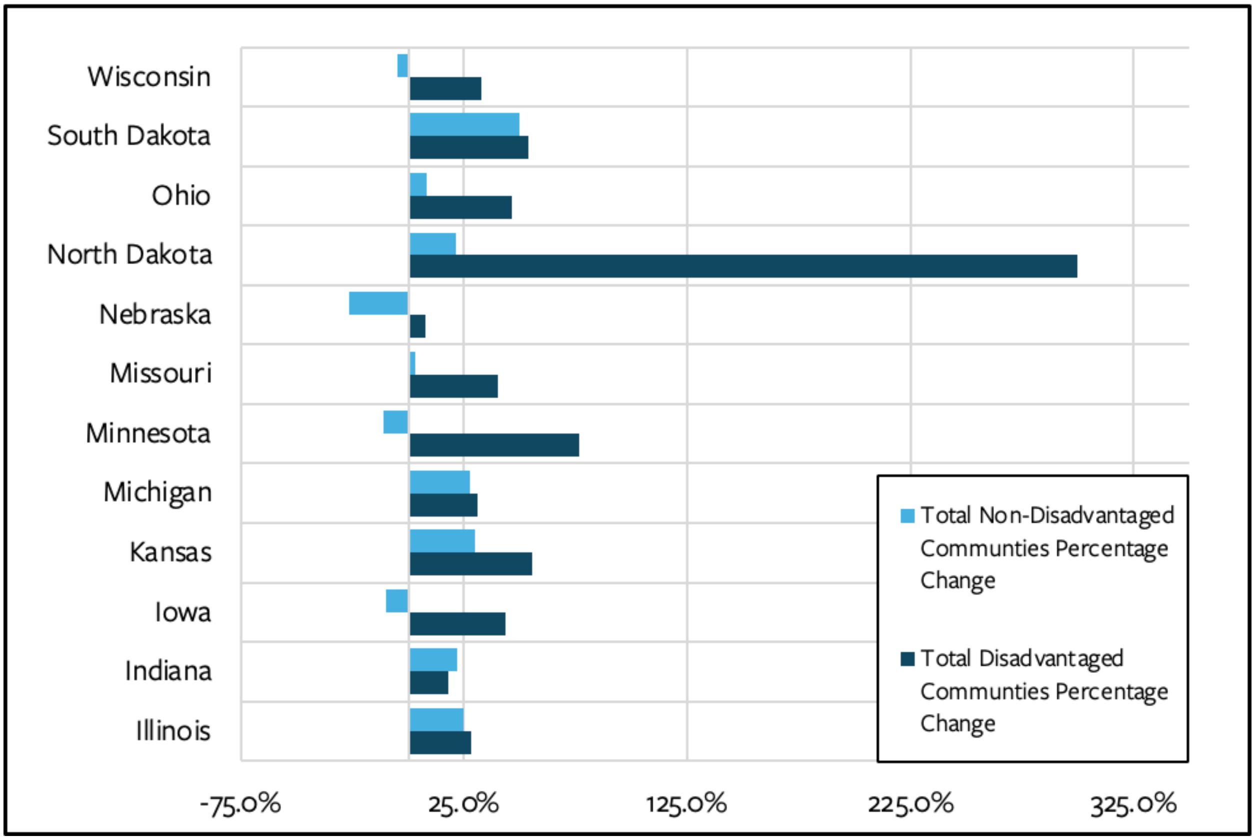

Figure 9. Per Capita Percentage Change Pre- and Post-Pandemic in Disadvantaged and Non-Disadvantaged Communities Ped/Bike Fatalities - Midwest Region

South Region

Tennessee (+60%) saw the largest increase in ped/bike fatality rates in disadvantaged census tracts, followed by Arkansas (+51%), Georgia (+46%), Delaware (+33%) and Kentucky (+32%) (see Figure 10). All states saw an increase in ped/bike fatality rates in disadvantaged census tracts. Only 3 states saw a decrease in ped/bike fatality rates in non-disadvantaged communities with rates in West Virginia, Delaware and Maryland decreasing by 11, five and three percent respectively.

