CPBS
Center for Pedestrian and Bicyclist Safety

A Tier-1 University Transportation Center

Geographic and Time-of-Day Shifts in Pedestrian Crashes by Injury Severity Level

July 2024

A Report From the Center for Pedestrian and Bicyclist Safety

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16. Abstract

Pedestrian fatalities increased by more than 50% in the 2010s, despite many local, state, and federal efforts to provide complete streets and establish policies to move toward a fatality-free transportation system. To better understand the US pedestrian safety crisis, we analyzed crashes at a finer geographic and temporal scale than previous research. Using crash data from eight states, we compared fatal and serious injury (K&A) pedestrian crashes by neighborhood (census tract) and by hour of the week and month of year between 2008-2012 and 2017-2021. K&A pedestrian crash characteristics shifted between these two periods. At the neighborhood level, low-income, high-unemployment, and racial and ethnic minority populations were overrepresented in K&A pedestrian crashes in 2008-2012, and these groups were more likely to experience increases in K&A pedestrian increases during the 2010s, further exacerbating inequitable pedestrian safety outcomes. Neighborhoods with lower population density, at least one high-traffic arterial or collector roadway, an interstate or other type of freeway, and higher proportions of retail jobs were also significantly more likely than other tracts to experience increases in K&A pedestrian crashes during the 2010s. Considering temporal shifts in nine states, the highest numbers of K&A pedestrian crashes occurred between 6 pm and midnight, particularly on Friday and Saturday nights. However, the largest increases during the 2010s were during the midnight to 6 am time period on weekdays, suggesting that pedestrian and motor vehicle activity levels or pedestrian and driver behaviors may have shifted over the decade.

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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)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		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)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		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

Geographic and Temporal Shifts in Fatal and Severe Pedestrian Crashes

A Center for Pedestrian and Bicyclist Safety Research Report

July 2024

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Acronyms, Abbreviations, and Symbols

AADT	Annualized Average Daily Traffic
ADA	Americans with Disabilities Act
FHWA	Federal Highway Administration
NHTSA	National Highway Traffic Safety Administration

Abstract

Pedestrian fatalities increased by more than 50% in the 2010s, despite many local, state, and federal efforts to provide complete streets and establish policies to move toward a fatality-free transportation system. To better understand the US pedestrian safety crisis, we analyzed crashes at a finer geographic and temporal scale than previous research. Using crash data from eight states, we compared fatal and serious injury (K&A) pedestrian crashes by neighborhood (census tract) and by hour of the week and month of year between 2008-2012 and 2017-2021. K&A pedestrian crash characteristics shifted between these two periods. At the neighborhood level, low-income, high-unemployment, and racial and ethnic minority populations were overrepresented in K&A pedestrian crashes in 2008-2012, and these groups were more likely to experience increases in K&A pedestrian increases during the 2010s, further exacerbating inequitable pedestrian safety outcomes. Neighborhoods with lower population density, at least one high-traffic arterial or collector roadway, an interstate or other type of freeway, and higher proportions of retail jobs were also significantly more likely than other tracts to experience increases in K&A pedestrian crashes during the 2010s. Considering temporal shifts in nine states, the highest numbers of K&A pedestrian crashes occurred between 6 pm and midnight, particularly on Friday and Saturday nights. However, the largest increases during the 2010s were during the midnight to 6 am time period on weekdays, suggesting that pedestrian and motor vehicle activity levels or pedestrian and driver behaviors may have shifted over the decade.

Executive Summary

The US transportation system experienced a tragic shift in safety outcomes during the 2010s, as annual traffic fatalities increased from 32,999 in 2010 to 39,007 in 2020 (+18%). Pedestrians were impacted more than any other type of roadway user. After more than three decades of steady decreases, pedestrian fatalities in the US increased from 4,302 in 2010 to 6,565 in 2020 (+53%). This trend has continued into the 2020s. Vexing the safety profession, this increase in pedestrian fatalities occurred during a decade when many local, state, and national organizations established visionary goals to reduce traffic-related deaths to zero.

We conducted this longitudinal study to help understand geographic and temporal shifts in fatal and severe injury (K&A) pedestrian crashes between 2008-2012 and 2017-2021. We gathered K&A crashes from states with publicly-available, police-reported pedestrian crashes that covered these two time periods. Our geographic analysis used data from eight states: California, Colorado, Massachusetts, New York, Oregon, Pennsylvania, Washington, and Wisconsin. Our temporal analysis used data from nine states, also including Minnesota.

Our geographic analysis compared total K&A pedestrian crashes and shifts in these crashes between 2008-2012 and 2017-2021 at the census tract level with demographic, employment, land use, and transportation characteristics from the American Community Survey, EPA Smart Location Database, Longitudinal Employment Household Dynamics dataset, and Highway Pavement Management System. Our longitudinal analysis explored numbers of K&A pedestrian crashes and shifts in these crashes between hours of the week and months of the year.

Geographic Shifts in K&A Pedestrian Crashes

The results of our geographic analysis showed that, after controlling for characteristics representing pedestrian exposure, census tracts with lower incomes, more unemployed workers, fewer people older than age 64, and greater proportions of Black and Hispanic residents in the baseline period were more likely to experience increases in K&A pedestrian crashes. Tracts with lower population densities, interstate highways or other types of freeways, at least one high-volume roadway (>20,000 AADT), and greater baseline proportions of retail jobs tended to have more K&A pedestrian crashes during 2017-2021 than during 2008-2012.

Temporal Shifts in K&A Pedestrian Crashes

The results of our temporal analysis show that K&A pedestrian crashes tend to be concentrated during the 6 pm to midnight period throughout the week. These nighttime crashes are even more prominent and extend later into the night on Friday and Saturday nights. Between 2008-2012 and 2017-2021, K&A pedestrian crashes increased during nighttime hours throughout the week, with a particularly high percentage increase between midnight and 6 am on weekdays. Considering months of the year, the fourth quarter (October through December) had the highest concentration of K&A pedestrian crashes and experienced proportional increases in K&A pedestrian crashes between 2008-2012 and 2017-2021. Both temporal trends underscore the importance of darkness as a factor associated with the increase in K&A pedestrian crashes during the 2010s.

Insights and Future Research

Our multi-state study provides important insights about how K&A pedestrian crashes shifted during the 2010s, but additional work is needed. Future analysis should gather data from more states, incorporate additional pedestrian exposure data, explore more land use and economic variables that may be associated with geographic or temporal shifts in K&A pedestrian crashes, and attempt to understand differences between fatal and severe injury crashes.

While further work is needed, this study helps increase our understanding of pedestrian injury outcomes over space and over time. We hope that our results help practitioners understand and anticipate neighborhood-level shifts in pedestrian risk and prioritize safety measures to prevent future injuries and fatalities.

Introduction

The US transportation system experienced a tragic shift in safety outcomes during the 2010s, as annual traffic fatalities increased from 32,999 in 2010 to 39,007 in 2020 (+18%) (NHTSA 2023a). Pedestrians were impacted more than any other type of roadway user. After more than three decades of steady decreases (Schneider 2020), pedestrian fatalities in the US increased from 4,302 in 2010 to 6,565 in 2020 (+53%) (NHTSA 2023a). This trend has continued into the 2020s (Petraglia & Macek 2023). The increase in US pedestrian fatalities during the 2010s was not simply due to increases in pedestrian activity or other types of exposure: pedestrian fatalities per population, per walk commuter, per reported pedestrian trip, and per reported vehicle miles traveled all increased in the 2010s (Schneider 2020).

Vexing the safety profession, this increase in pedestrian fatalities occurred during a decade when many local, state, and national organizations established visionary goals to reduce traffic-related deaths to zero (Toward Zero Deaths 2011; Ecola et al. 2018; Vision Zero Network 2019) and adopted "complete streets" policies to better accommodate pedestrians in roadway projects (Smart Growth America 2022). While the US is an international outlier (International Transport Forum 2022; Buehler & Pucher 2023), understanding reasons for these increasingly poor pedestrian safety outcomes is critical for communities in the US—and elsewhere if the US is on the leading edge of a broader trend.

A range of explanations for the pedestrian fatality increase have been hypothesized. Most research suggests multiple factors that have contributed to this change, such as shifts in demographics, road user behavior, roadway design, vehicle design, and activity times and locations. However, most studies have examined pedestrian safety data at the national or state level, potentially obscuring the importance of neighborhood-scale and temporal changes in activity patterns, demographics, and other land use and transportation characteristics.

This longitudinal study helps fill this gap by analyzing shifts in fatal and severe injury (K&A) pedestrian crashes between 2008-2012 and 2017-2021. We focus on two main questions:

1) What neighborhood characteristics had significant associations with increases in K&A pedestrian crashes during the 2010s? We use census tracts to represent neighborhoods. In addition to variables that have been examined in previous studies, we also examine changes in the number and types of jobs at the neighborhood level to represent land use shifts that may be associated with pedestrian safety outcomes.

2) During which time periods did K&A pedestrian crashes increase during the 2010s? In particular, we look for K&A pedestrian crash shifts among hours of the week and months of the year.

Previous Research

The rapid rise in US pedestrian fatalities during the 2010s has received significant attention in national media, including comprehensive summaries of possible reasons for this trend (Badger, Blatt, & Katz 2023). We focus our literature review on longitudinal studies of changes in pedestrian safety outcomes in the US. We also describe the scope of these studies, including their geographic and temporal coverage. Figure 1 provides a conceptual framework for how underlying transportation and land use system factors (e.g., roadway design, land use characteristics, vehicle characteristics), exposure (e.g., pedestrian and motor vehicle activity levels) and behavior (e.g., driver speeding, driver distraction, pedestrian drinking) may influence pedestrian injury outcomes.

