UNDERSTANDING PEDESTRIAN INJURIES AND SOCIAL EQUITY

Literature Review

PROJECT SPR 841

Oregon Department of Transportation

UNDERSTANDING PEDESTRIAN INJURIES AND SOCIAL EQUITY

Literature Review

PROJECT SPR 841

by

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16. Abstract
Transportation is an integral part of our lives, shaping our built environment, access to economic and social opportunities, exposure to traffic and pollution, and much more. There are incredible benefits as well as costs associated with the transportation system generally, and with individual modes, including walking. This literature review was crafted as part of an ODOT Research funded project titled *Understanding Pedestrian Injuries and Social Equity*, project number SPR 841. Though the focus of that project is on pedestrian injuries and the connection with social disparities this literature review summarizes a broader set of transportation outcomes that have been linked with existing and historic social disparities. Ideally this literature review can be a primer for understanding how the transportation creates and often times reinforces social disparity.

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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	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	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	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

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	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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1.0 INTRODUCTION

Transportation is an integral part of our lives, shaping our built environment, access to economic and social opportunities, exposure to traffic and pollution, and much more. There are incredible benefits as well as costs associated with the transportation system generally, and with individual modes, including walking. This literature review was crafted as part of an ODOT Research funded project titled *Understanding Pedestrian Injuries and Social Equity*, project number SPR 841. Though the focus of that project is on pedestrian injuries and the connection with social disparities this literature review summarizes a broader set of transportation outcomes that have been linked with existing and historic social disparities. Ideally this literature review can be a primer for understanding how the transportation creates and often times reinforces social disparity.

Chapter 1 outlines equity considerations of the broader transportation system, while Chapter 2 focuses in on pedestrian safety, including access to safe pedestrian facilities, injury and fatality statistics, and disparities by income, race, ethnicity, and other factors such as educational attainment and age. Chapter 3 focuses on research methodologies used to assess pedestrian safety and equity, including network and zonal analysis approaches.

2.0 INEQUITIES IN TRANSPORTATION

Aside from pedestrian safety, there are numerous ways in which transportation directly or indirectly touches on quality of life, health, opportunity, and equity.

Environmental justice focuses on the distribution of costs and benefits. In transportation, the discussion is usually about distributive justice, or who gets what, when and how, as opposed to weighing both benefits and costs to same groups/areas (Schweitzer & Valenzuela, 2004). Studies show us that transportation benefits have often accrued to richer and more educated people, while burdens have disproportionately fallen on lower-income people and people of color (Bullard, 2003). For example, throughout the United States over the course of several decades, lower-income urban neighborhoods, often communities of color, were displaced to make room for freeways that connected higher-income suburbs to cities in urban cores. Transportation cost benefit analysis should distinguish who receives benefit and who incurs the costs, and assess how to equitably value impacts that cannot be easily monetized such as impacts on health or environment, and intergenerational equity impacts (Di Ciommo & Shiftan, 2017).

Procedural equity is important to consider and relate to the mechanisms that result in inequitable outcomes. Procedural equity focuses on the "process by which transportation decisions may or may not be carried out in a uniform, fair and consistent manner with involvement of diverse public stakeholders" (Bullard, 2003). Among the considerations are process-based claims, which might include low-income and Black, Indigenous and People of Color (BIPOC) communities having less involvement or consideration in decision-making processes); benefits-based claims (poor and BIPOC residents have less access to opportunities); and cost-based claims (poor and BIPOC neighborhoods are more likely to "host" unwanted transportation facilities, are subject to greater externalities such as pollution and traffic safety impacts) (Schweitzer & Valenzuela, 2004).

One of the starting points in thinking about transportation inequity concerns how the built environment dictates where people need to travel, including where they live and work. Land use and zoning policies, home lending practices, and housing affordability have all contributed to income and racial differences in housing locations. Indeed, over the past 40 years, income-based housing segregation has increased dramatically (Bischoff & Reardon, 2013). Housing policies and practices effectively cut off housing equity as a viable pathway to personal wealth creation for many Black families, resulting in a current 10 to 1 wealth gap between White and Black households (McIntosh et al., 2020). More germanely, such spatial separation has negative impacts on low-income and BIPOC communities, ranging from increased exposure to environmental hazards, inferior schools, exposure to crime, and diminished access to jobs (Galster & Sharkey, 2017). While the details of these factors influencing housing options for low-income and BIPOC people are largely outside the purview of the current technical analysis, the resulting segregated housing landscape contributes to different transportation experiences, travel options, and safety conditions.

Spatial mismatch is the degree to which certain populations face a lack of jobs in locations accessible to their place of residence. An analysis of spatial mismatch in the U.S. for different groups found that Blacks, Hispanics and Asians in America all face greater spatial mismatch than white Americans, with the mismatch being greatest for Black Americans overall (Easley, 2017). The study found that "about 35% of group members, or jobs, would need to relocate to eliminate mismatch for whites, compared with 41% for all Asians and 40% for all Hispanics," while "47% of blacks or jobs would need to relocate to eliminate mismatch" (Easley, 2017, p. 1807).

Understanding of job/home mismatch has changed over the years. As jobs have shifted out of city centers, workers who rely on transit face longer and less direct commutes as housing and jobs become less aligned (Bullard, 2003). In more dispersed cities, particularly cities that matured in the 20th century, both housing and jobs have been more dispersed. This has made modal mismatch, or the relative disadvantage conferred by not having access to the right mode, usually a car, a more significant barrier (Blumenberg & Manville, 2004). Blumenberg and Manville also note that "although the automobile is remarkably useful, many of its advantages are structural and related to issues of land use and governance rather than to any inherent superiority it may enjoy" (Blumenberg & Manville, 2004, p. 197).

Transportation decisions may have impacts that positively or negatively disproportionately affect different areas, such as "rural vs urban vs central city" differences or specific neighborhoods that might be on the "wrong side of the tracks" (Bullard, 2003).

2.1 TRAVEL OPTIONS AND RESTRICTIONS

2.1.1 Travel Spending and Tradeoffs

Transportation is a major part of most people's lives and budgets, accounting for 17% of the average American's expenditures in 2018, which is more than is spent on food, education or health care, and only less than housing (Bureau of Transportation Statistics, 2018). A study examining the combined cost of the two highest household costs, transportation and housing, found that people in the lowest income quintile spend 55% of their total expenditures on housing and transportation compared to 51% for all households (Blumenberg & Agrawal, 2014). A third of the lowest quintile income population do not have a car compared to 11% of all households (from U.S. Bureau of Labor Statistics, 2010), documenting how car ownership is not equal across the population.

While lower-income households actually spend a modestly lower percentage of their incomes on transportation, those dollars are coming out of much more constrained budgets and are thus subject to many more tradeoffs, which may come at the expense of economic opportunity, social inclusion, and personal well-being. A number of studies show that low-income households use less transportation than they need or want (Blumenberg & Agrawal, 2014), limiting access to destinations and opportunities. Low-income families will often alter their travel patterns or behaviors in order to reduce spending on transportation, including traveling fewer miles, particularly by car, and/or shifting to lower cost modes, eliminating trips, particularly discretionary trips, and/or staying close to home (Blumenberg & Agrawal, 2014). Many will use multiple modes, calculating which is cheaper for a particular trip and changing to suit the trip.

Transportation costs effect spending choices in other areas as well. Some low-income individuals will reduce spending on other types of expenditures, including entertainment and restaurants, in order to pay transportation costs (Blumenberg & Agrawal, 2014).

2.1.2 Motor vehicle access

As discussed earlier, modal mismatch describes the "drastic divergence in the relative advantage between those who have access to automobiles and those who do not," and is more applicable to cities that developed in the 20th century's automobile age, with both housing and jobs being more dispersed (Blumenberg & Manville, 2004). Lower income households are less likely to have a car, which limits their ability to make trips and access economic and social opportunity. People living in households at or below the poverty level are much more likely to have zero cars in the household (about 25%) (*Federal Highway Administration*, 2014). Meanwhile, Black Americans are far less likely to own and drive a car (80% compared to 92% of all American households), while American Indians, Latinos/Hispanics, Asian, Pacific Islanders and people of mixed race are less likely to own cars than white Americans (Lucas, 2012).

Data from the 2017 National Household Transportation Survey related to household vehicles are shown in Table 2.11. Lower-income households and households with a Black primary household respondent were particularly likely to have fewer or no cars or drivers.

Households with incomes under $25,000 on average have fewer motor vehicles (1.08 on average) as those making $25,000-$49,999 (1.71), $50,000-$99,999 (2.14) or those making $100,000 or more (2.51). On a vehicle per household member basis, those numbers are 0.53 cars per household member (under $25k), up to 0.86 cars per household members (over $100). Black or African-American households have 1.3 vehicles per household, compared to the overall average of 1.88 vehicles per household and the average of 2 vehicle for white household. White households have an average of 0.82 vehicles per household member, more than the 0.58 for Black households, 0.6 for Asian households, and 0.63 for American Indian or Alaska Native households.

In terms of the percentage of households without a car, the numbers are starker, with 26.2% of households earning under $25,000 not owning a car, compared to 5.2% of those earning $25,000 to $49,999, 3.1% of those earning $50,000 to $99,999, and 2.3% of those earning $100,000 or more. Only 6% of white households had zero vehicles, while 23.3% of Black households, 15% of American Indian or Alaska Native households, 11.2% of Asian households, and 11.4% of Latino/Hispanic households had zero vehicles. Similar numbers hold for households with zero drivers in the household. As can be seen from Table 2.22, the difference by race is most extreme at the lower-income grouping of $25,000 or less, in which 42% of Black or African American households do not own a car, compared to 19% of white households in that income category. However, the difference persists at higher income levels as well. We looked at income difference by Latino/Hispanic status, but did not find any significant differences.

Lower income households are less likely to have a driver in the household, with 19.8% of households under $25,000 having a single driver, compared to just 3.6% of households earning $25,000 to 49,999, 1.6% of those earning $50,000 to 99,999, and 0.7% of those earning $100,000 or more.