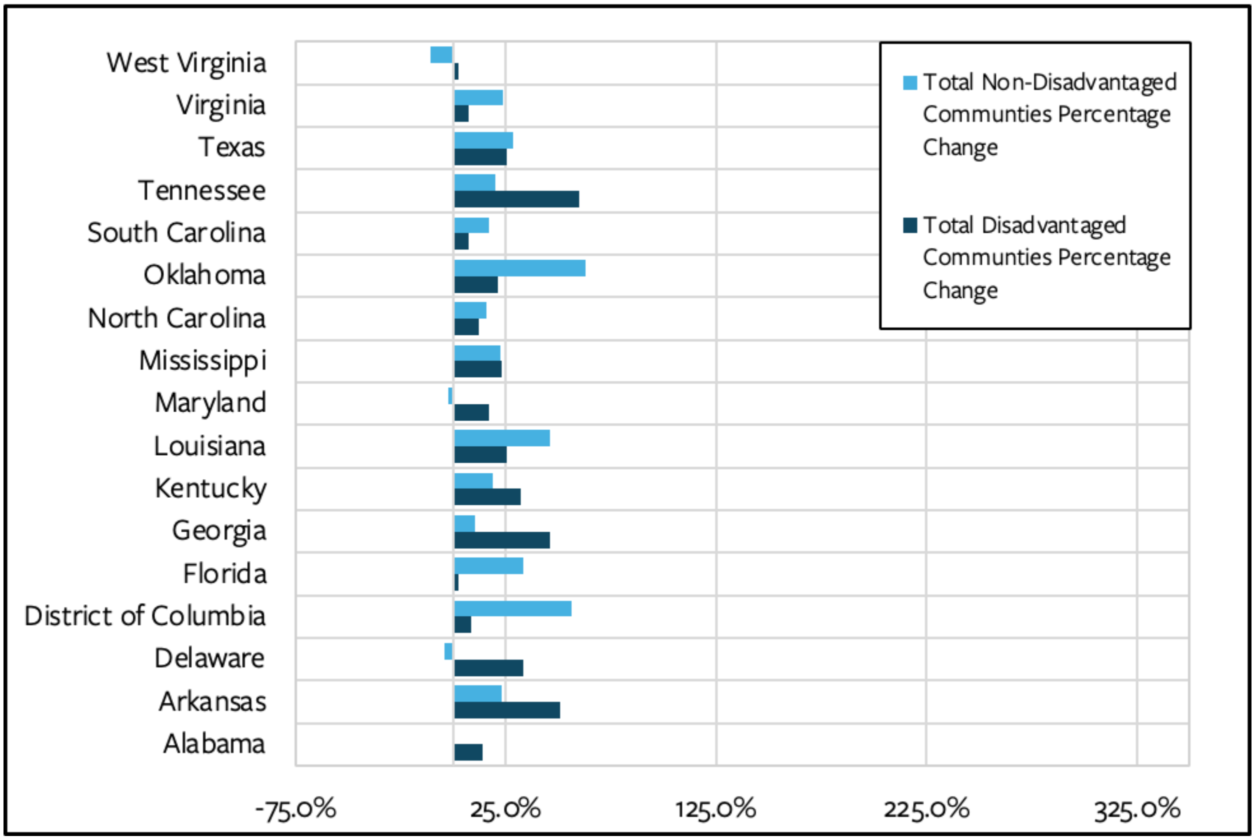

Figure 10. Per Capita Percentage Change Pre- and Post-Pandemic in Disadvantaged and Non-Disadvantaged Communities Ped/Bike Fatalities - South Region

West Region

Wyoming (+75%) saw the largest increase in ped/bike fatality rates in disadvantaged census tracts, followed by Alaska (+71%), Hawaii (+64%), Washington (+63%) and Idaho (+62%) (see Figure 11). All states saw an increase in ped/bike fatality rates in disadvantaged census tracts. Only one state saw a decrease in ped/bike fatality rates in non-disadvantaged communities with the rate in Hawaii decreasing by 42 percent.