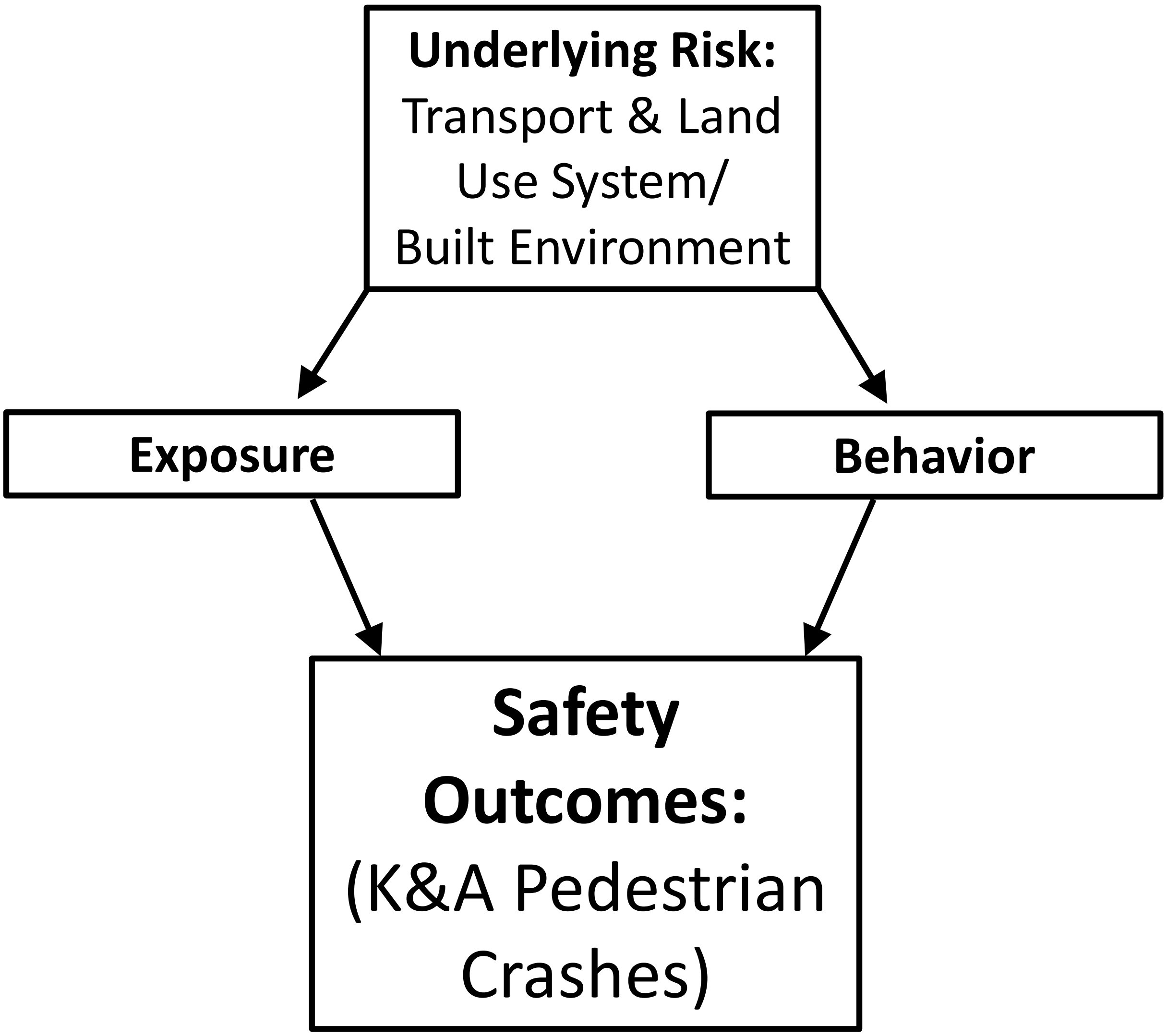

Figure 1. Conceptual Framework for Factors Influencing Fatal and Severe Pedestrian Injuries

Factors Associated with the Increase in Pedestrian Fatalities

Providing a long-term context for US pedestrian fatality trends, Schneider (2020) analyzed pedestrian fatality characteristics from 1977 to 2016. This study found significant decreases in the proportions of child pedestrian fatalities and drunk driver involvement in pedestrian fatalities and significant increases in the proportions of pedestrian fatalities during darkness, involving large vehicles, and on roadways with speed limits of 35 mph and higher or four or more lanes. However, this study covered four decades rather than just the 2010s.

Studies focused on the last 10 to 15 years have found that child pedestrian fatalities continued to decline between 2009 and 2018; most of the increase in pedestrian fatalities was among people aged 18 to 64 (Tefft, Arnold, & Horrey 2021). Pedestrian fatalities increased most markedly during the 2010s on urban arterials (Hu & Cicchino 2018; Sandt et al. 2020; Ferenchak & Abadi 2021; Tefft, Arnold, & Horrey 2021) and at non-intersection locations (Ferenchak & Abadi 2021; Tefft, Arnold, & Horrey 2021). There have been more pedestrian fatalities involving larger vehicles (e.g., sport utility vehicles (SUVs)) in recent years (Hu & Cicchino 2018; Retting 2020; Ferenchak & Abadi 2021), but sedans and smaller cars still contributed the most to the overall increase in pedestrian fatalities in the 2010s (Tefft, Arnold, & Horrey 2021).

Researchers have hypothesized a range of behavior-related changes that may have contributed to increased pedestrian fatalities during the 2010s. These include the introduction of ridehailing (e.g., Uber, Lyft) (Barrios, Hochberg, & Yi 2020), and growth in mobile device ownership and use (particularly among drivers) (Deka & Brown 2016; Retting 2020). Increases in driver speeding (Petraglia & Macek 2023) and driver and pedestrian drug use (Thomas et al. 2022) have also been suggested, but inconsistencies in longitudinal data limit our understanding of how these factors have changed.

The temporal and geographic distribution of pedestrian fatalities also changed during the 2010s, possibly reflecting changes in pedestrian exposure or behaviors due to population and employment shifts since the Great Recession. Research into these shifts is described below.

Geographic Shifts in Pedestrian Injuries

During the 2010s, pedestrian fatalities increased more in urban and suburban areas than rural areas (Hu & Cicchino 2018; Ferenchak & Abadi 2021; Tefft, Arnold, & Horrey 2021). However, studies have suggested that pedestrian activity and, therefore, crashes have shifted away from the core of urbanized areas. Ferenchak and Abadi (2021) hypothesized that the suburbanization of poverty may have led to more pedestrian activity in areas with high-speed, multi-lane roadways. Sanchez Rodriguez and Ferenchak (2023) mapped hot spots showing that fatal pedestrian crashes had shifted from downtown toward suburban locations in eight of nine large cities between the periods of 1999-2002 and 2017-2020. They also found that after 2009, fatal pedestrian crashes increasingly occurred in neighborhoods with high poverty rates, high proportions of non-Hispanic white residents, and low education levels (Sanchez Rodriguez & Ferenchak 2023).

Most longitudinal pedestrian safety studies have focused only on fatalities since these data are available for the entire country through the Fatality Analysis Reporting System (NHTSA 2023b). However, pedestrian fatalities in specific locations are relatively rare, so focusing on fatalities limits the geographic granularity of these studies. Indeed, most present results at the national or state level, which potentially obscure important geographic shifts that may be occurring within metropolitan regions, cities, and specific roadway corridors. One exception is a study by Sanchez Rodriguez and Ferenchak (2023), which examined fatal pedestrian crashes in nine large cities as its unit of analysis. The authors assigned data from the closest census tract(s) to the crash to assess shifts in socioeconomic and built environment characteristics over time. Another study included serious, minor, and possible injuries in addition to pedestrian fatalities (Ferenchak, Gutierrez, & Singleton 2022). However, pedestrian injury data are not often available in consistent formats over time across multiple states (Ferenchak, Gutierrez, & Singleton 2022).

The literature points toward the importance of local economic shifts in changes in the spatial distribution of pedestrian fatalities and injuries. Some traffic safety studies have analyzed the overall number and types of jobs as explanatory variables (Merlin et al. 2020). Mansfield et al. (2018) found that pedestrian fatalities were associated with retail job density; Cai et al. (2016) found a positive relationship between the number of pedestrian crashes and the number of service jobs in Florida. However, we did not find any longitudinal pedestrian safety studies that have examined the association between pedestrian crash shifts over time and employment by sector.

Temporal Shifts in Pedestrian Injuries

Pedestrian fatalities are most common during the first two hours of darkness in the evening and are particularly high on Friday and Saturday evenings and nights (Griswold et al. 2011). Few studies have examined monthly trends in pedestrian safety outcomes, though research shows that the fourth quarter (October through December) typically has the highest numbers of pedestrian fatalities (Schneider 2020).

Relatively little research has explored temporal shifts in pedestrian fatalities or severe injuries. Most of the growth in pedestrian fatalities in the 2010s occurred during darkness rather than daylight, although daylight pedestrian crashes have also been getting more severe (Hu & Cicchino 2018; Retting 2020; Ferenchak & Abadi 2021; Tefft, Arnold, & Horrey 2021; Ferenchak, Gutierrez, & Singleton 2022).

Research Gaps Addressed by this Study

Our study helps fill gaps in the literature by examining both fatal and severe injury pedestrian crashes, analyzing how these crashes have shifted between neighborhoods (including considering the types of jobs within neighborhoods), and analyzing how these crashes have shifted within specific temporal periods.

Methods

We investigated shifts in the geographic and temporal distribution of K&A pedestrian crashes using police-reported crash data from eight states. The first part of this section describes our pedestrian crash data, and the two final parts summarize how we analyzed geographic and temporal shifts in K&A pedestrian crashes.

Pedestrian Crash Data

Our analyses of geographic and temporal shifts in pedestrian injury patterns are based on data from states with the most robust, publicly-available, police-reported crash databases. In most states, injury severity was assessed by law enforcement officers at the scene of the crash. For fatal crashes, a fatal injury could be assigned up to 30 days after the crash had occurred. While some states used slightly different injury scales, all states in this analysis used injury scales with "fatal" and "severe" categories (often referred to as "K" and "A" injuries on the KABCO injury severity scale). Example definitions of "severe" included "Injury (Severe)" (California), "Suspected Serious Injury" (Oregon), and "Incapacitating" (Wisconsin).

Following state crash reporting systems, we defined a pedestrian crash as a collision between a moving motor vehicle and a pedestrian. We analyzed all pedestrian crashes from selected states in which the most severe injury recorded from the crash was either fatal or severe. We used the most severe injury to query the crashes in our study because some states lacked person-specific injury data, and pedestrians almost always experience the most severe injuries of all people involved in a crash. Note that multiple pedestrians were injured in some crashes, but we only counted each crash once because we focused on the occurrence of K&A pedestrian crash incidents rather than on specific pedestrian injuries.