Table 2.1 NHTS 2017 Household Vehicle Data

	Count of household vehicles	HH vehicles per HH member	Zero vehicle HHs	Zero drivers in HH
Household income 4 categories				
Less than $25,000	1.08	0.53	26.2%	19.8%
$25,000 to $49,999	1.71	0.76	5.2%	3.6%
$50,000 to $99,999	2.14	0.83	3.1%	1.6%
$100,000+	2.51	0.86	2.3%	0.7%
Race of household respondent				
White	2.00	0.82	6.0%	4.3%
Black or African American	1.30	0.58	23.3%	16.7%
Asian	1.72	0.60	11.2%	6.0%
American Indian or Alaska Native	1.79	0.63	15.0%	12.2%
Native Hawaiian or other Pacific Islander	2.10	0.85	8.3%	4.6%
Multiple responses selected	1.83	0.69	10.6%	6.6%
Some other race	1.69	0.62	15.9%	11.9%
Total	1.88	0.77	8.9%	6.3%
Ethnicity of household respondent				
Latino/Hispanic	1.82	0.66	11.4%	8.1%
Not Latino/Hispanic	1.89	0.79	8.6%	6.0%
Total				
	1.88	**0.77**	**8.9%**	**6.3%**

Source: NHTS 2017 data

Table 2.2 NHTS 2017 Household Vehicles Race and Income

	Less than $25,000		$25,000 to $49,999		$50,000 to $99,999		$100,000+		Total	
HH respondent race	**Cars per hh**	**0 car hhs**	**Cars per hh**	**0 car hhs**	**Cars per hh**	**0 car hhs**	**Cars per hh**	**0 car hhs**	**Cars per hh**	**0 car hhs**
White	1.2	19%	1.8	4%	2.2	3%	2.5	2%	2.0	6%
Black or African American	0.8	42%	1.4	10%	1.9	5%	2.4	4%	1.3	23%
Asian	1.2	28%	1.5	12%	1.7	9%	2.1	4%	1.7	11%
American Indian or Alaska Native	1.0	31%	1.8	6%	2.4	2%	3.2	0%	1.8	14%
Native Hawaiian or other Pacific Islander	1.4	13%	1.7	6%	2.0	10%	3.2	1%	1.9	9%
Multiple responses selected	1.0	28%	1.9	4%	2.2	1%	2.5	2%	1.8	11%
Some other race	1.1	34%	1.7	5%	2.2	4%	2.6	2%	1.7	15%
Total	1.1	26%	1.7	5%	2.1	3%	2.5	2%	1.9	9%

Source: NHTS 2017 data

2.1.3 Travel behavior

Beyond, though likely not unrelated to, vehicle availability, there are notable differences in the trip-making behaviors, barriers, and mode choices of lower-income and BIPOC individuals and households.

2.1.3.1 Number of trips taken

Income is correlated with the number of trips that people take. One study found that people who did not travel on the day of the 2009 NHTS travel survey were more likely to be poor, had less education, and lived in large households compared to travelers who took had traveled by one mode (Blumenberg & Pierce, 2013). As shown in Table 2.32.3, 2017 NHTS data shows that households earning under $25,000 took 5.64 trips on average, compared to 7.09 for those earning $25,000 to $49,999, 8.29 for those earning $50,000 to $99,999, and 10.08 for those earning $100,000 and above. Further, 16.4% of households earning less than $25,000 reported taking zero trips, compared to 8.5% of those earning $25-49k, 5.9% of those earning 50-99k, and 4.4% of those earning 100k or more.

Table 2.3 NHTS 2017 Household Trip Data

	Count of household trips on travel day	Zero trips taken
Household income 4 categories		
Less than $25,000	5.6	16%
$25,000 to $49,999	7.1	9%
$50,000 to $99,999	8.3	6%
$100,000+	10.1	4%
Race of household respondent		
White	8.0	10%
Black or African American	6.6	11%
Asian	8.0	9%
American Indian or Alaska Native	8.4	11%
Native Hawaiian or other Pacific Islander	7.5	7%
Multiple responses selected	8.3	9%
Some other race	7.6	11%
Total	7.8	10%
Ethnicity of household respondent		
Latino/Hispanic	8.2	9%
Not Latino/Hispanic	7.7	9%
Total	7.8	9%

Source: NHTS 2017 data

2.1.3.2 Travel choices and financial burden

It is also important to note that, for low-income households, cars represent a financial burden, as they tend to be older, less reliable, and more likely to need expensive repairs

(Blumenberg & Manville, 2004). NHTS data shows that the cost of travel is a financial burden that influences travel modes. Table 2.42.4 shows the percentage of NHTS respondents who agreed with statements relating to the financial burden of transportation. Fifty-five percent of those with household incomes of $25,000 or less agreed that travel is a financial burden for them, compared to 38% of all respondents, and 25% of those earning $100,000 or more. That burden pushes people to choose modes other than driving, particularly walking and transit, modes that increase exposure to pedestrian crashes. Twenty-nine percent of those in the lowest income bracket agreed that they choose to walk in order to reduce the financial burden of travel, compared to 17% of those households earning $25,000 to $49,000, 14% of those earning $50,000 to $99,999, and 11% of those earning $100,000 or more. Twenty-one percent of those earning $25,000 or less agreed that they take public transit to reduce the financial burden of travel, compared to 10% of those households earning $25,000 to $49,999, 9% of those earning $50,000 to $99,999, and 11% of those earning $100,000 or more.

Table 2.4 Burden of Transportation by Income and Race / Ethnicity

	Price of Gasoline Affects Travel	Travel is a Financial Burden	Walk to Reduce Financial Burden of Travel	Bicycle to Reduce Financial Burden of Travel	Take Public Transportation to Reduce Financial Burden of Travel
Household Income					
Less than $25,000	63%	55%	29%	11%	21%
$25,000 to $49,999	55%	43%	17%	7%	10%
$50,000 to $99,999	45%	35%	14%	7%	9%
$100,000+	29%	25%	11%	6%	11%
Race of household respondent					
White	44%	36%	15%	7%	10%
Black or African American	62%	50%	24%	8%	23%
Asian	49%	47%	26%	14%	30%
American Indian or Alaska Native	64%	56%	30%	14%	19%
Native Hawaiian or other Pacific Islander	60%	49%	25%	15%	20%
Multiple responses selected	53%	46%	24%	12%	18%
Some other race	61%	56%	30%	15%	25%
Ethnicity of household respondent					
Latino/Hispanic	57%	50%	24%	11%	19%
Not Latino/Hispanic	46%	37%	16%	7%	11%
Total	47%	38%	16%	8%	12%

Source: NHTS 2017.

A literature review looking at the relationship between the built environment and walking across different socioeconomic contexts (Adkins et al., 2017) lends support to the notion that for underserved communities, walking is less of a choice and more of a necessity. The review noted that low-income people walk more than high-income people, on average, in places where the built environment is not conducive or supportive of walking. While both groups had higher levels of walking in a supportive built environment, advantaged groups increased their walking much more than disadvantaged group. This illustrates that, for disadvantaged groups, walking is more of a non-choice or captive mode, while for advantaged groups walking is more of a choice mode. In their review of 17 studies examining the link between built environment and walking activity, 13 showed a weaker effect for disadvantaged groups (usually determined by income or race and income). The average built environment effect on walking and physical activity was 2.3 to 2.7 times greater for advantaged groups than for disadvantaged groups. Disadvantaged groups appear to be less influenced by the built environment because they are already walking more, even when the built environment is unsupportive.

Another review noted that people who are low-income, BIPOC, or immigrants are more likely to have non-standard working hours, commuting in the middle of the day, later in the evening or at night, rather than at peak commute times (Sandt et al., 2016). Commuting at these times may leave them walking to and from transit outside of daylight hours, which is when a disproportionate number of pedestrian crashes occur, as well as leaving them relying on transit during periods in which transit waits and transfers may take longer and less express service is available.

2.2 ACCESS IMPACTS OF TRANSPORTATION INEQUITY ON OPPORTUNITIES

Transportation-disadvantaged households, and particularly those who are not able to afford cars or limit travel due to financial concerns, face barriers in accessing essential goods, services, and opportunities. "Mobility-related exclusion" is defined by Kenyon et al as "The process by which people are prevented from participating in the economic, political and social life of the community because of reduced accessibility to opportunities, services and social networks, due in whole or in part to insufficient mobility in a society and environment built around the assumption of high mobility" (Kenyon et al., 2002). This section will briefly touch on some of the numerous ways that mobility-related exclusion can affect people and communities.

2.2.1 Employment

Multiple studies have found that people who are reliant on public transit can reach fewer jobs than those who have cars, ranging from 6 to over 50 times fewer jobs given a similar commute time (Blumenberg & Manville, 2004; Stoll, 2005). Blumenberg and Manville conclude that the "evidence that automobiles make it easier to find and keep work is diverse and persuasive," including in compact and sprawling cities, even when accounting for the potential causality bias - e.g. that having a job also makes it easier to own a car (Blumenberg & Manville, 2004, p. 196). Aside from commuting, mobility is important for maintaining the networks, acquaintances, work travel, work-related social travel that some jobs/professions may require, including to find work or be promoted (Cass et al., 2005).

2.2.2 Healthy food

A literature review of access to healthy food found that poor residents had to travel further, with fewer transportation options (particularly cars) to get to stores and resources, including chain stores, food outlets, and stores with healthy options (Walker et al., 2010). Low-income neighborhoods often have fewer stores offering healthy foods, including fruits and vegetables; and improved transportation access, including access to a vehicle, are connected to shopping for and eating healthier foods (Dillahunt & Veinot, 2018; Walker et al., 2010).

2.2.3 Health and health care

A literature review looking at 61 studies relating to healthcare access and transportation barriers found that transportation is particularly a barrier for low-income and un- or under-insured people, with a particular barrier being lack of a car (Syed et al., 2013). For example, transportation barriers are responsible for about half of medical missed appointments, and difficulties in accessing pharmacies is an important contributor to people not filling prescriptions (Dillahunt & Veinot, 2018; Syed et al., 2013). Limited transportation is also associated with not getting regular medical care, cancellations, and unmet referrals (Dillahunt & Veinot, 2018).