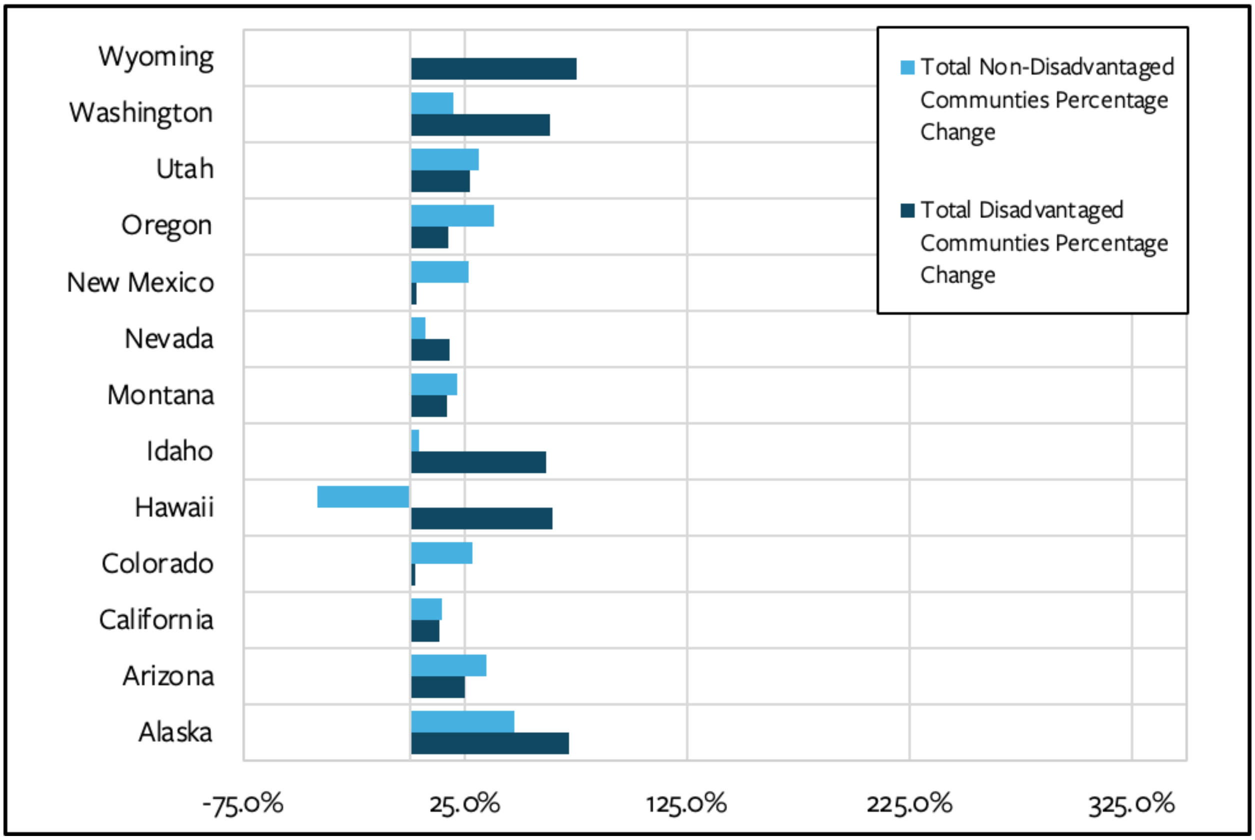

Figure 11. Per Capita Percentage Change Pre- and Post-Pandemic in Disadvantaged and Non-Disadvantaged Communities Ped/Bike Fatalities - West Region

Pedestrian and Bicyclist Fatal and Serious Injury Trends in California

Spatial Distribution of Pedestrian and Bicyclist Fatalities and Serious Injuries in California

Overall, California saw a noticeable increase in pedestrian-bicyclist fatalities and serious injuries (FSI) rates from the pre-pandemic period to post-pandemic period. Alpine County had the highest ped/bike FSI per capita both pre- and post-pandemic out of every county (See Figure 12, Table 9, and Table 10). This result, however, should be interpreted with caution as Alpine is a very sparsely populated county, meaning even a relatively small increase in ped/bike fatalities can lead to a large percentage increase. 7 out of 10 states that originally had the highest ped/bike FSI per capita, remained in the top 10 post-pandemic. Mono, Mendocino and Marin county were no longer in the top 10 post-pandemic while Sacramento, Lake and Kern County occupied seventh, eighth and tenth place respectively.