Our geographic analysis used police-reported crash data from California, Colorado, Massachusetts, New York, Oregon, Pennsylvania, Washington, and Wisconsin. After we scanned all 50 states, these were the only eight states that provided geocoded pedestrian crash data with injury severity categories for all years within the two analysis periods (with the minor exception of Washington, where we compared crashes reported during 2010-2014 versus 2017-2021).

There were 30,940 reported K&A pedestrian crashes across the eight states during 2008-2012 and 35,697 during 2017-2021. However, for our geographic analysis, we only analyzed crashes with longitude and latitude data. Therefore, we analyzed 29,826 geocodable K&A pedestrian crashes in the baseline five-year period and 35,137 in the later five-year period (Table 1). Note that Colorado and Wisconsin had relatively low geocoding rates for their K&A pedestrian crashes during 2008-2012, so we controlled for this data shortcoming by using state-specific dummy variables.

For our temporal analysis, we only analyzed crashes with hour of day, day of week, and month of year data. We used data from the same eight states as our geographic analysis plus Minnesota.

Overall, we analyzed 31,059 K&A pedestrian crashes in the baseline period and 36,238 in the later period (Table 2).

Table 1. Fatal and Severe Injury (K&A) Pedestrian Crashes Included in Geographic Analysis

	Total Number of K&A Pedestrian Crashes		Total Number of K&A Pedestrian Crashes Geocoded and Included in Analysis		Percent Geocoded and Included in Analysis	
State	**2008-2012**	**2017-2021**	**2008-2012**	**2017-2021**	**2008-2012**	**2017-2021**
California	10,639	15,235	10,322	14,798	97.02%	97.13%
Colorado	1,481	1,923	1,131	1,922	76.37%	99.95%
Massachusetts	2,018	1,957	1,944	1,920	96.33%	98.11%
New York	10,333	8,512	10,328	8,509	99.95%	99.96%
Oregon	756	980	756	980	100.00%	100.00%
Pennsylvania	2,318	3,139	2,295	3,121	99.01%	99.43%
Washington[1]	1,763	2,358	1,760	2,357	99.83%	99.96%
Wisconsin	1,632	1,593	1,290	1,530	79.04%	96.05%
Total	**30,940**	**35,697**	**29,826**	**35,137**	**96.40%**	**98.43%**

1) We compared 2010-2014 vs. 2017-2021 for Washington because there were fewer than five geocoded pedestrian fatal and severe injury crashes in the Washington dataset from 2008-2009.

Table 2. Fatal and Severe Injury (K&A) Pedestrian Crashes Included in Temporal Analysis

	Total Number of K&A Pedestrian Crashes		Total Number of K&A Pedestrian Crashes with Temporal Data and Included in Analysis		Percent with Temporal Data and Included in Analysis	
State	**2008-2012**	**2017-2021**	**2008-2012**	**2017-2021**	**2008-2012**	**2017-2021**
California	10,639	15,235	10,639	15,235	100.00%	100.00%
Colorado	1,481	1,923	1,481	1,923	100.00%	100.00%
Massachusetts	2,018	1,957	1,542	1,559	76.41%	79.66%
Minnesota	638	916	634	916	99.37%	100.00%
New York	10,333	8,512	10,280	8,512	99.49%	100.00%
Oregon	756	980	752	973	99.47%	99.29%
Pennsylvania	2,318	3,139	2,294	3,132	98.96%	99.78%
Washington[1]	1,805	2,395	1,805	2,395	100.00%	100.00%
Wisconsin	1,632	1,593	1,632	1,593	100.00%	100.00%
Total	**31,620**	**36,650**	**31,059**	**36,238**	**98.23%**	**98.88%**

1) We compared 2008-2012 vs. 2017-2021 for Washington in our temporal analysis because all crashes included time and date information.

Analysis of Geographic Shifts

We analyzed the total number of K&A pedestrian crashes in each census tract for each period, 2008-2012 versus 2017-2021. In urban and suburban communities, census tracts generally represent neighborhood areas. The 2010 US Census Bureau TIGER/Line files include a total of 22,545 census tracts across our eight states. Using 2010 census tract boundaries added some complication because the 2008-2012 data corresponded with 2010 census tract boundaries, but the 2017-2021 data corresponded with 2020 boundaries. For tracts that changed between 2010 and 2020, we used the geographic crosswalk files from the Census Bureau to match 2017-2021 data from 2020 tracts with 2008-2012 data from 2010 tracts and the intersect function in geographic information systems to assign 2017-2021 data to 2010 tract boundaries.

Note that major roadways often form census tract boundaries, so we assigned all fatal and severe injury pedestrian crashes in a given census tract and within 50m of its boundary to that census tract. Therefore, crashes on boundary roadways were counted multiple times, one time in each adjacent tract.

As we cleaned our dataset, we excluded 253 census tracts with limited data, including tracts with no population, no households, no workers, or no jobs in either analysis period. This produced an analysis dataset with 22,292 tracts (Table **3**). There were 459 tracts that had median income data in 2008-2012 but did not have median income data in 2017-2021. Therefore, our models that used 2017-2021 data accounted for 21,833 tracts.

Table 3. 2010 Census Tracts Included in Analysis

State	Total Number of 2010 Tracts
California	7,970
Colorado	1,234
Massachusetts	1,455
New York	4,789
Oregon	825
Pennsylvania	3,186
Washington	1,443
Wisconsin	1,390
Total	**22,292**

Before we started our analysis of geographic shifts, we estimated a negative binomial model to understand how existing census tract characteristics were associated with the raw counts of K&A pedestrian crashes in each census tract in the 2008-2012 baseline period. After establishing this context, we estimated two binomial logit models to examine geographic shifts in K&A pedestrian crashes. These models identify which of the census tract characteristics that were present during the baseline period were significantly associated with census-tract-level increases in K&A pedestrian crashes during the 2010s.

Our geographic shift analysis variables are presented in Table 4. We used two versions of our dependent variable to quantify increases in K&A pedestrian crashes during the 2010s in our binomial logit models. The first, a "simple increase," assigned a value of one to the 42% of tracts (9,375 of 22,292) that experienced more K&A pedestrian crashes during 2017-2021 than during 2008-2012 (and a value of zero, otherwise). This is a straightforward representation of an increasing number of crashes, but it treats all magnitudes of increase the same (e.g., an increase from zero to one crash is the same as an increase from zero to four crashes). The change from zero to one or one to zero crashes in a tract is more likely to reflect random chance than an increase with more magnitude. So we also used a dependent variable called "increase of at least four" to assign a value of one to the 8.6% of tracts (1,922 of 22,292) that experienced at least four more K&A pedestrian crashes during 2017-2021 than during 2008-2012. This version of our dependent variable is less influenced by random chance, but it is more likely to represent tracts that have a higher absolute number of pedestrian crashes (and more baseline pedestrian activity) (e.g., a tract with zero crashes is less likely to increase to four crashes than a tract with ten crashes to increase to fourteen crashes). Models with two versions of our dependent variable help show which explanatory variables have strong relationships with pedestrian crash increases, regardless of which measure is used. Note that we also estimated models to identify which explanatory variables were associated with the 24% of tracts (5,431 of 22,292) that had increases of at least two K&A pedestrian crashes. Their results were consistent with models using the other two versions of the dependent variable, so we do not show them in this report.

Explanatory variables for our geographic analysis came from four sources: the American Community Survey (ACS), the US Census Bureau Longitudinal Employment Household Dynamics (LEHD) Origin-Destination Employment Statistics Workplace Area Characteristics (LODES WAC) dataset, the US Environmental Protection Agency Smart Location Database (SLD), and the Federal Highway Administration Highway Performance Monitoring System (HPMS). Our ACS data include census tract population, socioeconomic characteristics, and journey-to-work travel modes from the 2008-2012 five-year estimates and the 2017-2021 five-year estimates. LODES WAC data included total number of jobs, jobs by sector, and low-wage jobs in 2010 (except for Massachusetts data, which were from 2011) and 2019. We summed the numbers of jobs from census blocks to the census tract level. The job data are proxies for the land use types and activity intensity within each tract. SLD data included general land use and transportation system characteristics. We represented the earlier period with SLD Version 2, which has data from 2010, and the later period with SLD Version 3, which has data from 2018 and 2020. We averaged the variable values from census block groups to the census tract level. Lastly, our HPMS data included roadway functional classification and annualized average daily traffic (AADT) estimates within each census tract. We used the 2016 HPMS dataset because that edition had the most complete AADT data for our eight states, and it was in the middle of our earlier and later analysis periods. We did not have reliable data to represent changes in AADT between the two periods at the census tract level. Instead, to represent traffic volume, we categorized each tract according to its highest-volume arterial or collector roadway AADT in 2016.

Our explanatory variables did not include any direct measures of pedestrian activity levels, or exposure. However, we included total population, total jobs, walk commute mode share, and public transit commute mode share as proxies for exposure to help represent the association between pedestrian activity and numbers of K&A pedestrian crashes in each tract.

Our final set of explanatory variables were dummy variables representing tracts from each of the eight states. We included these variables in our models to control for state-level variation in crash geocoding rates, crash reporting procedures, and injury severity definitions, as well as other state-level differences not captured by other variables.

To avoid multicollinearity in our models, we calculated variance inflation factors (VIFs) for our potential explanatory variables. Based on the VIFs, we excluded the proportion of households with zero vehicles and roadway density. After removing these variables, all variables in our final models had VIFs less than five.

Table 4. 2010 Dependent and Explanatory Variables used in Analysis of Geographic Shift

Part A. Dependent Variables (n = 22,292 tracts)

Variable	Years[1]	Mean	SD	Min	Max
K&A Crashes: Number of fatal (K) and severe (A) injury pedestrian crashes in and within 50m of census tract boundary	2008-2012	2.18	2.85	0.00	36.00
	2017-2021	2.54	3.13	0.00	55.00
Simple Increase: K and A injury pedestrian crashes increased by 1 or more = 1; no change or decrease = 0	2008-2012 vs. 2017-2021	Number and percent in each category. Increase by 1 or more: 9,375 (42%), No change or decrease: 12,917 (58%)			
Increase of at least 4: K and A injury pedestrian crashes increased by 4 or more = 1; increase by 3 or fewer crashes or decrease = 0	2008-2012 vs. 2017-2021	Number and percent in each category. Increase by 4 or more: 1,922 (8.6%), Increase by 3 or fewer crashes or decrease: 20,370 (91.4%)			

1) We compared 2010-2014 vs. 2017-2021 for Washington.