2.2.4 Social opportunities

Although people consider social interactions such as attending weddings, funerals, visiting friends, and celebrating special events as necessary for a full social life, those who are transport disadvantaged may not be able to engage in some of these activities due to lack of transport or transport affordability (Cass et al., 2005). Cass et al. note that families, outside of nuclear families, are increasingly dependent on mobility to come together and support one another, including supporting aging family members, which transport disadvantage can negatively affect (Cass et al., 2005).

2.3 DISCRIMINATION

Discrimination can play an important role in transportation, ranging from traffic enforcement, access to services, and more. The potential impact of discrimination on traffic safety for pedestrians, related to motorist yielding, is discussed in Chapter 2.

2.3.1 Enforcement

Following traffic crashes, Black and Latino/Hispanic people are much more likely than white people to face arrest and prosecution for similar situations, and also more likely be subject to force in interactions with police (Conner, 2017). Further, Black drivers are much more likely to be stopped for discretionary purposes, with numerous documented cases of such stops resulting in violent and sometimes deadly force used on the drivers (Conner, 2017). Baumgartner et al. find that Black and Latino/Hispanic men are considerably more likely than women and white men to be stopped by police and needlessly searched for contraband (Baumgartner et al., 2018).

Given the exact same circumstances, they estimate that Black drivers are 4% more likely and Latino/Hispanic drivers are 5% more likely than white drivers to be arrested. They point to the discretionary power that police have in determining potential criminality, and that “falsely assuming criminality, like falsely assuming law abidingness, differs systematically,” with Black and Latino/Hispanic males being “systematically subjected to more intrusive police action than is warranted,” in both search and arrest decisions (Baumgartner et al., 2018, p. 23).

2.3.2 Transit and taxi

For many who are not able to afford a car or have limited their travel due to financial burden, there are a number of problems associated with being dependent on transit, walking and other modes. A review of urban transportation equity noted that transit systems have “taken their low-income and people of color “captive riders” for granted and concentrated their fare and service policies on attracting middle class and affluent riders out of their cars,” and that “transit subsidies have favored investment in suburban transit and expensive new commuter bus and rail lines that disproportionately serve wealthier “discretionary riders”” (Bullard, 2003).

Taxis and ride-hail companies (also known as transportation network companies or TNCs) may fill some gaps for people who do not have cars, although in addition to cost barriers, discrimination and other factors present equity concerns. The taxi industry has a history of discrimination, in terms of not picking up Black riders and avoiding certain neighborhoods (Brown, 2018). Ride-hailing services such as Uber and Lyft can help expand car service availability in areas with limited taxi availability – a 2018 study found that ride-hailing services were available in nearly all neighborhoods of LA County, including considerable usage in areas with lower household vehicle ownership (Brown, 2018). However, even when available, some riders may face longer wait times or more cancellations. A 2016 study of TNCs in Seattle and Boston found that Black riders were subject to longer wait times (Uber drivers see rider photos after accepting a fare), while riders with African American sounding names, and particularly African American men, were subject to more frequent cancellations (Ge et al., 2016). A 2018 study in Los Angeles confirmed these findings, noting that “Black riders were 73 percent more likely than white riders to have a taxi trip cancelled and waited between six and 15 minutes longer than white riders, all else equal” (Brown, 2018).

2.3.3 Driver behavior

While adequate crossing facilities are necessary for pedestrian safety, it is still incumbent upon drivers to comply with yielding requirements. Several studies in recent years are uncovering bias in driver yielding behavior. A 2015 study of driver yielding behavior in Portland, Oregon, found that Black male pedestrians waiting to cross at a marked midblock crosswalk “were passed by twice as many cars and experienced wait times that were 32% longer than White pedestrians” (Goddard et al., 2015). Although the study did not test whether this difference was due to explicit or implicit bias, the authors suggest that split second decisions about safety related behaviors are likely representative of implicit assumptions. A study of driver yielding in Las Vegas had four crossing participants, including one Black male, one white male, one Black female and one white female. The study found that “cars yielded more frequently for females (31.33%) and whites (31.17%) compared to males (24.06%) and non-whites (24.78%).” Further, more expensive cars were associated with decreased odds of yielding, with decreased 3% per $1000 increase in car value (Coughenour et al., 2020). A related study of driver yielding behavior in Las Vegas, which had one white female and one Black female crossing participant, found that yielding in the nearside lane was lower for the white participant, while yielding in the next lane, while the participant was already in the street, was lower for the Black participant (Coughenour et al., 2017). That study also found that yielding rates were lower in a high-income area than in a low-income area, though the authors speculate this may have been related to pedestrians being less common in the high-income neighborhood, as well as the street having higher speed limits.

2.4 HEALTH AND AIR POLLUTION

Low-income and BIPOC travelers have traditionally been marginalized and had less access to opportunities, while at the same time they may have the most to gain from active transportation because they may "bear the largest burden from physical inactivity-related health ailments" and "tend to have lower levels of vehicle access and are consequently more reliant on alternative transportation modes" (Lee et al., 2016). Black and Latino/Hispanic people in the United States suffer disproportionately from diseases associated with lack of physical activity such as obesity, diabetes, hypertension and cardiovascular disease (Day, 2006). Recent statistics show that Black Americans, particularly Black women are at higher risk of obesity and severe obesity (Hales et al., 2020). Black, Asian and Latino/Hispanic Americans are disproportionately likely to have diagnosed or undiagnosed diabetes, compared to white Americans (Mendola et al., 2018). Black Americans are also at higher risk of hypertension (Ostchega et al., 2020). According to the Oregon Health Authority, African-American, American Indian, Pacific Islander or Latino/a Oregonians have a higher burden of disease than white Oregonians, including a greater proportion who are overweight and fewer who report exercising outside of work (Oregon Health Authority, 2019)

Although low-income and BIPOC travelers may have more to gain from increased physical activity associated with active travel, they are also more susceptible to various negative health contributors, before even considering traffic safety. For example, air quality, particularly from transportation emissions, is worse in general in communities of color (Adkins et al., 2017; Bullard, 2003), which leads to higher asthma rates, and is particularly burdensome to people without health insurance. Low-income and BIPOC populations are also disproportionately exposed to industrial emissions (Adkins et al., 2017). A recent study noted that, not only are Black and Latino/Hispanic populations exposed to higher level of fine particular matter pollution, but they are also less likely to cause such air pollution. Indeed, "On average, non-Hispanic whites experience a "pollution advantage": They experience ∼17% less air pollution exposure than is caused by their consumption," while "Blacks and Hispanics on average bear a "pollution burden" of 56% and 63% excess exposure, respectively, relative to the exposure caused by their consumption" (Tessum et al., 2019, p. 6001).

Health outcomes related to walking must consider both the physical activity side and the traffic injury side. One study modelling predicted health impacts from physical activity and traffic injury found that, as walking and bicycling increased under a Sacramento Area COG sustainability plan, which included reductions in VMT, health gains from physical activity would start right away, however traffic injury death would also increase until enough people shifted away from driving to reduce the number of vehicles that pedestrians encountered (Wu et al., 2019).

2.5 CRASH SAFETY

There are a number of other mechanisms by which the outcomes of crash safety can be worse for some populations than others. For example, crash test dummies, used to test vehicle safety and upon which vehicle standards and designs are set, are designed after a single medium build male body type (Barry, 2019). A smaller "female" dummy, which is consistent with a 5th percentile small female body, is sometimes used as a passenger, resulting in safety designs that may not work well for different body types.

There's also evidence that ambulance response time may be slower depending on where you live. A study in Washington State found that ambulance response and transport times were far longer for rural trauma victims than from urban victims. Rural response time was an average of 13.6 minutes compared to 7 minutes in urban areas, and transport time was 17.2 minutes to 8.2 minutes. The result was that rural victims are much more likely to die before arriving at a hospital (Grossman et al., 1997). A more recent study of ambulance response times for cardiac arrest encounters found that, even after controlling for urban zip codes, weekday and time of day, higher income zip codes had faster ambulance response times (by 10%) than lower income zip codes. Overall mean response time was 37.5 minutes in the highest income zip code quartile and 43 minutes in the lowest quartile (Hsia et al., 2018).

Crash outcomes also vary by the type of vehicle by which a pedestrian is hit. A study of the safety outcomes of pedestrians hit by motor vehicles found that light trucks and vans (LTV), including SUVs, pose a significantly greater risk to pedestrians than passenger cars do. The study found that pedestrians have a "two to three times greater likelihood of dying when struck by an LTV than when struck by a car," and the disparity exists even when considering impact speed (Lefler & Gabler, 2004). Further, the proportion of pedestrian fatalities involving trucks, light trucks and SUVs has been going up, increased from 22% to 44% between the five-year period ending in 1986 and that ending in 2016 (Schneider, 2020).

Part of the problem may be that the safety outcomes of such vehicle are not distributed evenly – vehicle occupants have better crash outcomes in heavier vehicles, while pedestrians and cyclists have worse outcomes when hit by heavier vehicles. A Norwegian study found that vehicle characteristics associated with better safety outcomes for vehicle occupants involved in crashes include having newer and heavier cars; however, for pedestrians and cyclists, vehicle weight was associated with worse safety outcomes (Høye, 2019).

Finally, a study of traffic fatalities in the United States between 1995 and 2010 found that, while such fatalities dropped for most groups, they increased, from an already comparatively high rate, for those with less than a higher school diploma when considering vehicle miles travelled (Harper et al., 2015).

3.0 PEDESTRIAN SAFETY INEQUITIES

This chapter is focused on pedestrian safety, factors that contribute to pedestrian safety outcomes, and demographic disparities in both.

3.1 BUILT ENVIRONMENT FACTORS

Although most traffic safety studies focus on specific roadway features, such as roadway volumes, speeds, widths, and so on, the broader built environment, including how humans have shaped and interact with the land and transportation system, is an important factor when attempting to understand and contextualize safety outcomes. Factors such as population or employment density, types of land uses, density and types of roadway networks, and other built environment factors have been associated with traffic safety generally, and pedestrian safety specifically.

3.1.1 Density of people and jobs

While it would make sense that where there are more people and pedestrians, there would be more pedestrian crashes. In general, this is true, however, the relationships are more complex in many cases.