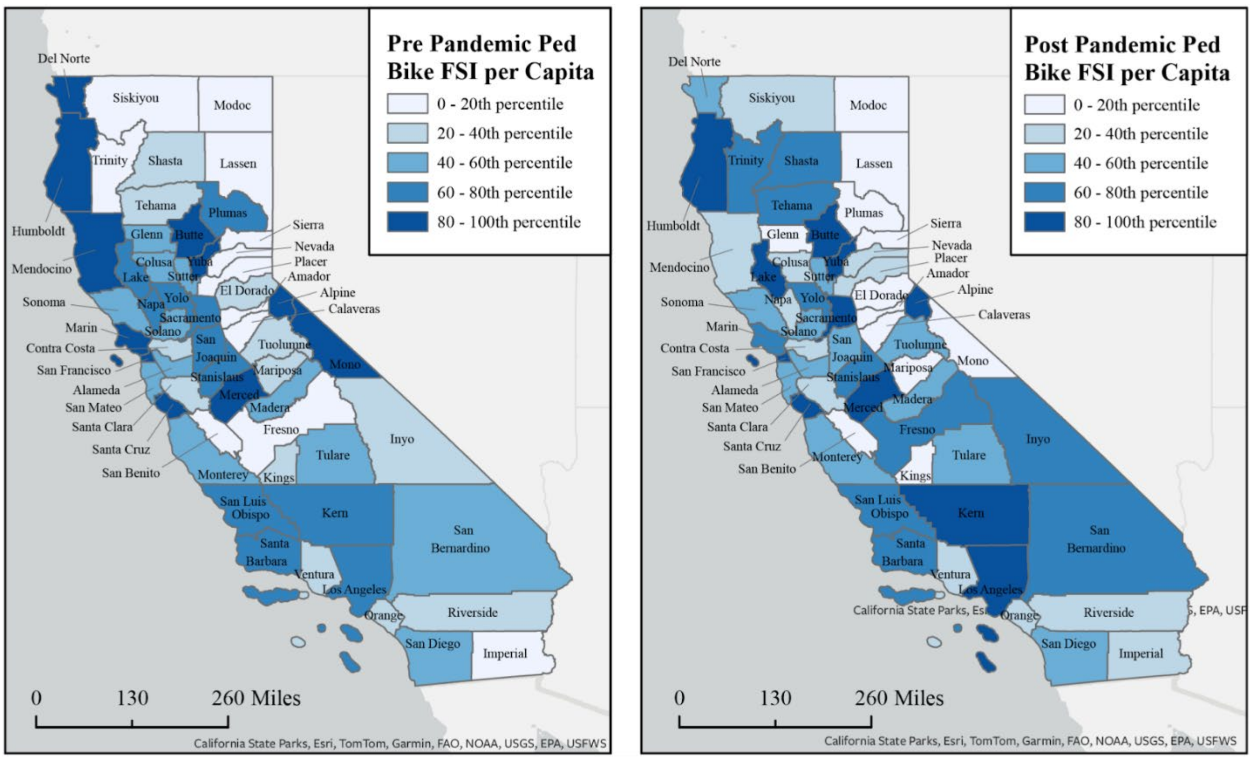

Figure 12. Pre- and Post-Pandemic Ped/Bike FSI per Capita in California.

Table 9. Top 10 Counties with the Highest Ped/Bike FSI per Capita - Pre-Pandemic

County	Pre-Pandemic Ped/Bike FSI	Pre-Pandemic Ped/Bike FSI per 10,000 Population
Alpine County	2	19.249
Mono County	9	6.289
Humboldt County	66	4.855
San Francisco County	381	4.354
Santa Cruz County	109	3.979
Merced County	107	3.943
Butte County	85	3.764
Mendocino County	32	3.669
Yuba County	27	3.536
Marin County	90	3.462

Table 10. Top 10 Counties with the Highest Ped/Bike FSI per Capita - Post-Pandemic

County	Post-Pandemic Ped/Bike FSI	Post-Pandemic Ped/Bike FSI per 10,000 Population
Alpine County	4	38.499
Humboldt County	64	4.708
Santa Cruz County	122	4.453
Merced County	118	4.348
Yuba County	32	4.191
San Francisco County	324	3.703
Sacramento County	562	3.686
Kern County	309	3.481
Butte County	76	3.366
Lake County	21	3.271

Overall, California saw a 6.74% (see Table 11) increase in FSI rate. The paired Wilcoxon-test conducted on the average ped/bike fatality rates across the California census tracts also shows a statistically significant rise in the FSI rates from the pre-pandemic period to the post-pandemic period.

Table 11. Paired Wilcoxon-test Analysis of Ped/Bike FSI across California Census Tracts

Location	Victim	Before Pandemic		After Pandemic		Percentage Change
		FSI	FSI per 10,000 Population	FSI	FSI per 10,000 Population	
California	Ped and Bike	9784	2.491	10445	2.659	6.74%
California Average of all Census Tracts*	Ped and Bike		2.811		2.979	5.98% P-value = 0.000

* Note that 64 out of 8057 California census tracts were excluded from this analysis due to having either zero or very low population.

Pedestrian-Bicyclist Fatality and Serious Injury Trends in Disadvantaged and Non-disadvantaged Communities in California

Similar to the analysis conducted nationally, ped/bike FSI per capita were broken down by census tracts in an effort to get a better understanding of how ped-pike FSI rates change pre-pandemic in disadvantaged communities versus non-disadvantaged communities. The result shown in Table 12 reveals a 5.55% increase in the FSI rate in disadvantaged communities in CA. The paired Wilcoxon-test conducted on the average ped/bike fatality rates across the disadvantaged census tracts also shows a statistically significant increase in the average FSI rates. Likewise, a 8.00% increase in the FSI rate in non-disadvantaged communities in CA and a statistically significant increase in the average FSI rates among CA non-disadvantaged census tracts.

Table 12. Paired Wilcoxon-test Analysis of Ped/Bike FSI across California Disadvantaged and Non-Disadvantaged Communities Census Tracts

Location	Victim	Before Pandemic		After Pandemic		Percentage Change
		FSI	FSI per 10,000 Population	FSI	FSI per 10,000 Population	
California - Disadvantaged Communities	Ped and Bike	4907	3.297	5179	3.480	5.55%
California Average of Disadvantaged Census Tracts*	Ped and Bike		3.635		3.843	5.73% P-value = 0.014
California Non-disadvantaged Communities	Ped and Bike	4877	1.999	5266	2.159	8.00%
California Average of Non-disadvantaged Census Tracts*	Ped and Bike		2.295		2.438	6.23% P-value = 0.006

* Note that 64 out of 8057 California census tracts were excluded from this analysis due to having either zero or very low population.