Part B. Explanatory Variables (n = 22,292 tracts)

Exposure Variables[1]	Years	Mean	SD	Min	Max
Total Population (000s): Total population of census tract, in thousands	2008-2012	4.35	1.87	0.02	39.14
	2017-2021	6.70	4.70	0.02	64.36
Total Jobs (000s): Total number of jobs in census tract, in thousands	2010[3]	2.13	5.14	0.00	194.56
	2019	2.52	6.22	0.00	208.68
% Transit: Proportion of workers commuting by public transit	2008-2012	0.10	0.17	0.00	1.00
	2017-2021	0.09	0.15	0.00	0.93
% Walk: Proportion of workers commuting by walking	2008-2012	0.04	0.07	0.00	1.00
	2017-2021	0.04	0.06	0.00	0.72

Socioeconomic Variables[1]	Years	Mean	SD	Min	Max
Population under 18: Number of people < 18 years old	2008-2012	1,021.56	602.67	0.00	11,306.00
	2017-2021	1,454.31	1,174.53	0.00	13,811.00
% Population under 18: Proportion of population < 18 years old	2008-2012	0.23	0.07	0.00	0.66
	2017-2021	0.21	0.06	0.00	0.67
Population over 64: Number of people > 64 years old	2008-2012	561.98	334.67	0.00	6,272.00
	2017-2021	1,081.19	870.84	0.00	11,295.00
% Population over 64: Proportion of population < 64 years old	2008-2012	0.13	0.07	0.00	0.93
	2017-2021	0.16	0.07	0.00	0.92
Asian: Number of people who are Asian alone (non-Hispanic ethnicity)	2008-2012	352.84	620.74	0.00	11,508.00
	2017-2021	616.52	1,179.85	0.00	25,877.00
% Asian: Proportion of population that is Asian alone (non-Hispanic ethnicity)	2008-2012	0.08	0.12	0.00	0.92
	2017-2021	0.09	0.13	0.00	0.91
Black: Number of people who are Black alone (non-Hispanic)	2008-2012	333.82	677.81	0.00	15,530.00
	2017-2021	441.38	809.34	0.00	21,178.00
% Black: Proportion of population that is Black alone (non-Hispanic)	2008-2012	0.09	0.17	0.00	1.00
	2017-2021	0.08	0.15	0.00	0.99
Native American: Number of people who are Native American alone (non-Hispanic)	2008-2012	18.22	69.73	0.00	2,498.00
	2017-2021	26.54	115.65	0.00	3,319.00
% Native American: Proportion of population that is Native American alone (non-Hispanic)	2008-2012	0.01	0.03	0.00	0.88
	2017-2021	0.00	0.02	0.00	0.77
White: Number of people who are White alone (non-Hispanic)	2008-2012	2,574.03	1,756.83	0.00	23,285.00
	2017-2021	3,846.77	3,649.62	0.00	51,102.00
% White: Proportion of population that is White alone (non-Hispanic)	2008-2012	0.60	0.32	0.00	1.00
	2017-2021	0.56	0.30	0.00	1.00
Other Race: Number of people who are other race alone, including Native Hawaiian/Pacific Islander (non-Hispanic)	2008-2012	21.08	58.36	0.00	1,300.00
	2017-2021	43.90	90.97	0.00	1,563.00
% Other Race: Proportion of population that is other race alone, including Native Hawaiian/Pacific Islander (non-Hispanic)	2008-2012	0.01	0.01	0.00	0.38
	2017-2021	0.01	0.02	0.00	0.44
Hispanic: Number of people who are Hispanic ethnicity	2008-2012	955.98	1,290.31	0.00	13,784.00
	2017-2021	1,486.90	1,965.37	0.00	25,650.00

% Hispanic: Proportion of population that is Hispanic ethnicity	2008-2012	0.21	0.24	0.00	1.00
	2017-2021	0.23	0.24	0.00	1.00
Median Income (0000s): Median household income, in ten-thousands of dollars	2008-2012	6.24	2.94	0.25	25.00
	2017-2021	13.81	11.57	0.25	151.82
Zero Vehicles: Number of households with 0 vehicles	2008-2012	202.78	355.23	0.00	6,254.00
	2017-2021	254.32	404.51	0.00	6,736.00
% Zero Vehicles: Proportion of households with 0 vehicles	2008-2012	0.13	0.17	0.00	1.00
	2017-2021	0.12	0.17	0.00	1.00
Labor Force: Number of people in the labor force	2008-2012	2,236.56	1,006.36	1.00	13,544.00
	2017-2021	3,444.73	2,450.36	5.00	36,748.00
Unemployed: Number of people in labor force who are unemployed	2008-2012	212.83	137.88	0.00	2,132.00
	2017-2021	194.69	163.98	0.00	2,923.00
% Unemployed: Proportion of people in labor force who are unemployed	2008-2012	0.10	0.05	0.00	0.72
	2017-2021	0.06	0.04	0.00	0.48
Workers: Number of workers	2008-2012	1,985.18	926.60	1.00	22,542.00
	2017-2021	3,195.55	2,323.92	5.00	33,263.00
Home: Number of workers working from home	2008-2012	93.03	90.51	0.00	3,523.00
	2017-2021	357.10	386.00	0.00	5,330.00
% Home: Proportion of workers working from home	2008-2012	0.05	0.04	0.00	1.00
	2017-2021	0.11	0.07	0.00	0.60
Employment Variables[2]	**Years**	**Mean**	**SD**	**Min**	**Max**
Retail: Number of retail jobs (CNS07)	2010[3]	208.55	435.04	0.00	8,988.00
	2019	223.23	453.82	0.00	8,657.00
% Retail: Number of total jobs that are retail jobs (CNS07)	2010[3]	0.12	0.12	0.00	1.00
	2019	0.11	0.11	0.00	1.00
Office: Number of office jobs (CNS09+CNS10+CNS11+CNS12+CNS13+CNS20)	2010[3]	459.53	2,246.42	0.00	96,427.00
	2019	535.02	2,722.81	0.00	113,432.00
% Office: Proportion of total jobs that are office jobs (CNS09+CNS10+CNS11+CNS12+CNS13+CNS20)	2010[3]	0.14	0.13	0.00	1.00
	2019	0.14	0.13	0.00	1.00
Industrial: Number of industrial jobs (CNS01+CNS02+CNS03+CNS04+CNS05+CNS06+CNS08)	2010[3]	450.35	1,350.95	0.00	51,889.00
	2019	534.12	1,641.08	0.00	53,151.00

% Industrial: Proportion of total jobs that are industrial jobs (CNS01+CNS02+CNS03+CNS04+CNS05+CNS06+CNS08)	2010[3]	0.21	0.21	0.00	1.00
	2019	0.21	0.20	0.00	1.00
Service: Number of service jobs (CNS12+CNS14+CNS15+CNS16+CNS19)	2010[3]	808.49	2,242.03	0.00	187,175.00
	2019	972.59	2,391.74	0.00	69,607.00
% Service: Proportion of total jobs that are service jobs (CNS12+CNS14+CNS15+CNS16+CNS19)	2010[3]	0.42	0.22	0.00	1.00
	2019	0.43	0.22	0.00	1.00
Entertainment: Number of entertainment jobs (CNS17+CNS18)	2010[3]	198.86	459.23	0.00	12,838.00
	2019	251.83	573.28	0.00	15,685.00
% Entertainment: Proportion of total jobs that are entertainment jobs (CNS17+CNS18)	2010[3]	0.11	0.11	0.00	1.00
	2019	0.12	0.11	0.00	0.99
Low-Wage: Number of low-wage workers (<$1250/month) (CE01)	2010[3]	482.90	843.40	0.00	30,360.00
	2019	466.92	938.26	0.00	61,008.00
% Low-Wage: Proportion of total jobs that are low-wage (<$1250/month) (CE01)	2010[3]	0.31	0.12	0.00	1.00
	2019	0.24	0.09	0.00	0.86
Land Use and Transportation System Variables[4]	**Years**	**Mean**	**SD**	**Min**	**Max**
Residential Density: Gross residential density (HU/acre) on unprotected land (total land area that is not protected from development…i.e., not a park, natural area or conservation area) (D1a)	2010	7.39	14.63	0.00	312.64
	2018/2020	7.57	14.66	0.00	250.36
Population Density: Gross population density (people/acre) on unprotected land (D1b)	2010	17.88	31.76	0.00	623.10
	2018/2020	18.41	31.89	0.00	410.25
Employment Density: Gross employment density (jobs/acre) on unprotected land (D1c)	2010	6.47	39.55	0.00	1,389.11
	2018/2020	7.42	45.29	0.00	1,693.03
Employment Mix: 5-tier employment entropy (denominator set to observed employment types in the CBG) (D2b_E5Mix)	2010	0.52	0.23	0.00	0.99
	2018/2020	0.65	0.15	0.00	1.00
Road Density: Road network density (miles of roadway per square mile of total land area) (D3a)	2010	18.89	211.94	0.17	31,236.70
	2018/2020	19.12	10.42	0.18	92.68
Intersection Density: Street intersection density (intersections per square mile of total land area) (D3b)	2010	79.00	61.67	0.00	780.87
	2018/2020	98.75	80.55	0.00	1,422.45
Transit Nearby: The nearest transit stop is less than ¾ mile (1207 m) away from the census tract centroid (1 = yes; 0 = no)	2010	0.46	0.50	0.00	1.00
	2018/2020	0.53	0.50	0.00	1.00