There is evidence to suggest that higher levels of pedestrian activity, on average, result in more, but less severe crashes. A number of studies have found that, in general, higher population and jobs densities are associated with more vehicle-pedestrian collisions (Loukaitou-Sideris et al., 2007; Merlin et al., 2020; Wier et al., 2009), and in some analyses have used these measures as exposure variables.

However, there are a number of situations wherein further context is needed. For example, while Merlin et al, in a literature review, found that pedestrian crashes increase with more population and employment density, "the relationship between fatalities and density is negative," suggesting that crashes were less severe (Merlin et al., 2020). Guerra et al, in a study of crashes in the Philadelphia region, found different trends in the suburbs than in the city. In the suburbs, higher population densities were generally associated with more pedestrian-involved collisions, but in the city higher population densities were associated with fewer pedestrian-involved collisions (Guerra et al., 2019). That study did not find a relationship between job density and pedestrian crashes or injuries. Another study found that for block groups, population density was negatively associated with pedestrian crashes, while for counties, population was positively associated with pedestrian crashes - suggesting that lower density areas in higher density counties may be the most dangerous places (Jermprapai & Srinivasan, 2014). The block group and county level effect were similar for income, suggesting that low income areas in higher income counties are most at risk.

There is some evidence that areas with larger BIPOC populations are associated with higher population densities. For example, a 2010 study in Chicago found that population density was higher, on average, in census tracts with higher proportions of Black, Latino/Hispanic or low-income residents (Cottrill & Thakuriah, 2010).

3.1.2 Land uses

In general, land uses that are significant attractors of pedestrian activity are associated with higher pedestrian crash risk. A national study found that, in both urban and rural areas, higher employment in the retail sector was associated with higher pedestrian fatality rates (Mansfield et al., 2018). Merlin et al found that commercial and mixed-use areas, along with areas nears schools, are associated with higher crash risk (Merlin et al., 2020). A study in San Francisco, CA, found that areas with a higher percentage of land area zoned for neighborhood commercial and residential neighborhood commercial, both potential pedestrian attractors, were associated with more vehicle-pedestrian collisions (Wier et al., 2009). A study in Los Angeles found more pedestrian collisions in areas of more concentrated commercial and retail land uses, and fewer pedestrian collisions in areas of vacant land, industrial use or office land uses (Loukaitou-Sideris et al., 2007).

While denser urban areas experience more pedestrian crashes, there is evidence that they are on average less severe. A Florida statewide pedestrian crash analysis found that census block groups in urban areas had more pedestrian crashes, but fewer fatal crashes than rural areas (Jermprapai & Srinivasan, 2014), possibly due to the lower speeds and more walking activity - proximity to medical care may be related as well. Another study notes that, when controlling for miles walked, pedestrian fatality rates are higher in rural (and small urban) areas than in urban and suburban areas (Jamali & Wang, 2017).

Consistent with the notion that higher density zones with lower density larger areas are more prone to pedestrian crash risk, there is considerable evidence that land uses such as strip malls and areas associated with arterial style big box commercial areas are connected to higher crash risk. A literature review of pedestrian risk factors found that rural areas and sprawling urban areas have higher pedestrian crash and fatality rates (not necessarily absolute numbers), which may be due to higher vehicle miles traveled (VMT) per capita and higher speeds (Stoker et al., 2015). More specifically, they found that characteristics associated with urban sprawl, including more arterials and strip malls, and big box stores are associated with higher traffic injury rates, while denser street networks are associated with fewer crashes (Stoker et al., 2015). A study in Florida found that density of discount stores, convenience stores and fast food stores was also associated with increased pedestrian crash frequency (Lin et al., 2019).

Some studies have found that alcohol sales locations (including bars, liquor stores, restaurants, and grocery stores) are associated with increased pedestrian crash risk. One study in New York City looked at the presence or absence of alcohol outlets in a census tract, and found that the presence of such an outlet in a tract increased the risk of an alcohol-related pedestrian or bicycle crash by 47%, although the authors noted that many such tracts had concentrations of outlets, such as entertainment districts (DiMaggio et al., 2016). A pair of studies in Baltimore found that each additional alcohol outlet in a census tract was associated with a 12-14% increase in pedestrian injury risk (Nesoff et al., 2018, 2018). These studies attempted to control for confounding factors; however, it should be noted that other studies have found that alcohol outlets tend to be concentrated in underserved communities (LaVeist & Wallace, 2000; Pollack et al., 2005).

3.1.3 Density of roads and intersections

Focusing in on the density of roads and intersections, most studies (though not all) have found that increased intersection density is associated with more crashes, including pedestrian-involved crashes, although a few studies have found that either injury severity is less when crashes occur at intersections (Abdel-Aty et al., 2013; Merlin et al., 2020). For example, one study in Florida found that more road miles and more intersections in a block group were associated with more pedestrian crashes (Jermprapai & Srinivasan, 2014). Another study in Florida found that block groups with more traffic signals and more bus stops per mile were associated with increased pedestrian crash frequency (Lin et al., 2019).

3.1.4 Walkability

While higher densities of people may be correlated with more pedestrian crashes, studies that have measures street connectivity and walkability have found that more walkable environments offer safety benefits. For example, a study in the Philadelphia region found that more connected and gridded street networks were inversely correlated with pedestrian crashes, injuries and fatalities (Guerra et al., 2019).

An array of studies show that built environments that are supportive of walking, bicycle and transit use are associated with higher levels of walking and physical activity (Adkins et al., 2017). The "safety in numbers" theory postulates that as more pedestrians and bicyclists are on the streets, collision rates relative to exposure go down – although the absolute number of pedestrian collisions go up, the collisions per pedestrian go down (Jacobsen & BMJ Publishing Group, 2003). A systematic literature review of the safety in numbers phenomenon confirmed that the effect exists, but concluded that the causes of the effect are still not completely understood. (Elvik & Bjørnskau, 2017). Further, the Philadelphia study also found that higher rates of walking were associated with more pedestrian collisions and injuries, on an absolute basis, but not fatalities (Guerra et al., 2019).

In some areas, evidence suggests that disadvantaged areas may in fact offer more walkable environments than more advantaged areas. For example, a Chicago study found that, by several measures, walking access and transit access was somewhat better in neighborhoods with higher than average concentrations of Black, Latino/Hispanic and/or lower-income (less than 150% of the poverty rate) residents (Cottrill & Thakuriah, 2010). However, this may be related to Black, Latino/Hispanic and low-income areas in Chicago being more focused on gridded urban neighborhoods, and higher income areas being in more suburban style development.

3.2 PEDESTRIAN INFRASTRUCTURE

A recent study looking at characteristics associated with increased crash risk found that the areas with the highest increases in pedestrian deaths nationally between 2009 and 2016 were urban areas (54% increase), arterials (67% increase), non-intersections (50% increase) and in dark conditions (56% increase) (Hu & Cicchino, 2018). Pedestrian infrastructure targeted at known pedestrian needs and safety gaps can help make walking safer. A number of the pedestrian infrastructure elements that are associated with improved pedestrian safety are less available in underserved communities. This section will discuss pedestrian infrastructure and its impact on safety, as well as evidence of disparities in availability or utility of the features.

Table 3.1 NHTS 2017 Data on Infrastructure and Safety Barriers to Walking by Demographic Group

	Infrastructure			Safety		
	No nearby paths or trails	**No nearby parks**	**No sidewalks or sidewalks are in poor condition**	**Street crossings are unsafe**	**Heavy traffic with too many cars**	**Not enough lighting at night**
Income						
Less than $25,000	9%	7%	11%	7%	11%	14%
$25,000 to $49,999	9%	7%	10%	6%	9%	12%
$50,000 to $99,999	8%	6%	9%	5%	7%	10%
$100,000+	7%	5%	8%	4%	6%	8%
Total	8%	6%	9%	5.5%	8%	11%
Race						
White	8%	6%	9%	5%	8%	10%
Black or African American	8%	6%	9%	6%	9%	12%
Asian	7%	8%	8%	8%	8%	11%
American Indian or Alaska Native	9%	7%	10%	7%	9%	12%
Native Hawaiian or other Pacific Islander	10%	11%	10%	10%	13%	11%
Multiple responses selected	9%	6%	9%	6%	8%	11%
Some other race	6%	6%	7%	6%	8%	10%
Total	8%	6%	9%	6%	8%	10%

Source: 2017 National Household Travel Survey

3.2.1 Sidewalks

The literature is mixed on the relationship of the presence of sidewalks on crash risk for pedestrians, with some studies finding decreased risk and others finding increased risk - the latter may be due to the presence of sidewalks being correlated with higher pedestrian activity, and therefore higher exposure (Merlin et al., 2020). A 2014 study in Austin found that both sidewalk completeness and land use mix were positively associated with commuting by walking and with pedestrian crash rates (Yu, 2014). The author points out that pedestrian infrastructure quality and maintenance are not considered in the analysis, nor are the role of gaps in the pedestrian network, and may have some role in safety outcomes. Other studies have noted the challenge of finding adequate information on sidewalk completeness.

There is evidence that underserved communities are less likely to have safe, accessible and high-quality pedestrian facilities (Sandt et al., 2016). A University of Illinois at Chicago study conducted street fields audits in a nationally representative sample 154 communities around the U.S., and found that 89% of streets in high-income areas ($57k+ on average) have sidewalks on one or both sides of the street, while only 59% of streets in middle income ($45-57k) areas do, and only 49% of streets in 51-54% in low income (less than $45k) areas do (Gibbs et al., 2012). A literature review notes that areas with higher poverty and lower education levels were less likely to have sidewalks built with federal funding (from 1994 to 2002), and that sidewalks have been documented to be lower in quality in lower income neighborhoods (Adkins et al., 2017). Further, NHTS data confirms that lower-income people are more likely to state that a lack of sidewalks, or sidewalks in poor condition are a barrier to them walking more, with 11% of respondents with household incomes under $25,000 stating this was a barrier, compared to 8 to 9% of those makes $50,000 or more (see Table 3.1).

Further, even areas with sidewalks may not be conducive to walking. First, sidewalks must have adequate clearance, such as unobstructed width for mobility devices to pass, lack of gaps, and access measures such as curb cuts, all of which are particularly important for pedestrians with disabilities. Other factors are also important when considering a walkable environment. For example, a 2016 study of street trees in the pedestrian realm in Spokane noted that areas with lower median income and lower home values had lower street tree canopy coverage, which is significant because trees can provide shade in hot months and protection from rain (Brooks et al., 2016).