Spatial Analysis of Non-Disadvantaged Communities in California

Overall, 28 counties in California observed an increase in ped-pike FSI per capita in non-disadvantaged communities, while three observed no change and 20 reported a decrease (See Figure 13, Table 13). Rates for Alpine, Imperial, Lassen, Modoc, Sierra, Siskiyou and Tehama County could not be computed because they reported no ped/bike FSI in non-disadvantaged communities during the pre-pandemic period. Sutter County (+267%) experienced the largest per capita increase in non-disadvantaged communities going from 3 ped/bike fatalities and serious injuries to 11. This increase, however, should be interpreted with caution given that Sutter is a very sparsely populated county, meaning even a relatively small increase in ped/bike fatalities and serious injuries can lead to a large percentage increase. Of counties with over 25 ped/bike FSI pre-pandemic, Fresno County (+114%) saw the largest increase per capita.

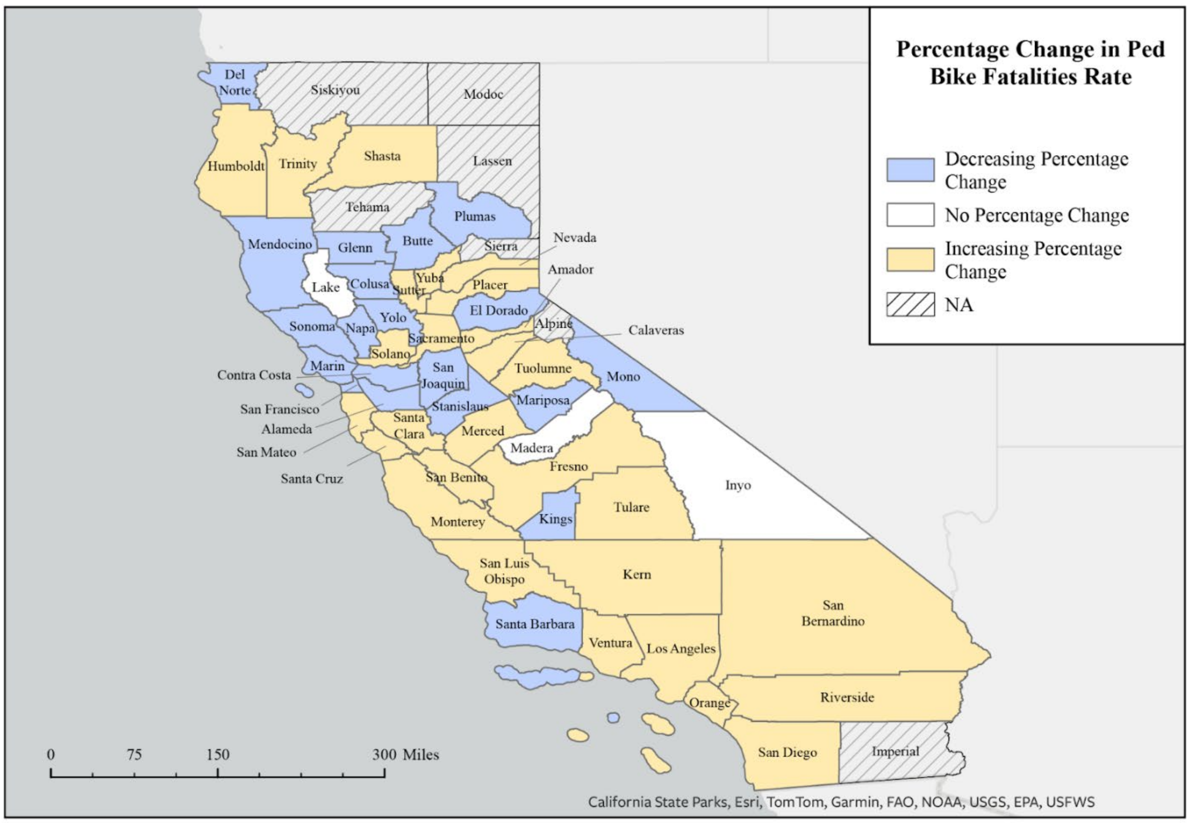

Figure 13. Ped/Bike FSI per Capita Percentage Change Pre- and Post-Pandemic in Non-Disadvantaged Communities Census Tracts in California

Table 13. Top 10 Counties with Highest Ped/Bike FSI per Capita Percentage Change in Non-Disadvantaged Communities in California

County	Pre- and Post-Pandemic Ped/Bike FSI per Capita Percentage Change
Sutter County	266.667 %
Trinity County	200.000 %
Fresno County	113.793 %
Placer County	91.667 %
Tuolumne County	75.000 %
Shasta County	72.727 %
Tulare County	68.750 %
Calaveras County	66.667 %
Monterey County	50.000 %
Yuba County	44.444 %

Note: This list only includes counties with a percentage change that can be computed. Counties that had 0 ped/bike FSI pre-pandemic but had one or more crashes post-pandemic were not included.