Interstate: Census tract contains an interstate highway (1 = yes; 0 = no)	2016	0.22	0.41	0.00	1.00
Other Freeway/Expressway: Census tract contains a non-interstate freeway or expressway (1 = yes; 0 = no)	2016	0.22	0.42	0.00	1.00
Arterial/Collector AADT Variables[5]	**Years**	**Mean**	**SD**	**Min**	**Max**
Maximum AADT <20K: The highest-volume arterial or collector roadway in the census tract has an AADT of 1 to 20,000 or the tract does not have an arterial or collector roadway (1 = yes; 0 = no)	2016	0.42	0.49	0.00	1.00
Maximum AADT 20-40K: The highest-volume arterial or collector roadway in the census tract has an AADT of 20,001 to 40,000 (1 = yes; 0 = no)	2016	0.43	0.49	0.00	1.00
Maximum AADT 40-60K: The highest-volume arterial or collector roadway in the census tract has an AADT of 40,001 to 60,000 (1 = yes; 0 = no)	2016	0.13	0.34	0.00	1.00
Maximum AADT >60K: The highest-volume arterial or collector roadway in the census tract has an AADT of over 60,000 (1 = yes; 0 = no)	2016	0.03	0.16	0.00	1.00
State Dummy Variables	**Years**	**Mean**	**SD**	**Min**	**Max**
California: California census tract (1 = yes; 0 = no)	2010	0.36	0.48	0.00	1.00
Colorado: Colorado census tract (1 = yes; 0 = no)	2010	0.06	0.23	0.00	1.00
Massachusetts: Massachusetts census tract (1 = yes; 0 = no)	2010	0.07	0.25	0.00	1.00
New York: New York census tract (1 = yes; 0 = no)	2010	0.21	0.41	0.00	1.00
Oregon: Oregon census tract (1 = yes; 0 = no)	2010	0.04	0.19	0.00	1.00
Pennsylvania: Pennsylvania census tract (1 = yes; 0 = no)	2010	0.14	0.35	0.00	1.00
Washington: Washington census tract (1 = yes; 0 = no)	2010	0.06	0.25	0.00	1.00
Wisconsin: Wisconsin census tract (1 = yes; 0 = no)	2010	0.06	0.24	0.00	1.00

1) Exposure and socioeconomic variables data source (except for Total Jobs): US Census Bureau American Community Survey 5-year estimates.
2) Job variables data source: US Census Bureau Longitudinal Employment Household Dynamics LODES WAC v8.0.
3) The LODES WAC employment data for Massachusetts are from 2011 and 2019.
4) Land use and transportation system variables data sources: US Environmental Protection Agency Smart Location Database v2 and v3 (for land use and road and intersection density variables); Federal Highway Administration Highway Performance Monitoring System (for functional classification variables).
5) Arterial/collector AADT variables data source: Federal Highway Administration Highway Performance Monitoring System.

Analysis of Temporal Shifts

We analyzed the total number of K&A pedestrian crashes during each temporal analysis period for our two study periods, 2008-2012 versus 2017-2021. To establish a baseline for the temporal distribution of K&A pedestrian crashes, we divided all K&A crashes during the 2008-2012 analysis period into 56 three-hour temporal periods across the full 168-hour week. We also divided these K&A crashes into each of the 12 months (each month was a temporal period).

To analyze crash shifts within the week, we measured changes between the 2008-2012 and 2017-2021 study periods in two ways. First, we calculated the percentage change in numbers of K&A crashes per temporal period. Second, we calculated the percentage change in proportions of K&A pedestrian crashes within each temporal period. We conducted our analyses for all nine states combined and for each state separately. To detect statistically-significant differences between K&A pedestrian crashes during particular time periods in 2008-2012 versus 2017-2021, we used two-tailed Z-tests of differences in proportions.

Results

This section describes the results of our analyses of geographic and temporal shifts in K&A pedestrian crashes.

Geographic Shifts in K&A Pedestrian Crashes

We used statistical modeling to examine socioeconomic and land use factors associated with K&A pedestrian crashes during the 2008-2012 baseline period and increases in these pedestrian crashes between 2008-2012 and 2017-2021 across 22,292 census tracts.

Neighborhood Characteristics Associated with Pedestrian Crashes at Baseline

Our initial negative binomial model provided a useful background for understanding the number of K&A pedestrian crashes per tract during 2008-2012 (Table 5). As expected, our exposure proxy variables were positively associated with these crashes. All else equal, adding one thousand more people to a tract would increase K&A pedestrian crashes by 12%. Total tract employment, percentage of walk commuters, and percentage of transit commuters were also positively associated with the number of K&A pedestrian crashes. These variables are likely to represent higher overall levels of pedestrian activity.

After controlling for these forms of exposure, the proportion of people in the tract who were Black or Hispanic and the proportion of labor force who were unemployed were positively associated with K&A pedestrian crashes while median household income was negatively associated with these crashes. K&A pedestrian crashes were also positively associated with the proportion of jobs that were in the retail and entertainment sectors but negatively associated with low-wage jobs. The prominence of retail jobs in our model is similar to previous studies that have analyzed pedestrian fatalities per census tract in the US (Mansfield 2018). Finally, broad measures of land use and transportation system characteristics were also significant: tracts with greater job density, greater intersection density, greater employment mix, an interstate highway, and at least one high-volume arterial or collector roadway (AADT >20,000), and tracts closer to transit stops had more K&A pedestrian crashes. These base-period results are similar to previous studies. Though Cai et al. (2016) suggested a significant positive relationship between population density and the overall number of pedestrian crashes, our model did not find a similar relationship between the population density and the number of K&A pedestrian crashes.

Table 5. Negative Binomial Model of K&A Pedestrian Crashes per Census Tract, 2008-2012

	Exp(B)[1]	Sig.[2]
Constant	0.438	***
Socioeconomic Variables[3]		
Total Population (000s)	1.115	***
% Population Under 18	0.899	
% Population Over 64	0.914	
% Asian	1.046	
% Black	1.427	***
% Native American	0.957	
% Other Race	3.657	*
% Hispanic	1.580	***
Median Income (0000s)	0.927	***
% Unemployed	3.406	***
% Transit	3.071	***
% Walk	2.387	***
Job Variables		
Total Jobs (000s)	1.019	***
% Retail	1.738	***
% Industrial	0.914	
% Service	1.245	**
% Entertainment	1.807	***
% Low-Wage	0.604	***
Land Use and Transportation Variables		
Population Density	1.000	
Employment Density	1.001	***
Employment Mix	1.725	***
Intersection Density	1.002	***
Transit Nearby	1.215	***
Interstate	1.069	**
Other Freeway/Expressway	1.042	
Arterial/Collector AADT Variables **(base = Maximum AADT <20K)**		
Maximum AADT 20-40K	1.458	***
Maximum AADT 40-60K	1.891	***
Maximum AADT >60K	1.980	***
State Dummy Variables **(base = California)**		
Colorado	0.903	*
Massachusetts	1.097	*
New York	1.647	***
Oregon	0.754	***
Pennsylvania	0.672	***
Washington	1.079	
Wisconsin	1.039	

	Exp(B)[1]	Sig.[2]
Model Fit		
Log-Likelihood	-39,784	
AIC	79,642	
BIC	79,930	

1) Exp(B) presents the exponentiated form of the coefficient estimate.
2) Sig. indicates the statistical significance of the coefficient estimate: * is $p < 0.05$, ** is $p < 0.01$, *** is $p < 0.001$.
3) Race and ethnicity variables are relative to the base of % white.

Neighborhood Characteristics Associated with Increases in Pedestrian Crashes

Our binomial logit models provided important insights about how increases in K&A pedestrian crashes between 2008-2012 and 2017-2021 were associated with the characteristics of census tracts. Models 2010A and 2010B use variables representing tract characteristics during the 2008-2012 baseline period, and Models 2019A and 2019B include variables representing characteristics during the 2017-2021 later period (Table 6). Both pairs of models generally show similar results.

Importantly, we included the following pedestrian exposure proxy variables as controls in each model: change in total population, change in total jobs, change in walk mode share, and change in transit mode share between 2008-2012 and 2017-2021. Increases in tract population and jobs had statistically-significant associations with increases in K&A pedestrian crashes in all four models.

After controlling for changes in exposure, tracts with the following socioeconomic characteristics in the baseline period were more likely to experience increases in K&A pedestrian crashes during the 2010s: greater proportions of Black and Hispanic residents, smaller proportions of people over age 64, lower median household incomes, and greater proportions of unemployed labor force. The odds ratios in each model show the relationships between the explanatory variables and K&A pedestrian crash increases. For example, comparing 2017-2021 later period to 2008-2012 baseline period, tracts with all Black residents in the baseline period were 1.6 times more likely than tracts with no Black residents to have at least one more K&A pedestrian crash (Model 2010A) and 4.2 times more likely to have at least four more K&A pedestrian crashes (Model 2010B). Tracts with all unemployed residents in the baseline period were 3.2 times more likely than tracts with no unemployed residents to have a simple increase in K&A pedestrian crashes (Model 2010A) and 7.7 times more likely to have an increase of four or more K&A pedestrian crashes (Model 2010B). The models based on 2017-2021 data showed even higher likelihoods that tracts with these characteristics experienced increases in K&A pedestrian crashes during the 2010s (Models 2019A and 2019B).

Baseline employment characteristics were also associated with pedestrian crash increases. Tracts with higher proportions of retail jobs in 2010 were significantly more likely to experience increases in K&A pedestrian crashes during the following decade. Tracts with all retail jobs were 2.2 times more likely than tracts with no retail jobs to have at least one more K&A pedestrian crashes in 2017-2021 than in 2008-2012 (Model 2010A) and 2.5 times more likely to have at least four more K&A pedestrian crashes between these time periods (Model 2010B). Tracts with more low-wage jobs were negatively associated with increases in K&A pedestrian crashes.

Finally, tracts with the following baseline land use and transportation system characteristics were significantly more likely to experience increases in K&A pedestrian crashes between the two study periods: lower population density, greater employment mix, higher intersection density, contained an interstate highway, contained another type of freeway, contained at least one high-volume arterial or collector roadway (>20,000 AADT), and transit was located nearby. The population density finding is worth noting. Controlling for increases in overall tract population, lower-density areas (possibly suburbs) were more likely than higher-density areas to experience increases in K&A pedestrian crashes during the 2010s. Note that the same roadway functional classification and maximum AADT variables from 2016 were used in both the baseline and later study period models.