3.2.2 Crossing features

Having access to safe crossing features is a core requirement for a safe pedestrian network, particularly for higher volume and wide roads. A study in Los Angeles, CA, found that 40% of pedestrian collisions occurred in marked crosswalks at intersections, while 28% took place while crossing outside marked crosswalk; 12% while a pedestrian was walking along the side of the road (not crossing), and 20% in other locations such as on a sidewalk, in parking lot, or other non-road locations (Loukaitou-Sideris et al., 2007). Nationally, the proportion of pedestrian fatalities occurring on roads with four or more lanes has increased from 41% to 58% between 1977 and 2016 (Schneider, 2020).

Longer block lengths appear to pose a hazard for pedestrians. A study in LA found that, of 12 intersections with high pedestrian collision rates selected for a case study, many had block lengths much larger than the city average (potentially inducing mid-block crossings) (Loukaitou-Sideris et al., 2007). A Florida study found that 57% of pedestrian crashes and 65% of pedestrian fatalities occurred outside of intersections, and recommended mid-block crossing signals, high visibility crosswalks, median islands, and appropriate landscaping (Lin et al., 2019).

State roads may pose a particular threat to pedestrians. A 2011 study in King County, WA, found that, for state routes, crossing at an unsignalized intersection was associated with an increased likelihood of a severe or fatal injury, though this was not true on city streets (Moudon et al., 2011).

There is evidence that lower-income neighborhoods are less likely to have crossing features. A 2012 study found that streets in high income areas are much more likely to have marked crosswalks (13% of streets), than middle income (8%) or low income (7%) (Gibbs et al., 2012). In terms of traffic calming features such as pedestrian medians and islands and curb extensions, 8% of streets in high income areas have such features, compared to 4% in middle income areas and 3% in low-income areas (Gibbs et al., 2012).

NHTS survey data adds further evidence to the existence of disparities, with lower income respondents being more likely to note that lack of safe crossings is a barrier to walking for them (see Table 3.1). Respondents with household incomes under $25,000 were 75% more likely to list this as a barrier than those earning 100,000 or more (7.3% compared to 4.1%).

A number of pedestrian crossing features have noted pedestrian safety benefits, which could be further assessed for equitable distribution. Among these are:

- **High-visibility crosswalk markings**, including continental or "zebra" crosswalks, are associated with better detection by motorists and increased yielding. A 2011 study found that such markings were detected by motorists at twice the distance from the crosswalk as parallel crosswalk markings both in daytime and nighttime conditions (Fitzpatrick et al., 2011). A literature review found that these crosswalk markings are associated with reduced collisions of 37% to 48% compared to parallel lines (Zegeer et al., 2017).

- **Rectangular rapid flashing beacons** (RRFBs), have been found to increase motorist yielding in all of nine separate studies (Zegeer et al., 2017). Zegeer et al estimated a pedestrian crash modification factor (CMF) of 0.526 for RRFBs, indicating they reduce pedestrian crashes by 47% (Zegeer et al., 2017).

- **Pedestrian hybrid beacons** have been found to have a pedestrian safety CMF of 0.453, and of 0.432 for hybrid beacons paired with advanced stop markings (Zegeer et al., 2017).

- **Pedestrian median refuge islands** are associated with reductions in pedestrian crashes (ranging from 23% to 73% across three studies), but may lead to an increase in vehicle-island crashes, which might be mitigated through design measures (Zegeer et al., 2017). A study of factors that influence the safety of elderly pedestrians found that medians and pedestrian refuges offer a particular safety benefit for older people, who are likely to cross more slowly, and take advantage of the median to rest, find a gap, and split their crossing (Kim, 2019)

- **Advanced yield or stop markings** were found to increase motorist yielding and decreasing pedestrian-motorist conflicts in 10 of 11 studies, with a CMF of 0.75 (Zegeer et al., 2017).

- **Raised pedestrian crossings** are associated with reduced vehicle speeds, although no CMF has been identified (Zegeer et al., 2017).

- **Signage** designed to increase pedestrian visibility and increase motorist yielding has generally been found to be effective in improving pedestrian safety, although most studies are behavioral rather than crash-based (Zegeer et al., 2017).

- **Curb extensions** have some mixed findings in terms of effectiveness for pedestrian safety. A literature review found that three of four studies looking at curb extensions demonstrated benefits such as reduced wait time, improved yielding, and increased yield distances; however, one study did not find any such benefits (Zegeer et al., 2017).

3.2.3 Speed, Volume, and Traffic Calming

Numerous studies have found that higher speeds are directly tied to higher injury severity and increased fatality risk for pedestrians (Stoker et al., 2015). Merlin et al. noted that that most studies agree "arterials, multilane streets, and roads with high speed limits are all associated with higher risk and more serious injuries (Merlin et al., 2020).

A meta-analysis of traffic safety studies found that pedestrian fatality risk increases dramatically between impact speeds of 30 and 60 kilometers per hour (about 19 to 37 miles per hour) – specifically "The risk of a fatality reaches 5% at an estimated impact speed of 30 km/h [19 mph], 10% at 37 km/h [23mph], 50% at 59 km/h[37mph], 75% at 69 km/h [43mph] and 90% at 80 km/h [50mph]" (Hussain et al., 2019). Roads with speed limits between 35 and 50 mph are responsible for 50% of pedestrian fatalities as of 2016, up from 33% in 1977 (Schneider, 2020). A study in NYC found that average speed limit of travel in census tract was associated with increased pedestrian injury risk. Specifically, "for every 10-mile-per-hour increase in average traffic speed in a census tract, there was a 24% decrease in pedestrian injury risk" (DiMaggio, 2015). Conversely, a study in Florida found that block groups with higher proportion of lower speed roads had fewer pedestrian crashes, and that lower speed limits were associated with less severe pedestrian crashes (Lin et al., 2019). Although not specifically speed, Lin et al also found that "aggressive drivers" were associated with increased pedestrian crash severity.

Higher traffic volumes are also associated with more pedestrian crashes (Jermprapai & Srinivasan, 2014). A national study of pedestrian fatalities found that traffic volumes on non-access controlled principal and minor arterials is strongly associated with increased pedestrian fatalities in urban areas (Mansfield et al., 2018). Multiple studies in urban areas have found traffic volume to positively associate with pedestrian injuries (Guerra et al., 2019; Loukaitou-Sideris et al., 2007; Stoker et al., 2015; Wier et al., 2009). Wier et al found that traffic volume was the strongest predictor of pedestrian collisions, while Guerra et al. noted that a doubling of AADT corresponded to 25 to 30% more pedestrian crashes and serious injuries. Assessments looking at vehicle miles travelled, rather than AADT, have also been found to be positively associated with pedestrian crashes (Abdel-Aty et al., 2013; Stoker et al., 2015). In the 2017 NHTS, low-income households were much more likely to list 'heavy traffic volumes' as being a barrier to walking, with 11% of those with household incomes under $25,000 reporting this as a barrier to walking, compared to 6% of those earning over $100,000 (see Table 3.1).

A number of approaches to slowing down motor vehicle traffic, including refuge islands with marked crossings, road narrowing, staggered lanes, and speed humps, show a reduction in pedestrian-vehicle collisions (Stoker et al., 2015). A Florida study found that the presence of traffic control devices such as a signal, stop sign, yield sign, school zone device or flashing signal were associated with lower injury severity in pedestrian crashes (Lin et al., 2019).

Narrower roads in particular are associated with slower speeds and fewer vehicle pedestrian crashes, while roadway expansions have the opposite effect (Stoker et al., 2015). An interesting exception to the road narrowing speed connection is that road reconfigurations (or diets), which usually result in wider lanes, but fewer lanes, are also associated with fewer crashes - perhaps because "faster" drivers must go the pace of more prudent drivers in one-lane configurations (Stoker et al., 2015).

3.2.4 Street Lighting

Two-thirds of fatal pedestrian collisions occur at night or in low light conditions, with twilight or the first hour of darkness having the highest frequency of such collisions (Stoker et al., 2015). Lack of adequate street lighting is also associated with pedestrian crashes and fatalities. A study in block groups in Broward and Palm Beach counties, Florida, found that a "dark-not lighted condition," particularly in higher speed limit locations, was the most influential variable relating to severe pedestrian crashes (Lin et al., 2019). In that study 72% of pedestrian fatalities occurred at night, and 22% of nighttime fatalities were on streets without lighting. Loukaitou-Sideris et al found that, of a dozen pedestrian high-crash intersections in Los Angeles, half lacked pedestrian lighting (Loukaitou-Sideris et al., 2007).

A literature review noted that roadway lighting and pedestrian held lighting or reflective clothing are both associated with decreased pedestrian-vehicle crash risk (Stoker et al., 2015). Presence of lighting, adequate lighting and uniformity, and pedestrian oriented lighting are recommended to address non-daylight crashes (Lin et al., 2019).

A University of Illinois at Chicago study found that 75% of streets in high-income areas have street or sidewalk lighting, while only 51-54% of those in middle- and low-income areas have such lighting (Gibbs et al., 2012). NHTS data confirms that this is a bigger barrier to walking for low-income residents – 13.8% of respondents in households earning $25,000 or less indicated this was a barrier, compared to 8.3% of those in households earning $100,000 or more (see Table 3.1)

3.2.5 Transit Stops

Transit stops may be an amenity connecting people with transportation, however they are also associated with higher pedestrian crash rates, which may be due to the increased pedestrian activity at these locations (Merlin et al., 2020). A Florida study found that more commuters using transit, and more bus stops in a block group were associated with more pedestrian crashes (Lin et al., 2019). Loukaitou-Sideris et al. found that high-crash intersection locations for pedestrians were likely to have transit, attracting pedestrians to stops and possibly limiting passing vehicles visibility (Loukaitou-Sideris et al., 2007).