Spatial Analysis of Disadvantaged Communities in California

In disadvantaged communities across California, 24 counties in California observed an increase in ped-pike FSI per capita in disadvantaged communities while eight observed no change and 20 reported a decrease (See Figure 14, Table 14). Rates for Amador, Calaveras, Inyo, Modoc, Plumas, and Sierra County could not be computed because they reported no ped/bike FSI in disadvantaged communities during the pre-pandemic period. Placer County (+167%) experienced the largest per capita increase in non-disadvantaged communities going from 3 ped/bike fatalities and serious injuries to 8. This increase, however, should be interpreted with caution given that Placer County, similar to Sutter County, is a very sparsely populated county, meaning even a relatively small increase in ped/bike fatalities and serious injuries can lead to a large percentage increase. Of counties with over 100 ped/bike FSI pre-pandemic, Fresno County (+68%) saw the largest increase per capita in disadvantaged communities.

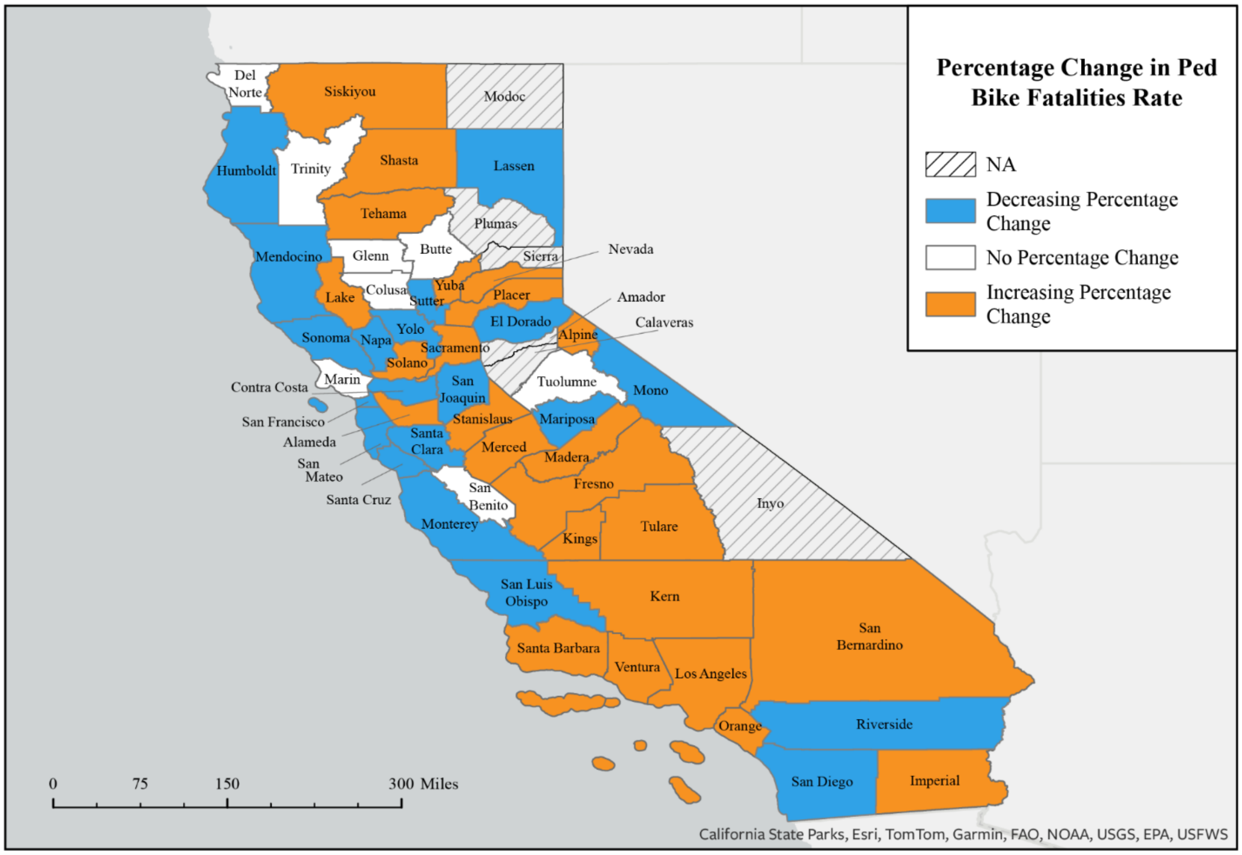

Figure 14. Ped/Bike FSI per Capita Percentage Change Pre- and Post-Pandemic in Disadvantaged Communities Census Tracts in California

Table 14. Top 10 Counties with Highest Ped/Bike FSI per Capita Percentage Change in Disadvantaged Communities in California

County	Pre- and Post-Pandemic Ped/Bike FSI per Capita Percentage Change
Placer County	166.667 %
Nevada County	150.000 %
Alpine County	100.000 %
Fresno County	67.797 %
Kings County	61.538 %
Tehama County	50.000 %
Kern County	38.333 %
Imperial County	32.143 %
Shasta County	28.000 %
Lake County	25.000 %

Note: This list only includes counties with a percentage change that can be computed. Counties that had 0 ped/bike FSI pre-pandemic but had one or more crashes post-pandemic were not included.