Table 6. Binomial Logit Models of Increases in Fatal and Severe Injury Pedestrian Crashes per Census Tract, 2008-2012 to 2017-2021

	Tract Characteristics in Baseline Period Associated with Increases in K&A Pedestrian Crashes[1]				Tract Characteristics in Later Period Associated with Increases in K&A Pedestrian Crashes[1]			
	Model 2010A: Simple Increase		**Model 2010B: Increase of at least 4**		**Model 2019A: Simple Increase**		**Model 2019B: Increase of at least 4**	
	Odds Ratio[2]	**Sig.[3]**	**Odds Ratio[2]**	**Sig.[3]**	**Odds Ratio[2]**	**Sig.[3]**	**Odds Ratio[2]**	**Sig.[3]**
Constant	0.464	***	0.035	***	0.487	***	0.024	***
Exposure Variables[4]								
Ch. Total Population (000s)	1.010	**	1.024	***	1.031	***	1.059	***
Ch. Total Jobs (000s)	1.023	**	1.029	***	1.027	***	1.043	***
Ch. % Transit	1.246		2.368	*	0.928		0.875	
Ch. % Walk	0.874		0.663		0.618		0.200	**
Socioeconomic Variables[5]								
% Population under 18	1.591		1.491		1.096		0.902	
% Population over 64	0.593	*	0.259	**	0.331	***	0.111	***
% Asian	1.001		0.992		0.872		0.846	***
% Black	1.620	***	4.189	***	1.698	***	6.088	***
% Native American	0.612		1.973		1.871		5.117	
% Other Race	2.599		2.194		0.545		3.123	
% Hispanic	1.417	***	1.908	***	1.713		3.397	***
Median Income (0000s)	0.943	***	0.832	***	0.988	***	0.977	***
% Unemployed	3.219	***	7.718	***	4.625	***	58.494	***
Job Variables								
% Retail	2.154	***	2.491	**	2.902	***	3.224	***
% Industrial	1.255		1.343		1.208		1.215	
% Service	1.474	**	1.525		1.397	*	1.089	
% Entertainment	1.449	*	1.350		1.481	*	1.478	
% Low-Wage	0.613	***	0.548	*	0.521	***	0.465	*
Land Use and Transportation Variables								
Population Density	0.994	***	0.996	**	0.994	***	0.997	**
Employment Density	0.999		1.001		0.999		1.001	
Employment Mix	1.455	***	2.874	***	1.097		1.335	
Intersection Density	1.001	***	1.002	***	1.001	***	1.001	***
Transit Nearby	1.157	***	1.485	***	1.124	**	1.421	***
Interstate	1.228	***	1.453	***	1.252	***	1.498	***
Other Fwy/Expressway	1.207	***	1.267	***	1.196	***	1.266	**

	Tract Characteristics in Baseline Period Associated with Increases in K&A Pedestrian Crashes[1]				Tract Characteristics in Later Period Associated with Increases in K&A Pedestrian Crashes[1]			
	Model 2010A: Simple Increase		Model 2010B: Increase of at least 4		Model 2019A: Simple Increase		Model 2019B: Increase of at least 4	
	Odds Ratio[2]	Sig.[3]	Odds Ratio[2]	Sig.[3]	Odds Ratio[2]	Sig.[3]	Odds Ratio[2]	Sig.[3]
Arterial/Collector AADT[6]								
Maximum AADT 20-40K	1.395	***	2.261	***	1.361	***	2.171	***
Maximum AADT 40-60K	1.385	***	2.489	***	1.342	***	2.380	***
Maximum AADT >60K	1.418	***	2.934	***	1.330	**	2.662	***
State (base = California)								
Colorado	1.076		0.999		1.096		1.188	
Massachusetts	0.654	***	0.394	***	0.715	***	0.505	***
New York	0.606	***	0.530	***	0.615	***	0.506	***
Oregon	0.716	***	0.453	***	0.818	*	0.668	*
Pennsylvania	0.739	***	0.361	***	0.801	***	0.443	***
Washington	0.861	*	0.929		0.892		1.107	
Wisconsin	0.722	***	0.368	***	0.795	**	0.508	***
Model Fit								
-2 Log-Likelihood	28921		11161		28386		11077	
Cox & Snell R Square	0.062		0.083		0.058		0.074	
Nagelkerke R Square	0.083		0.187		0.079		0.168	

1) Models 2010A and 2010B are based on n = 22,292. Models 2019A and 2019B exclude 459 tracts that lack median income data, so they are based on n = 21,833. The state dummy, interstate, other freeway/expressway, and AADT variables have the same values in the baseline and later period models.
2) Odds ratio presents the exponentiated form of the coefficient estimate. Odds ratios less than one indicate a negative relationship, and odds ratios more than one indicate a positive relationship with increases in K&A pedestrian crashes.
3) Sig. indicates the statistical significance of the coefficient estimate: * is p < 0.05, ** is p < 0.01, *** is p < 0.001.
4) The exposure variables represent absolute changes in each tract characteristic, calculated by subtracting the 2008-2012 variable value from the 2017-2021 variable value.
5) Race and ethnicity variables are relative to the base of % white.
6) Arterial/Collector maximum AADT variables are relative to the base of maximum AADT <20K.

Implications of Geographic Shifts in K&A Pedestrian Crashes

The results from our models paint a picture of how neighborhood-level characteristics were associated with geographic shifts in K&A pedestrian crashes during the 2010s.

First, exposure is a key factor: neighborhood variables that are likely to represent more pedestrian activity had more growth in K&A pedestrian crashes between 2008-2012 and 2017-2021. Census tracts that experienced growth in population and jobs during the 2010s were more likely to have increases in K&A pedestrian crashes over the decade. Interestingly, changes in the proportions of walk and transit commuters did not show consistent significant relationships with K&A pedestrian crash increases across all models. This could be due to the journey-to-work data not adequately capturing exposure to K&A pedestrian crashes, many of which occur at night. Further, while only one walk commute mode share coefficient was significant (Model 2019B), all models had odds ratios less than one, hinting that increases in walk commute mode shares may be negatively associated with increases in K&A pedestrian crashes. Future neighborhood-level pedestrian crash shift studies should explore this possible "safety in numbers" effect (Jacobsen 2015), to determine if shifting commute modes away from automobiles and toward other modes may reduce the risk of K&A pedestrian crashes for each individual walk commuter.

Second, growth in K&A pedestrian crashes was not spread evenly across population groups. The burden of K&A pedestrian crashes was higher in 2010 in neighborhoods with low socioeconomic status (lower median household incomes; more unemployed workers). Moreover, K&A pedestrian crashes also disproportionately impacted tracts with greater proportions of Black and Hispanic residents in 2010. These disparities worsened during the following decade, as census tracts with these characteristics were significantly more likely than others to experience increases in K&A pedestrian crashes during the 2010s.

Third, job types (and land use types associated with these jobs) were associated with increases in K&A pedestrian crashes. After controlling for total population and jobs, census tracts with greater proportions of retail jobs were more likely to experience increases in K&A pedestrian crashes than tracts with other types of jobs. Retail districts might experience more pedestrian crashes than other areas because they have particularly high levels of pedestrian activity, riskier pedestrian and driver behaviors, or some combination of both of these characteristics (Schneider et al. 2010; Mansfield et al. 2018). Across our eight study states, retail districts experienced even more significant increases in K&A pedestrian crashes than other types of areas. Cai et al. (2016) suggested a positive relationship between the number of pedestrian crashes and the proportion of service jobs. However, we did not find consistent evidence that shifts in the proportions of any other specific job types during the 2010s were associated with changes in K&A pedestrian crashes over this time, but we saw that tracts with a greater proportion of low-wage jobs did not experience increases in K&A pedestrian crashes.

Fourth, our results provide further evidence that high-volume, at-grade arterial roadways are associated with pedestrian safety problems. Unfortunately, this problem worsened during the

2010s. Census tracts that had at least one roadway with more than 20,000 AADT were associated with higher baseline numbers of K&A pedestrian crashes in 2010 and were also associated with increases in K&A pedestrian crashes during the 2010s. Roadways with more than 20,000 AADT often have combinations of high speeds and multiple through and turning lanes that create conditions with a high level of pedestrian risk.

Other countries have improved pedestrian safety over the last 40 years, including during the 2010s, so the US should look internationally for policy strategies to address these trends. Actions that could be taken in neighborhoods that have experienced increases in K&A pedestrian crashes include: close sidewalk gaps, reduce motor vehicle lanes, slow motor vehicle speeds, increase development density and mix to reduce trip distances, reduce automobile parking supply and increase parking prices, and install speed safety cameras and red-light safety cameras (Buehler & Pucher 2021; Buehler & Pucher 2023).

Temporal Shifts in K&A Pedestrian Crashes

We used descriptive analyses to compare how the distribution of K&A pedestrian crashes shifted among hours of the week and months of the year between our 2008-2012 baseline period and 2017-2021 later period. Some of these temporal shifts varied by state.

Shifts in K&A Pedestrian Crashes by Hour of Week

Across all nine states, in both 2008-2012 and 2017-2021, the largest proportions of weekly K&A pedestrian crashes occurred between 3 pm and 9 pm on most days of the week as well as between 9 pm and midnight on Friday and Saturday nights (Figure 2). Comparing 2008-2012 with 2017-2021 showed that the 6 pm to midnight time period experienced increases on every day of the week (many of these increases were statistically significant). Notably, the greatest proportional increases were on weekday late nights and very early mornings, particularly between 3 am and 6 am (most of these increases were also statistically significant). The steep increase in very early morning pedestrian crashes may indicate more pedestrian or driving activity or possibly more dangerous behaviors during these hours. They could also be associated with commuting to and from nighttime service or third-shift jobs, but more research is needed to understand the cause of these shifts.

Analyzing each state separately showed minor differences in significant K&A pedestrian crash shifts throughout the week between 2008-2012 and 2017-2021 (Figure 3). California had a similar pattern to the overall nine-state trend toward more weekday, late-night crashes. In fact, California likely helps establish the national trend because it accounts for more than one-third of the nine-state sample. States with smaller populations and K&A pedestrian crashes had fewer time periods with statistically-significant differences, though most of the periods that are significant follow the general national pattern in shifting times of K&A pedestrian crashes. Further research is needed to identify and understand possible reasons behind geographic differences in temporal crash patterns.