3.3 CRASH RATES AND OUTCOMES

Data from NHTSA's Fatality Analysis Reporting System (FARS), shows that total fatal crashes and fatalities slowly rose from 1994 to 2005, peaking at 39,252 fatal crashes, and 43,510 fatalities nationally. After several years of modest declines, both numbers dropped sharply between 2007 and 2009, coinciding with the economic recession. After hitting a relative low of 30,056 fatal crashes and 32,744 fatalities in 2014, annual numbers have jumped back up to around 34,000 annual fatal crashes and 37,000 fatalities. In 2018, there were 36,560 reported traffic fatalities, of which 6,283 were pedestrians, 857 were pedalcyclists, and 214 with other or unknown nonoccupants.

Pedestrian deaths increased 35.4% nationally from 2008 to 2017, even though rates of walking have not increased (Smart Growth America & National Complete Streets Coalition, 2019). Between 2002 and 2007, pedestrians accounted for 11% of traffic fatalities; however, that percentage has increased since 2008 and is now at 17%.

At the core of the question of inequity in pedestrian safety is whether different groups, and particularly disadvantaged groups, experience a disproportionate number of pedestrian crashes, injuries or fatalities. A study looking at pedestrian fatality statistics found that "even after controlling for differences in population size and walking rates, we see that drivers' strike and kill people over age 50, Black or African American people, American Indian or Alaska Native people, and people walking in communities with lower median household incomes at much higher rates" (p.17) (Smart Growth America & National Complete Streets Coalition, 2019). This section will examine the literature pertaining to what is known about those outcomes.

3.3.1 Travel characteristics

A geographic analysis found that areas with higher numbers of people commuting by transit, as well as higher number of workers commuting by walking, are associated with significant increases in pedestrian crashes (Abdel-Aty et al., 2013). Other factors that suggest higher rates of walking are also associated with higher crash rates. For example, areas with lower rates of car ownership have been found to be positively correlated with pedestrian crashes (Chimba et al., 2014). High proportions of people who commute using public transit or by biking, as well as higher proportion of zero-car ownership households, are associated with increased pedestrian crash frequency, according to a study in Broward and Palm Beach countries (Lin et al., 2019). Relatedly, areas or segments with more transit stops/availability have been found to be positively correlated with pedestrian crashes in a number of studies (Cottrill & Thakuriah, 2010; Dai & Jaworski, 2016). However, at least one study, which focused on the City of Baltimore, found transit access to be negatively correlated with pedestrian crash severity (Clifton et al., 2009). Table 3.2 provides a summary of findings related to travel characteristics and other pedestrian activity generators.

Table 3.2 Literature Review Pedestrian Crash Findings - Activity Related

Variable	Summary of significant findings
Population Density	• 8 studies found population density is associated with more pedestrian crashes (Apardian and Smirnov 2020; Chakravarthy et al 2010; Dai and Jaworski 2016; Dumbaugh and Li 2010; Lin et al 2019; Loukaitou-Sideris et al 2007; Ukkusuri 2012; Yu 2014) • 1 study found population density is negatively associated with pedestrian crashes (Jermprapai and Srinivasan 2014) • 5 studies found population density is associated with a higher number of injury or severe injury pedestrian crashes, or increased severity of pedestrian crashes (La Scala 2000; Lin et al 2019; Moudon et al 2011; Ukkusuri 2012; Yu 2015) • Two studies found that increase population density was associated wither fewer fatalities in cities or urban areas (Guerra et al 2019; Mansfield et al 2018), while one also found it associated increased pedestrian crashes, injury crashes, and fatalities in suburban areas (Guerra et al 2019)
Employment Density	• Three studies found that higher employment density (or more weekly work trips) were associated with more pedestrian crashes (Guerra et al 2019; Jermprapai and Srinivasan 2014; Loukaitou-Sideris et al 2007; Wier at al 2009). Mansfield et al 2018 noted that in particular the employment density of entertainment and food services employees was associated with more pedestrian crashes. Two studies did not find employment density to be significant (Moudon et al 2011; Yu 2015)
No cars in household	• Three studies found higher proportions of household without a car to be associated with increased pedestrian crashes (Chimba et al 2014; Cottrill and Thakuriah 2010; Lin et al 2019).
Walking and Transit Commute Rates	• Of six studies looking at walking or transit commute rates, one found that walking commute rates was associated with increased pedestrian crashes (Abdel-Aty el al 2013), two found that transit commute rates were associated with more pedestrian crashes (Abdel-Aty et al 2013; Dai and Jaworski 2016). • Two others found that combined active commute measures (either transit plus biking or transit plus walking) were associated with increased pedestrian crashes (Lin et al 2019; Ukkusuri 2012). • Two studies considered the variables but did not include them in their final models (Mansfield et al 2018; Wier at al 2009).
Transit Stops	• Three studies found that more transit stops were associated with more pedestrian crashes (Dai and Jaworski 2016; Jermprapai and Srinivasan 2014; Ukkusuri 2012; Yu 2014). • One study found that more transit stops were associated with fewer pedestrian crashes (Clifton et al 2009) and one found decreased pedestrian crash severity (Yu 2015)

Arterials and Traffic Speed	• Six studies looked at the miles or proportion of arterial roads. Four found that higher proportion of arterials (Wier et al 2009), or more miles of arterial roads (Abdel Aty et al 2013; Dumbaugh and Li 2010; Guerra et al 2019), were associated with more pedestrian crashes. Two others found that higher proportion of lower speed or local roads were associated with fewer pedestrian crashes (Lin et al 2019; Ukkusuri 2012) • Five studies looked at average vehicle speeds, with four finding that higher average speeds were associated with more pedestrian crashes (Chimba et al 2014; DiMaggio 2015; Guerra et al 2019) C and /or increased injury severity (Guerra et al 2019; Yu 2015). One looked at maximum speed limit (Dai and Jaworski 2016) and found it to not be significant.
Traffic Volume	• Of 11 studies looking at traffic volumes, such as VMT or AADT density, seven found that higher average traffic volumes levels were associated with more pedestrian crashes (Cottrill and Thakuriah 2010; DiMaggio 2015; Guerra et al 2019; La Scala 2000; Loukaitou-Sideris et al 2007; Mansfield et al 2018; Wier at al 2009). Four studies did not find volume to be significant (Dumbaugh and Li 2010; Kim 2019; Yu 2014;Yu 2015)

3.3.2 Racial / Ethnic differences

See Table 3.3 for a summary of literature review findings on sociodemographic variables, including race and ethnicity. Across the U.S., Black or African American pedestrians and American Indian of Alaska Native pedestrians are more likely to be struck and killed while walking, than the overall U.S rate (Smart Growth America & National Complete Streets Coalition, 2019). African-Americans and Native Americans are disproportionately likely to be pedestrian fatality victims "the U.S. population was 12% Black in 2000 and 13% Black in 2010, but 17% of pedestrians killed during 2002–2016 were Black. Native Americans were also overrepresented: they made up 0.9% of the population but 2.3% of pedestrian fatalities" (Schneider, 2020). Geographic analyses are consistent with these national numbers, with areas of higher BIPOC populations being associated with more pedestrian crashes. For example, a geographic analysis in Florida found that areas with a higher proportion of BIPOC residents are associated with significant increases in pedestrian crashes (Abdel-Aty et al., 2013). A 2010 study in Chicago found that census tracts with higher than average (for the region) proportion of black, Latino/Hispanic or low-income residents had nearly 3 times the number of pedestrian crashes (9.66 crash per 10,000 residents compared to 3.37), including more hit-and-run type crashes (Cottrill & Thakuriah, 2010).

Numerous studies have found that areas with higher proportions of Black residents are correlated with more pedestrian crashes. A study in Toledo, Ohio found that census tracts with higher proportions of black residents and higher total black population were associated with increased pedestrian crashes (Apardian & Smirnov, 2020). A study in Philadelphia found that increase in proportion of Black residents in a census tract was associated with an increase in pedestrian crashes, though not significant connection to injuries and fatalities (Guerra et al., 2019).

One challenge with studies using demographic characteristics as pedestrian crash correlates is that there can be considerable multicollinearity between variables such race and income. A study in Los Angeles used percentage of the population that was Hispanic or Latino as the sole socio demographic factor in their regression of pedestrian collisions, due to strong multicollinearity between ethnicity and other factors such as age and poverty. Proportion of Latino/Hispanic residents was positively associated with pedestrian collisions, and the authors note that "these findings support the assumption that pedestrian collisions are more likely to occur in low income, minority neighborhoods once other aspects of risk are controlled for" (Loukaitou-Sideris et al., 2007).

Areas with more non-English speakers are also associated with more pedestrian crashes. A study in Orange County, California, found that census tracts with more people who speak English less than very well are associated with greater numbers of pedestrian crashes (Chakravarthy et al., 2010). Another study of pedestrian crashes in Florida found that as the proportion of people who do not speak English well in census block groups increase, pedestrian crashes increase (Jermprapai & Srinivasan, 2014).

Aside from the number of pedestrian crashes, other inequities exist in areas that can impact pedestrian injury severity. A national study of outcomes for vehicle-struck pedestrians revealed that, compared to white pedestrians, African Americans had 22% greater odds of mortality while Latinos/Hispanics had 33% greater odds of mortality (Maybury et al., 2010). The same study also found that black and Latino/Hispanic trauma patients were more likely than white trauma patients to be uninsured, a factor which compounded their mortality outcomes, as uninsured patients were 77% more likely to die than privately insured patients. The study notes that certain trauma comorbidities and untreated conditions may be more common among these groups, including diabetes and hypertension. A meta-analysis of trauma care and outcomes confirmed the independent negative outcomes for Black and uninsured trauma victims, though found mixed findings on the outcomes for Latino/Hispanic trauma patients (Haider et al., 2013). The authors noted seven out of eight studies found that the worse mortality outcomes for Black trauma victims were independent of socioeconomic status. Several studies have also found that lower socioeconomic status is associated with worse mortality outcomes for trauma victims (Haider et al., 2013).

A further consideration is that pedestrian non-fatal injuries may be disproportionately underreported for Black men, which would further exacerbate the difference in pedestrian crashes. A study in San Francisco compared police crash records to hospital injury records found that crash records underreported pedestrian injuries by 21%, with men and African-Americans being more likely to be under-reported (Sciortino et al., 2005). The authors note that “these biases are likely due to the reluctance of some pedestrians to summon the police and file a report when the police were not initially present at the scene of a collision” (pg. 1111), and have the potential to systematically alter perception of traffic safety, such as predominantly African-American neighborhoods having artificially low pedestrian crash rates.