Modeling Results, Case Study of California

Table 15 presents a Random-effects Negative Binomial model with panel data, analyzing pedestrian and bicyclist fatalities and serious injuries per capita in California at the census tract level. The log-likelihood value of -23695.81, along with the AIC (47415.62) and BIC (47507.43), indicate the model's fit. The dispersion parameters (r=11.151 and s=0.752) suggest significant variability between panels, justifying the negative binomial approach over a Poisson model. The Log-likelihood ratio test and the Wald chi-squared test confirm the model's overall significance. All eight disadvantage indicators are included in the model to investigate their associations with FSI rates. The model shows that workforce development, energy, transportation, housing, and health disadvantage community indicators are all statistically significant and associated with increased FSI rates, with health disadvantage community indicator showing the highest increase. Indicators for water and wastewater, climate change, and legacy pollution disadvantages are not statistically significant. According to the Z-value of the 'Post-pandemic period' variable, the post-pandemic period is associated with a statistically significant increase in the FSI rate compared to the before-pandemic period. These findings highlight the need for targeted interventions in disadvantaged communities to improve pedestrians and bicyclists safety in the post-pandemic era.

Table 15. Random-effects Negative Binomial Regression with Panel Data

Variable	Coefficient	Std. Error	Z-value	P-value	Incidence Rate Ratio
Constant	-6.862	0.075	-90.88	0.000	0.001
Water and wastewater disadvantaged: Yes	0.016	0.032	0.320	0.750	1.016
Workforce development disadvantaged: Yes	0.104	0.032	3.280	0.001	1.110
Climate change disadvantaged: Yes	-0.026	0.041	-0.620	0.533	0.975
Energy disadvantaged: Yes	0.161	0.046	3.480	0.001	1.175
Transportation disadvantaged: Yes	0.299	0.043	6.880	0.000	1.349
Housing disadvantaged: Yes	0.231	0.046	4.980	0.000	1.260
Legacy pollution disadvantaged: Yes	-0.056	0.045	-1.240	0.215	0.946
Health disadvantaged: Yes	0.433	0.054	8.020	0.000	1.542
Post-pandemic period (base: pre-pandemic)	0.066	0.016	4.170	0.000	1.069
Ln (Population) (exposure)	1				
r	11.151	0.604			
s	0.752	0.042			
Log Likelihood	-23695.81				
AIC	47415.62				
BIC	47507.43				
Log likelihood ratio test vs. pooled: chibar2(01) = 1357.13; Prob >= chibar2 = 0.000					
Wald chi2 (12) = 676.41; Prob > chi2 = 0.000					

Discussion and Limitations

This study highlights significant changes in pedestrian and bicyclist safety trends across the United States and California during the post-pandemic era. The analysis revealed a notable nationwide increase in pedestrian and bicyclist fatality rates in the post-pandemic period, with an 18.76% increase in fatality rate. However, this overall rise masks substantial regional variations, with some states experiencing increases in fatality rates while others saw slight decreases.

These regional disparities could be attributed to a multitude of factors, including differences in pandemic-related policies and restrictions, changes in travel patterns and mode choices, variations in infrastructure and built environment characteristics, and socioeconomic factors that influence vulnerability and exposure to traffic risks, which have been shown to significantly impact road safety outcomes (Jacobsen, 2015). The observed increase in VMT in most states during the post-pandemic period suggests a return to pre-pandemic mobility levels or even higher, which could be due to changes in commuting patterns and the resumption of economic activities. For instance, some states that experienced significant increases in VMT after the pandemic may have seen a corresponding rise in pedestrian and bicycle fatalities due to increased exposure to traffic.

Conversely, states with notable decreases in VMT could have benefited from reduced exposure, contributing to lower fatality rates.

Urban and rural analyses revealed differing trends in pedestrian and bicyclist fatalities. The variations in urban and rural fatality trends suggest that the pandemic's impact may have been more pronounced in urban environments, potentially due to more exposures and differences in transportation infrastructure, land use patterns, and mobility behaviors. This finding suggests that while urban centers benefit from concentrated safety measures, persistent challenges remain that may require targeted interventions. Studies have indicated that urban areas often struggle with issues such as congestion, higher interaction rates between vehicles and pedestrians, and complex traffic patterns, which can negate the effects of safety measures (Litman, 2020). Likewise, rural areas saw a slight increase in fatality trends nationally, with states like Massachusetts (+100%) seeing the largest increase, followed by Vermont (+80%), Maine (+64%), New Jersey (+63%) experiencing a notable increase during the post-pandemic period. The increase in rural VMT and fatalities underscores the importance of addressing rural road safety, potentially through infrastructure improvements and increased enforcement of traffic laws (IIHS, 2020).