Number of Crashes

2008-2012

	12a-3a	3a-6a	6a-9a	9a-12p	12p-3p	3p-6p	6p-9p	9p-12a	
Monday	185	159	534	392	538	914	952	511	4185
Tuesday	171	166	564	405	512	974	974	543	4309
Wednesday	188	148	583	386	552	988	1064	571	4480
Thursday	213	155	579	406	545	917	1023	555	4393
Friday	296	185	547	411	596	981	1172	927	5115
Saturday	644	351	220	380	479	658	1055	956	4743
Sunday	803	323	141	227	363	553	844	580	3834
Total	2500	1487	3168	2607	3585	5985	7084	4643	31059

2017-2021

	12a-3a	3a-6a	6a-9a	9a-12p	12p-3p	3p-6p	6p-9p	9p-12a	Total
Monday	342	304	568	432	495	970	1179	710	5000
Tuesday	268	298	623	398	569	912	1275	804	5147
Wednesday	250	329	565	434	588	849	1262	819	5096
Thursday	311	325	582	438	561	906	1310	917	5350
Friday	359	340	583	448	612	1026	1500	1164	6032
Saturday	643	317	275	374	452	693	1202	1174	5130
Sunday	827	363	182	260	379	560	1082	830	4483
Total	3000	2276	3378	2784	3656	5916	8810	6418	36238

Change in Number of Crashes

Absolute Increase from 2008-2012 to 2017-2021

	12a-3a	3a-6a	6a-9a	9a-12p	12p-3p	3p-6p	6p-9p	9p-12a	Total
Monday	157	145	34	40	-43	56	227	199	815
Tuesday	97	132	59	-7	57	-62	301	261	838
Wednesday	62	181	-18	48	36	-139	198	248	616
Thursday	98	170	3	32	16	-11	287	362	957
Friday	63	155	36	37	16	45	328	237	917
Saturday	-1	-34	55	-6	-27	35	147	218	387
Sunday	24	40	41	33	16	7	238	250	649
Total	500	789	210	177	71	-69	1726	1775	5179

Percentage Increase from 2008-2012 to 2017-2021

	12a-3a	3a-6a	6a-9a	9a-12p	12p-3p	3p-6p	6p-9p	9p-12a	Total
Monday	84.9%	91.2%	6.4%	10.2%	-8.0%	6.1%	23.8%	38.9%	19.5%
Tuesday	56.7%	79.5%	10.5%	-1.7%	11.1%	-6.4%	30.9%	48.1%	19.4%
Wednesday	33.0%	122.3%	-3.1%	12.4%	6.5%	-14.1%	18.6%	43.4%	13.8%
Thursday	46.0%	109.7%	0.5%	7.9%	2.9%	-1.2%	28.1%	65.2%	21.8%
Friday	21.3%	83.8%	6.6%	9.0%	2.7%	4.6%	28.0%	25.6%	17.9%
Saturday	-0.2%	-9.7%	25.0%	-1.6%	-5.6%	5.3%	13.9%	22.8%	8.2%
Sunday	3.0%	12.4%	29.1%	14.5%	4.4%	1.3%	28.2%	43.1%	16.9%
Total	20.0%	53.1%	6.6%	6.8%	2.0%	-1.2%	24.4%	38.2%	16.7%

Significance Test for Change in Proportions of Crashes

2008-2012 vs 2017-2021

	12a-3a	3a-6a	6a-9a	9a-12p	12p-3p	3p-6p	6p-9p	9p-12a
Monday	+++	+++	NS	NS	---	-	NS	++
Tuesday	++	+++	NS	-	NS	---	++	+++
Wednesday	NS	+++	--	NS	NS	---	NS	+++
Thursday	+	+++	-	NS	-	---	+	+++
Friday	NS	+++	NS	NS	-	-	+	NS
Saturday	--	---	NS	-	--	NS	NS	NS
Sunday	-	NS	NS	NS	NS	-	+	+++

Results of a Z-test of the difference in proportions:

Positive signs indicate that the proportion of weekly crashes during the temporal period was significantly higher in 2017-2021 than in 2008-2012 (+++ indicates 99.9% confidence; ++ indicates 99% confidence, + indicates 95% confidence).

Negative signs indicate that the proportion of weekly crashes during the temporal period was significantly lower in 2017-2021 than in 2008-2012 (--- indicates 99.9% confidence; -- indicates 99% confidence, - indicates 95% confidence).

NS indicates no significant difference.

Figure 2. Fatal and Severe Pedestrian Crashes by Hour of Week, 2008-2012 and 2017-2021

Significance Test for Change in Proportions of Crashes: 2008-2012 vs 2017-2021

Results of a Z-test of the difference in proportions:

Positive signs indicate that the proportion of weekly crashes during the temporal period was significantly higher in 2017-2021 than in 2008-2012 (+++ indicates 99.9% confidence; ++ indicates 99% confidence, + indicates 95% confidence).

Negative signs indicate that the proportion of weekly crashes during the temporal period was significantly lower in 2017-2021 than in 2008-2012 (--- indicates 99.9% confidence; -- indicates 99% confidence, - indicates 95% confidence).

NS indicates no significant difference.

California

	12a-3a	3a-6a	6a-9a	9a-12p	12p-3p	3p-6p	6p-9p	9p-12a
Monday	+++	+++	NS	NS	--	NS	NS	+
Tuesday	+	++	NS	NS	--	--	NS	+++
Wednesday	++	+++	---	---	--	---	NS	+++
Thursday	+++	+++	-	NS	NS	---	+	+++
Friday	NS	+++	-	NS	-	--	NS	++
Saturday	NS	NS	NS	NS	--	--	NS	NS
Sunday	NS	NS	NS	NS	NS	-	NS	+

Colorado

	12a-3a	3a-6a	6a-9a	9a-12p	12p-3p	3p-6p	6p-9p	9p-12a
Monday	NS	NS	--	NS	NS	NS	NS	NS
Tuesday	NS	NS	-	NS	NS	--	NS	NS
Wednesday	NS	NS	NS	NS	NS	--	NS	NS
Thursday	NS	NS	NS	NS	NS	NS	NS	NS
Friday	NS	NS	+	NS	NS	-	NS	NS
Saturday	NS	NS	NS	NS	NS	NS	NS	NS
Sunday	NS	NS	NS	NS	NS	NS	++	NS

Massachusetts

	12a-3a	3a-6a	6a-9a	9a-12p	12p-3p	3p-6p	6p-9p	9p-12a
Monday	NS	NS	NS	NS	NS	NS	NS	+
Tuesday	NS	NS	NS	NS	NS	NS	NS	NS
Wednesday	NS	NS	NS	NS	NS	NS	+	NS
Thursday	NS	NS	NS	+	NS	NS	NS	NS
Friday	NS	NS	NS	NS	NS	NS	NS	NS
Saturday	NS	NS	-	NS	NS	NS	-	NS
Sunday	-	NS	NS	NS	NS	NS	NS	NS

Minnesota

	12a-3a	3a-6a	6a-9a	9a-12p	12p-3p	3p-6p	6p-9p	9p-12a
Monday	NS	+	NS	NS	NS	NS	NS	NS
Tuesday	NS	NS	NS	NS	NS	NS	NS	NS
Wednesday	NS	NS	NS	NS	NS	NS	NS	NS
Thursday	NS	NS	NS	NS	NS	NS	NS	NS
Friday	NS	NS	NS	NS	NS	NS	NS	NS
Saturday	-	-	NS	NS	NS	NS	NS	NS
Sunday	-	NS	NS	NS	NS	NS	NS	NS

New York

	12a-3a	3a-6a	6a-9a	9a-12p	12p-3p	3p-6p	6p-9p	9p-12a
Monday	+++	NS	NS	NS	NS	NS	NS	NS
Tuesday	NS	NS	NS	-	NS	NS	NS	NS
Wednesday	NS	NS	NS	++	NS	NS	NS	NS
Thursday	NS	NS	NS	NS	NS	NS	NS	+
Friday	NS	NS	NS	NS	NS	NS	NS	NS
Saturday	NS	---	NS	NS	NS	NS	NS	NS
Sunday	NS	NS	NS	NS	NS	NS	NS	NS

Oregon

	12a-3a	3a-6a	6a-9a	9a-12p	12p-3p	3p-6p	6p-9p	9p-12a
Monday	NS	NS	NS	NS	NS	NS	NS	NS
Tuesday	NS	++	NS	NS	NS	NS	NS	NS
Wednesday	NS	NS	NS	NS	NS	-	NS	NS
Thursday	+	NS	NS	NS	NS	NS	-	NS
Friday	+	NS	NS	NS	NS	-	NS	NS
Saturday	NS	++	NS	NS	NS	NS	NS	NS
Sunday	NS	NS	NS	NS	NS	NS	NS	NS

Pennsylvania

	12a-3a	3a-6a	6a-9a	9a-12p	12p-3p	3p-6p	6p-9p	9p-12a
Monday	NS	NS	NS	NS	NS	NS	NS	-
Tuesday	NS	NS	NS	NS	NS	-	NS	NS
Wednesday	--	+	NS	NS	NS	NS	NS	NS
Thursday	-	NS	NS	NS	NS	NS	NS	+
Friday	NS	NS	NS	NS	NS	+	NS	NS
Saturday	NS	-	NS	NS	NS	NS	NS	NS
Sunday	---	NS	NS	NS	NS	NS	NS	NS

Washington

	12a-3a	3a-6a	6a-9a	9a-12p	12p-3p	3p-6p	6p-9p	9p-12a
Monday	NS	NS	NS	NS	NS	NS	NS	NS
Tuesday	NS	NS	NS	NS	NS	NS	NS	NS
Wednesday	+	NS	NS	NS	NS	--	NS	NS
Thursday	NS	NS	NS	NS	NS	NS	NS	NS
Friday	NS	NS	--	--	NS	NS	NS	NS
Saturday	NS	NS	+	NS	NS	NS	NS	NS
Sunday	NS	NS	NS	NS	NS	NS	NS	+

Wisconsin

	12a-3a	3a-6a	6a-9a	9a-12p	12p-3p	3p-6p	6p-9p	9p-12a
Monday	NS	+	NS	NS	NS	NS	++	NS
Tuesday	NS	NS	NS	NS	NS	NS	NS	NS
Wednesday	NS	NS	-	NS	NS	NS	NS	NS
Thursday	NS	NS	--	NS	NS	NS	NS	NS
Friday	NS	NS	NS	NS	NS	NS	NS	NS
Saturday	NS	NS	NS	NS	NS	NS	NS	+
Sunday	NS	NS	NS	-	NS	NS	NS	NS

Figure 3. Significant Changes in Proportions of K&A Pedestrian Crashes by Hour of Week by State

Shifts in K&A Pedestrian Crashes by Month of Year

Across all nine states, in both 2008-2012 and 2017-2021, the largest proportions of monthly K&A pedestrian crashes occurred in the fourth quarter of the year (October through December) (Figure 4). This period corresponds with the darkest season of the year in the northern latitudes. After the return to standard time, sunset happens before or during the typical weekday evening commute in many parts of the country. Comparing 2008-2012 with 2017-2021 showed that the fourth quarter of the year experienced increases in K&A pedestrian crashes (the November increases was statistically significant). In contrast, the second quarter of the year (April through June) experienced significant decreases in K&A pedestrian crashes across the nine states. This could be related to longer days in the spring.