3.3.3 American Indian, Indigenous Populations

Native and indigenous people suffer from pedestrian injury fatality rates higher than any other racial or ethnic group (LaValley et al., 2004; Quick & Narváez, 2018). In fact, American Indian or Alaska Natives suffered pedestrian fatality rates of more than twice the national average, with 33 pedestrian fatalities per 100,000 people, compared to a national average of 14.8 (Smart Growth America & National Complete Streets Coalition, 2019). Data from the National Highway Traffic Safety Administration’s Fatality Analysis Reporting System (FARS) shows an average of 124.2 annual pedestrian fatalities for American Indian individuals nationally, with 37 of those occurring on reservations (FARS, 2020). A focus on pedestrian safety of these individuals, including on reservations, is an important consideration. It is also important to note that approximately 22% of American Indians live on reservations, and so American Indian safety and safety on reservations overlap, but are not the same thing (Quick & Narváez, 2018). One challenge for reservation safety is a patchwork of road ownership between reservation, state, county and others, making comprehensive safety planning and coordination challenging (Quick & Narváez, 2018).

A national survey of tribal and state governments found that pedestrian safety was consistently rated a top priority, along with prioritizing safe pedestrian infrastructure, for reservations (Quick & Narváez, 2018).

3.3.4 Income and poverty differences

Income is strongly correlated with pedestrian crashes and fatalities. Numerous studies have found an inverse relationship between socioeconomic status and injury and fatality risk (Stoker et al., 2015). A literature review of correlates with pedestrian crashes found five studies looking at the connection between income and pedestrian crashes - in each study, higher income levels were associated with fewer pedestrian crashes (Jermprapai & Srinivasan, 2014). In a study of pedestrian crashes in Orange County, California, the percentage of residents living in low-income households was a strong predictor of pedestrian crashes. The quartile of census tracts with the lowest percentage of low-income households, defined as under 185% of poverty line, had 11 pedestrian crashes per 100,000 residents compared to 44 per 100,000 residents in the quartile with the most low-income households (Chakravarthy et al., 2010). Chakravarthy also noted, with regard to the pedestrian crash rate being four times higher in the lowest income quartile than in the upper income quartile tracts, that "neither the age of the population, education, English-language fluency, nor population density explained the effect of poverty" (Chakravarthy et al., 2010).

Other studies have found consistent income effects on pedestrian crashes. A study in San Francisco found that areas with a higher proportions of people living in poverty were associated with more vehicle-pedestrian collisions (Wier et al., 2009). A study in Toledo, Ohio, found that census tracts with higher home-ownership rates were associated with lower pedestrian crash numbers, while lower median house value was associated with higher crash risk (Apardian & Smirnov, 2020). A study in Philadelphia found that higher poverty was more associated with pedestrian collisions and injuries than with total (i.e. - non-pedestrian) collisions and injuries. That study found that a 1% increase in poverty led to 0.22 increase in pedestrian crashes, 0.24 increase in injuries and 0.17 increase in fatalities (Guerra et al., 2019).

In terms of pedestrian fatalities, a report looking at NHTSA FARS data from 2008 to 2012 found that low income tracts, defined in the report as per capita income of less than $21,559, in metropolitan areas had pedestrian fatality rates twice as high as in more affluent areas, defined as those with per capita incomes of greater than $31,356 (Maciag, 2014). The percentage of residents in a census tract in poverty is also correlated with pedestrian fatalities. Tracts with less than 5% of residents in poverty had 3.8 pedestrian fatalities per 100,000 residents, while tracts with over 30% of residents in poverty had 12.6 fatalities per 100,000 residents (Maciag, 2014).

Another study looking at national data from 2008 to 2017 found that pedestrian fatality rates in neighborhoods with a median household income between $3,000 to $36,000 were more than 2.5 times higher than in neighborhoods with incomes from $79,000 to $250,000 (Smart Growth America & National Complete Streets Coalition, 2019). A study in NYC from 2001 to 2010 found that for each $10,000 increase in median household income, there was a 3% decrease in pedestrian injury risk (DiMaggio, 2015).

A study in Minneapolis found that pedestrian crash risk at intersections was significantly higher in lower-income areas with majority-BIPOC populations, and that, when the Central Business District is excluded, pedestrian mid-block crash risk is also significantly higher in such areas (Lindsey et al., 2019). Jermprapai and Srinivasan's results from a statewide Florida analysis confirm that census block groups with higher median income or higher proportion of households in poverty were associated with more pedestrian crashes, more severe and fatal crashes, and more nighttime crashes. (Jermprapai & Srinivasan, 2014).

Related to income and poverty, homelessness may be a factor in pedestrian safety, although few studies have examined the precise connection. Among the limited examinations of the connection between homelessness and pedestrian safety, a study in Clark County (including Las Vegas), Nevada, found that homeless people were about 20 times more likely to suffer a pedestrian fatality than other residents, including being more likely to occur in the evening hours, and being more likely to involve alcohol consumption on the part of the pedestrian (Hickox et al., 2014). A 2020 article on pedestrian fatalities in Portland noted that homeless people accounted for 2 out of 8 pedestrian fatalities in 2019, although both were in fact sleeping on the sidewalk when struck by motorists (Riski, 2020). As homelessness numbers have increased in recent years, further study of the link between homelessness and pedestrian safety is needed.

3.3.5 Education

A literature review of correlates with pedestrian crashes found three studies looking at the connection between education and pedestrian crashes - in each study, higher education levels were associated with fewer pedestrian crashes (Jermprapai & Srinivasan, 2014). Another Florida study (in Broward and Palm Beach counties) found that block groups with higher proportion of people with less than high school education are associated with more pedestrian crashes (Lin et al., 2019). Jermprapai and Srinivasan's results from a statewide Florida analysis confirm that block groups with higher education levels are associated with lower pedestrian crash rates. A study in Orange County, CA, found that census tracts with more people with less than a high school education are associated with greater numbers of pedestrian crashes (Chakravarthy et al., 2010).

3.3.6 Age

People who cannot drive, including children, older adults and people with disabilities are more reliant on walking and transit to get around, and are more reliant on high quality facilities to navigate safely (Sandt et al., 2016).

Young children are overrepresented in traffic deaths, representing 21% of road traffic deaths, making it a second leading cause of death for young children and a leading cause of childhood disability (Stoker et al., 2015). The reasons for their vulnerability range from underdeveloped abilities and perception, unpredictability, and lesser visibility due to small size (Stoker et al., 2015). Further, numerous studies have found that the risk to children in particular is much higher for those with lower socioeconomic status, ranging from twice as high to up to seven times higher than for children of higher socioeconomic status (Stoker et al., 2015).

Walking is a primary mode of transportation, and by extension, independence and physical activity, for many older adults (Stoker et al., 2015). There is mixed evidence on whether areas with older adults result in more pedestrian crashes. However, there is considerable evidence that such areas are associated more severe pedestrian crashes. Studies of pedestrian crashes in Florida have found that higher median age for a census block group, or higher proportions of older adults, are associated with fewer pedestrian crashes (Jermprapai & Srinivasan, 2014; Lin et al., 2019). However, one of those studies found such areas were associated with fewer severe crashes (Jermprapai & Srinivasan, 2014), while the other found they were associated with more severe pedestrian crashes (Lin et al., 2019). On the other hand, a study in San Francisco found that areas with a higher proportions of people over 65 years of age were associated with more vehicle-pedestrian collisions (Wier et al., 2009).

Regardless, elderly individuals are the most overrepresented in traffic deaths (Stoker et al., 2015). Based on fatality risk, pedestrian danger for people 75 and over is twice that of the U.S. overall (Smart Growth America & National Complete Streets Coalition, 2019). A study in King County, Washington, found that, for pedestrian involved in motor vehicle-pedestrian crashes, older pedestrians were more likely to suffer a severe or fatal injury (Moudon et al., 2011). Contributing factors in older adults' higher risk of traffic injury and fatality include reduced mobility and visual acuity, higher frailty, slower rate of travel when crossing streets, which is directly related to crossing times being too fast for many older adults (Stoker et al., 2015).

Table 3.3 Literature Review Pedestrian Crash Findings - Sociodemographic

Variable	Summary of significant findings
Race / Ethnicity	• Seven studies found that higher proportion of minorities are associated with more pedestrian crashes (Abdel-Aty et al 2013; Apardian and Smirnov 2020; Chimba et al 2014; Guerra et al 2019; Lin et al 2019; Loukaitou-Sideris et al 2007; Mansfield et al 2018), including 5 finding specific connections between higher African-American or Black populations and pedestrian crashes (Apardian and Smirnov 2020; Chimba et al 2014; Guerra et al 2019; Lin et al 2019; Mansfield et al 2018), two findings connections between higher Latino populations and pedestrian crashes (Chimba et al 2014; Loukaitou-Sideris et al 2007), and one finding a connection between higher Asian populations and fatal pedestrian crashes (Mansfield et al 2018). • Conversely, two studies found connections between higher white populations and reduced pedestrian crashes (Chimba et al 2014; Yu 2014)
Income	• Six studies found household income to be associated with FEWER pedestrian crashes (Cottrill and Thakuriah 2010; Dai and Jaworski 2016; DiMaggio 2015; Jermprapai and Srinivasan 2014; Mansfield et al 2018). • One study found household income to be associated with more pedestrian crashes (Chimba et al 2014). • Five studies considered the variable but did not include it in their final models (Abdel-Aty et al 2013; Clifton et al 2009; La Scala 2000; Lin et al 2019; Yu 2015)
Poverty	• Five studies found that higher proportions of household below poverty level were associated with increased pedestrian crashes (Chakravarthy et al 2010; Chimba et al 2014; Guerra et al 2019; Jermprapai and Srinivasan 2014; Wier at al 2009)
Education Level	• Three studies looking at education levels found that the proportion of residents without a high school diploma or equivalent was associated with increased pedestrian crashes (Chakravarthy et al 2010; Lin et al 2019), pedestrian injuries (La Scala 2000) and severe pedestrian injuries (Lin et al 2019). One did not find the variable significant (Apardian and Smirnov 2020).
Non-English Language	• Three studies found connections between higher proportion of non-English speaking residents and more pedestrian crashes (Chakravarthy et al 2010; Dai and Jaworski 2016; Jermprapai and Srinivasan 2014), with Jermprapai and Srinivasan also finding proportion of non-English speaking residents associated with severe pedestrian crashes, fatal pedestrian crashes, and nighttime pedestrian crashes. • Two studies considered the variable but did not include it in their final models (Cottrill and Thakuriah 2010; Lin et al 2019)
Unemployment	• La Scala 2000 found that higher unemployment was associated with more pedestrian injury crashes. • However, Chimba et al 2014 found that higher labor force participation was associate with more pedestrian crashes.