The analysis of pedestrian and bicycle fatalities in disadvantaged communities revealed a concerning trend. The fatality trend in disadvantaged communities was a 20.02% increase, while in non-disadvantaged communities, it was 17.46%. These findings underscore the persistent disparities in pedestrian and bicycle safety faced by disadvantaged communities. The modest decrease in fatality rates in these areas is a critical concern, as these populations typically face systemic barriers to safe transportation, including poorer infrastructure and limited access to safety resources (LaScala et al., 2000; Patwary et al., 2024). Addressing these disparities requires a concerted effort to prioritize investments and interventions in disadvantaged communities, with a focus on improving pedestrian and bicycle infrastructure, enhancing traffic calming measures, and promoting equitable access to safe and sustainable transportation options.

The detailed analysis of pedestrian and bicyclist FSI trends in California reveals a statistically significant increase across various settings in the post-pandemic period. Overall, pedestrian and bicyclist FSI crash data in California demonstrated a 6.74% rise in FSI rates, with 5.55% in disadvantaged communities and 8.00% in non-disadvantaged communities in the post-pandemic era. This upward trend underscores the heightened risk faced by these road users during the post-pandemic period. Additionally, the random-effects negative binomial regression model results highlight the significant increase in the ped/bike FSI rates in the post-pandemic period. The analysis also reveals significant associations with some of the disadvantaged burden indicators, with transportation, health, housing, and workforce development disadvantages being the most impactful. These findings underscore the compounded risks faced by disadvantaged communities, where limited access to safe infrastructure and resources exacerbates the likelihood of severe traffic injuries (LaScala et al., 2000; Patwary et al., 2024). Addressing these disparities requires targeted interventions to improve infrastructure and resources in these vulnerable communities.

While this study provides a comprehensive analysis of pedestrian and bicycle fatality and serious injury trends pre- and post-pandemic, it is essential to acknowledge its limitations and identify areas for future research. As the long-term impacts of the COVID-19 pandemic on transportation patterns and behaviors continue to unfold, ongoing monitoring and analysis will be crucial to identify emerging trends and adapt strategies accordingly. One limitation is the reliance on aggregated data at the state and census tract levels, which may obscure more granular patterns and nuances within smaller geographic units or specific communities. Future research could explore more localized analyses to capture the unique challenges and dynamics that shape pedestrian and bicycle safety at the neighborhood or community level. Additionally, the reliability of the findings may be impacted by data limitations, notably the potential underreporting of pedestrian and bicycle injuries during and immediately after the pandemic, as emergency response efforts and public health priorities may have diverted resources away from traditional traffic crash reporting and data collection methods.

Conclusions and Recommendations

This study aims to provide a comprehensive analysis of trends in pedestrian and bicyclist fatalities and serious injuries in the post-pandemic era, with a particular focus on disadvantaged communities in the United States and California. This study illuminates significant shifts in pedestrian and bicyclist safety trends across the U.S. at a state level and in California at a county and census tract level during the post-pandemic era. While there was a notable 18.76% nationwide increase in pedestrian and bicyclist fatality rates (per 10,000 population), the findings reveal substantial regional variations. The nationwide analysis indicates that despite targeted safety measures, urban areas still face persistent challenges and exhibit a large increase (21.02%) in fatality rates during the post-pandemic period compared to the pre-pandemic. However, rural areas also experienced substantial increases (7.29%) in fatality rates, highlighting the need for enhanced rural road safety measures. Disadvantaged communities experienced asubstantial increase in fatality rates, 20.02%, while non-disadvantaged communities experienced a 17.46% increase. Wilcoxon tests indicate that all rises are statistically significant.

Given the substantial variation in pedestrian and bicyclist safety outcomes observed across different regions, including urban, rural, and disadvantaged communities, it is crucial to implement targeted safety improvements and interventions tailored to the specific challenges and settings of each region. This approach will ensure that safety disparities are effectively addressed by recognizing and responding to the unique factors that influence each area. Particularly, policies can address the possible systemic barriers faced by disadvantaged communities by ensuring equitable distribution of safety resources for pedestrians and bicyclists. By adopting a region-specific approach to pedestrian and bicyclist safety, policymakers and planners can more effectively utilize resources, enhance safety outcomes, and reduce disparities, ultimately leading to safer environments for all road users in the U.S.

In California, the analysis of pedestrian and bicyclist fatalities and serious injuries revealed a significant 6.74% rise in FSI rates, with 5.55% in disadvantaged communities and 8.00% in non-disadvantaged communities in the post-pandemic era. Wilcoxon tests indicate that all rises are statistically significant. Additionally, the comprehensive analysis utilizing a panel random-effects negative binomial regression model to assess pedestrian and bicyclist safety trends across California's census tracts conclusively demonstrates significant disparities in safety outcomes influenced by various disadvantaged burden factors, with transportation, health, housing, and workforce development disadvantage community indicators being the most impactful. These findings underscore the complexity of pedestrian and bicyclist safety in the post-pandemic era and highlight the necessity for targeted safety improvements tailored to regional characteristics to effectively address safety disparities and enhance the overall safety of vulnerable road users.

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