Viewing the hour-of-week and month-of-year shifts together underscores the increasing importance of darkness versus daylight in pedestrian crash dynamics during the 2010s. The challenge of drivers detecting and stopping for pedestrians in darkness seems to have been exacerbated during this decade (potentially due to higher speeds, more driver distraction, or other factors that create even greater risk at night than the daytime). This is further evidence of darkness being an important factor associated with the increase in K&A pedestrian crashes over the decade.

Number of Crashes

2008-2012

	Month 1	Month 2	Month 3	Total
Q1	2684	2415	2441	7540
Q2	2178	2368	2243	6789
Q3	2328	2407	2718	7453
Q4	3001	3073	3203	9277
Total	10191	10263	10605	31059

2017-2021

	Month 1	Month 2	Month 3	Total
Q1	3264	2824	2656	8744
Q2	2359	2488	2473	7320
Q3	2763	2889	3276	8928
Q4	3638	3755	3853	11246
Total	12024	11956	12258	36238

Change in Number of Crashes

Absolute Increase from 2008-2012 to 2017-2021

	Month 1	Month 2	Month 3	Total
Q1	580	409	215	1204
Q2	181	120	230	531
Q3	435	482	558	1475
Q4	637	682	650	1969
Total	1833	1693	1653	5179

Percentage Increase from 2008-2012 to 2017-202

	Month 1	Month 2	Month 3	Total
Q1	21.6%	16.9%	8.8%	16.0%
Q2	8.3%	5.1%	10.3%	7.8%
Q3	18.7%	20.0%	20.5%	19.8%
Q4	21.2%	22.2%	20.3%	21.2%
Total	18.0%	16.5%	15.6%	16.7%

Significance Test for Change in Proportions of Crashes

2008-2012 vs 2017-2021

	Month 1	Month 2	Month 3
Q1	NS	NS	- -
Q2	- -	- - -	-
Q3	NS	NS	NS
Q4	NS	+	NS

Results of a Z-test of the difference in proportions:
Positive signs indicate that the proportion of weekly crashes during the temporal period was significantly higher in 2017-2021 than in 2008-2012 (+++ indicates 99.9% confidence; ++ indicates 99% confidence, + indicates 95% confidence).
Negative signs indicate that the proportion of weekly crashes during the temporal period was significantly lower in 2017-2021 than in 2008-2012 (--- indicates 99.9% confidence; -- indicates 99% confidence, - indicates 95% confidence).
NS indicates no significant difference.

Figure 4. Fatal and Severe Pedestrian Crashes by Month of Year, 2008-2012 and 2017-2021

Considerations and Future Research

Our multi-state study provides important insights about how K&A pedestrian crashes shifted during the 2010s, but additional work is needed.

We included both fatal and serious injuries to increase the sample of crashes available for our analyses, but there are likely to be differences in the factors that lead to these two different injury outcomes. Further research should explore fatal and serious crashes separately and see if there are any differences in the neighborhood-level shifts associated with each. In addition, geographic and temporal shifts K&A pedestrian crashes should be compared against less severe (and more common) pedestrian crashes. We chose to exclude these less severe crashes from this analysis because they are more likely to be underreported and are less likely to be reported consistently between states.

Our geographic analysis used data from more than 20,000 census tracts, but they only represented eight states. Future studies should incorporate data from more states, especially as more states build robust historical crash databases with accurate latitude and longitude coordinates. Further, our neighborhood-scale unit of analysis (census tracts) led to only having a small number of K&A pedestrian crashes per tract, even using five-year analysis periods (2008-2012 and 2017-2021). We considered conducting an analysis with a larger number of shorter time periods, but this approach is hampered by a large amount year-to-year variation in crash counts at the tract level. Five years provides some stability in crash counts. Further, we considered conducting an analysis with larger geographic areas (e.g., public use microdata areas or counties) to increase the number of crashes in each unit of analysis. However, these larger units tend to contain a greater range of populations and land uses, obscuring the more distinct socioeconomic characteristics, land uses, and job types that are delineated by census tracts. If more robust data were available (i.e., from more states, over more years), more sophisticated statistical modeling approaches could be applied. While we found eight states with pedestrian crash data that fit the needs of our longitudinal analysis, there are likely to be inconsistencies between how law enforcement officers in different states (and even local jurisdictions within states) define severe pedestrian injuries. We also know that pedestrian crashes, even those that involve severe injuries, are often underreported or misdiagnosed (Stutts and Hunter 1998; Doggett, Ragland, and Felschundneff 2018; Ferenchak and Osofsky 2022). Further, several states had lower geocoding rates in the earlier years of our study, potentially leading to an undercount of pedestrian crashes in some tracts during the 2008-2012 baseline period. We included state-level dummy variables to control for this inconsistency, but it would be ideal to have more complete historical crash data from all states.

Future research should explore the influence of several other variables on geographic shifts in fatal and severe pedestrian crashes. For example, we did not examine the proportion of zero-vehicle households and road network density in our models because they were correlated with other variables such as median household income and roadway intersection density. We also lacked historical data representing roadway characteristics, such as pedestrian crossing facilities and number of lanes. Other studies have noted the important association between roadway characteristics and pedestrian fatalities (Mansfield et al. 2010; Schneider 2020), so a longitudinal examination of roadway design changes on shifts in pedestrian crash risk would be insightful. Importantly, we only represented pedestrian exposure indirectly through land use and pedestrian and transit commuting variables. Future studies should incorporate locally-specific pedestrian counts, pedestrian trips, and other more direct measures of pedestrian activity levels.

Associations between other land use and transportation characteristics and K&A pedestrian crashes deserve additional investigation. Increases in K&A pedestrian crashes between 2008-2012 and 2017-2021 were significantly more likely to occur in neighborhoods served by public transit. However, there could be differences between pedestrian safety outcomes along transit routes in dense, urban core areas compared to suburban arterial corridors. Additional research should also explore potential associations between job mix and pedestrian crashes. Mixed-use development strategies to address pedestrian safety should be pursued in coordination with roadway designs that facilitate slower vehicle speeds and provide narrower and more protected pedestrian crossings. While we found increases in K&A pedestrian crashes in the 2010s to be significantly associated with tracts that had lower population densities, our results do not directly address the possible suburbanization of K&A pedestrian crashes or other geographic shifts in K&A pedestrian crash risk. Therefore, future studies should examine the spatial distribution of K&A pedestrian crashes and how their locations have shifted over time. For example, this could be done by examining crashes in relation to geographic concentrations of employment and specific job types within a sample of metropolitan regions.

We used all available census tracts in our analysis, but there may be important differences between urban, suburban, and rural contexts. Additional research should explore the differences in socioeconomic, land use, and transportation system factors associated with crashes in each of these contexts. Further, other land use context categories should be analyzed, such as suburban retail centers, urban commercial corridors, or rural villages. This can help provide an even more practical understanding of where the most severe pedestrian crashes are shifting to within states or metropolitan regions so that safety resources can be directed proactively toward these areas.

The Great Recession of 2008 through approximately 2012 and COVID pandemic that started in 2020 likely influenced the occurrence of K&A pedestrian crashes during our study periods. However, the specific impacts of major societal events like these are realized through changes in many of the variables that we analyzed in this study (population, employment, socioeconomic, and land use and transportation system characteristics). So, our neighborhood-level analysis of these factors helps us understand many of the fundamental relationships that underlie recession and pandemic shifts in K&A pedestrian crashes. However, we did not include other important variables that could have shifted and changed pedestrian injury outcomes in the 2010s, such as driver and pedestrian behavior and vehicle characteristics. While these variables are challenging to collect at a fine-grained geographic scale, future neighborhood-level pedestrian safety research should also explore these variables.

Our temporal analysis showed significant shifts between hours of the week and months of the year when considering all nine states combined. Significance levels were lower when states were considered individually. This suggests that even larger datasets are needed to develop a better understanding geographic differences in the temporal shifts in K&A pedestrian crashes.

Conclusion

Using data from more than 20,000 census tracts across eight states, we found significant geographic and temporal shifts in K&A pedestrian crashes between 2008-2012 and 2017-2021.

Geographic shifts were represented by associations between neighborhood-level characteristics and changes in K&A pedestrian crashes from the baseline to the later period. After controlling for characteristics representing pedestrian exposure, we found that tracts with lower incomes, more unemployed workers, fewer people older than age 64, and greater proportions of Black and Hispanic residents in the baseline period were more likely to experience increases in K&A pedestrian crashes. Tracts with lower population densities, interstate highways or other types of freeways, at least one high-volume roadway (>20,000 AADT), and greater baseline proportions of retail jobs tended to have more K&A pedestrian crashes during 2017-2021 than during 2008-2012.

Our temporal analysis showed that K&A pedestrian crashes continue to be concentrated during the 6 pm to midnight period throughout the week. These nighttime crashes are even more prominent and extend later into the night on Friday and Saturday nights. Between 2008-2012 and 2017-2021, K&A pedestrian crashes increased during nighttime hours throughout the week, with a particularly high percentage increase between midnight and 6 am on weekdays. Considering months of the year, the fourth quarter (October through December) had the highest concentration of K&A pedestrian crashes and experienced proportional increases in K&A pedestrian crashes between 2008-2012 and 2017-2021. Both temporal trends underscore the importance of darkness as a factor associated with the increase in K&A pedestrian crashes during the 2010s.

These insights help increase our understanding of pedestrian injury outcomes over space and over time. We hope that our results help practitioners understand and anticipate neighborhood-level shifts in pedestrian risk and prioritize safety measures to prevent future injuries and fatalities.

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