Variable	Summary of significant findings
Age	• Studies looking at average age have found age to be associated with increased severity of crashes (Moudon et al 2011 Yu 2015). • One study found age negatively associated with crashes, severity and nighttime crashes (Jermprapai and Srinivasan 2014). Proportion of 65+: • Of studies looking at the proportion of residents over age 65, five found that to be associated with fewer pedestrian crashes(Chakravarthy et al 2010; Dai and Jaworski 2016; Lin et al 2019; Ukkusuri 2012; Wier at al 2009), and one found it to be associated with more pedestrian crashes (Guerra et al 2019). • Two studies found higher proportions of 65+ residents to be associated with fewer severe pedestrian crashes(Jermprapai and Srinivasan 2014 Lin et al 2019), while three found it to be associated with more severe crashes (Clifton et al 2009; Moudon et al 2011; Yu 2015). Proportion of children: • Studies are mixed on the impact of higher proportion of children on pedestrian crash rates. Three found increases in pedestrian crash rates (Chakravarthy et al 2010; Clifton et al 2009; Ukkusuri 2012), while two found decreases (Apardian and Smirnov 2020; La Scala 2000). • Another study found the proportion of kids in K-12 in a TAZ associated with more pedestrian crashes, while the proportion of kids age 0-15 was associated with fewer pedestrian crashes (Abdel-Aty et al 2013)

3.4 OREGON DATA

Based on Oregon travel activity data, national trends are mostly with a short summary offered below. Lower-income Oregonians are less likely to own a car, are more likely to choose to travel by walking or transit due to financial burden, and yet do not feel they have safe places to walk. As noted below, that feeling is reflected in pedestrian crash data.

A 2019 report on Oregon travel behavior, based on data from the 2009-2011 Oregon Household Activity Survey (OHAS), found that lower-income households reported taking fewer daily trips on average and travelled fewer daily miles on average (Bricka, 2019). However, as seen in Figure 3.1, those households making under $25,000 per year, who took fewer trips and travelled fewer miles per day, were actually spending the same amount of time travelling as higher income households that were taking more trips travelling more miles, reflecting slower travel times.

Table 2-3: Travel Metrics by Household Income

Household income	Person Trips	Daily Trip Miles	Daily Travel Time (minutes)
Less than $25k	3.4	20	76
$25k-<$50k	3.5	25	73
$50k-<$75k	3.7	26	72
$75k+	3.9	31	76

Figure 3.1 OHAS travel metric by household income (Bricka 2019)

NHTS data from 2017 provides some further insight into the travel options of lower-income households. Table 3.4 shows details about vehicle availability and household trips for Oregon households included in the survey. While confirming the fewer trips per day for lower-income households (NHTS data shows lower-income households making half as many trips as higher-income households), it also shows that lower-income households were much less likely to own a car, with 19% of households earning under $25,000 not owning a car, compared to less than 4% of any other income category not owning a car.

Table 3.4 NHTS 2017 Oregon Data – Vehicle Availability and Trip-making

Household income	Number of vehicles per household	Vehicles per household member	Zero Vehicle households	Zero drivers in household	Household trips on travel day	0 trips on travel day
Less than $25,000	1.3	0.6	19%	15%	5.6	15%
$25,000 to $49,999	1.7	0.8	6%	4%	7.7	9%
$50,000 to $99,999	2.6	1.0	0%	0%	8.5	5%
$100,000+	2.3	0.8	4%	3%	11.7	1%
Total	2.0	0.8	6%	5%	8.4	7%

Source: Oregon households in 2017 NHTS data; MOE 5% at 95% confidence level

Looking back at the OHAS survey findings, Bricka (2019) noted that zero-vehicle households are much more likely to travel by walking or by transit. Table shows that walking accounted for 34% of trips for households without a car, compared to 8% of all adult travelers, while transit accounted for 25% of trips for households without a car, compared to 3% of all adult travelers.

Table 4-2: Travel Mode by Auto Availability for Adults

Auto Availability	Travel Mode					Total
	Auto-Driver	Auto-Passenger	Walk	Bike	Transit	
Zero Vehicle Households	9%	26%	34%	5%	25%	100%
Workers>Vehicles	64%	19%	9%	4%	3%	100%
Workers=Vehicles	77%	10%	8%	3%	2%	100%
Workers<Vehicles	83%	10%	5%	1%	1%	100%
All Adult Travelers	73%	13%	8%	3%	3%	100%

Figure 3.2 OHAS travel mode by vehicle availability. Source: (Bricka, 2019)

NHTS survey data for Oregon helps to understand some factors that influence travel mode choice, particularly for households earning under $25,000 (see Table 3.5). Households earning under that amount are much more likely to indicate that the price of gasoline affect their travel choices (65% compared to 44% for all respondents) and that travel is a financial burden (52% to 30%). This suggests that, even for low-income households with a car, the costs are burdensome. Further, respondents in that lower-income groups were much more likely to indicate that they use alternative modes, particularly walking and travel, in order to reduce financial burden.

Lower-income and BIPOC residents in Portland may further limit their travel due to unsafe travel conditions were they to travel by walking, biking or transit. Lubitow and Mahmoudi

(2016) conducted focus groups with Portlanders from six neighborhoods in East and North Portland, most of whom were low-income and BIPOC. The focus groups asked about barriers to walking, biking, and taking public transit. Many cited lack of safe places to walk - an issue for both walk trips as well as transit trips wherein people need to feel safe getting to and from transit stops (Lubitow & Mahmoudi, 2016).

Table 3.5 NHTS 2017 Oregon Data - Financial Burden of Travel

Household Income	Price of Gasoline Affects Travel	Travel is a Financial Burden	Walk to Reduce Financial Burden of Travel	Bicycle to Reduce Financial Burden of Travel	Public Transportation to Reduce Financial Burden of Travel
Less than $25,000	65%	52%	28%	15%	32%
$25,000 to $49,999	55%	31%	19%	6%	19%
$50,000 to $99,999	35%	26%	19%	12%	16%
$100,000+	27%	17%	11%	5%	9%
Total	44%	30%	19%	10%	18%

Source: Oregon households in 2017 NHTS data (N = 385) ; MOE 5% at 95% confidence level

There is also evidence that the travel choices that lower-income households are forced to make, either due to lacking a car or to reduce financial burden, are born out in worse pedestrian safety outcomes. A report looking at pedestrian fatalities in metro areas found that the Portland Metro area was, like most other regions, much deadlier for pedestrians in lower-income census tracts than it was for those in higher income census tracts. For 2008 to 2012, the overall Portland metro area had a pedestrian fatality rate of 5.3 fatalities per 100,000 residents. For tracts with over 25% of residents living in poverty that number was 12.8 fatalities per 100,000 people, while for tracts from 15% to 25% in poverty that number was 7.1 fatalities per 100,000, and for tracts less than 15% in poverty that number was 3.5 fatalities per 100,000 (Maciag, 2014).

3.4.1 Representation in Oregon survey data

As both a caveat to the interpretation of the NHTS survey data, and as a troubling inequity in its own right, it should be noted that lower-income and, especially, BIPOC Oregonians are underrepresented in the survey data (although the national data is weighted to reflect a demographically valid sample). For the 2017 NHTS survey, there were 385 households surveyed in Oregon. While 2017 ACS 5-year data for Oregon shows that 21.3% of the population earned less than $25,000 per year, the sample only included 16.5% in that income category. Starker were the race and ethnicity samples. The Oregon NHTS sample was 7.1% BIPOC, while the Oregon population is 15.1% BIPOC. Black residents make up 1.9% of the Oregon population, but only 0.5% of the NHTS sample, which was only 2 households. Meanwhile, 12.7% of the

Oregon population identifies as Latino/Hispanic, but only 2.9% of the NHTS sample did so. While NHTS provides weighting to account for these types of discrepancies, these groups are clearly underrepresented in data collection, and the data is subject to greater error due to the underrepresentation. OHAS similarly underrepresented BIPOC households in its 2011 collection at both aggregate and tract levels (Liévanos et al., 2019).

4.0 METHODS REVIEW – ASSESSING PEDESTRIAN CRASHES AND INEQUITY

4.1 ZONAL VS NETWORK APPROACH

Pedestrian safety analysis has often focused on roadway characteristics, with disaggregation at the intersection and segment level, looking at characteristics that might be associated with increased pedestrian crashes, injuries and fatalities. These usually consider roadway volumes, speeds (speed limit, 85% percentile speed, percent of vehicles travelling 5 or 10 miles over the speed limit, etc.), width (crossing distance, number of lanes, etc.), crossing facilities (presence, spacing, type, and quality), medians, sidewalks, lighting and other factors. Some consider adjacent land use, pedestrian volumes (a proxy for exposure), crash records factors (time of day, weather, participants involved), and other factors.

In order to incorporate equity considerations, including the potential influence of income, race, immigration status, age, or other factors, into analyses of pedestrian crash locations, frequency and severity, most studies have turned to census data. This allows for the assessment of whether, for example, lower-income areas are more likely to experience higher rates of pedestrian injury or fatality crashes. The process of connecting the network-based roadway characteristics, crash location data, and the zonal census-derived data (often in census tract or block group formats), requires the decision of whether to employ zonal or network analyses, or a combination.

Although crashes occurring within a zone (e.g. census tract) are not necessarily attributable to residents living within the zone, there is strong evidence that most pedestrian crashes occur nearby where people live. One study (Haas et al., 2015) found that half of pedestrian injuries occur within 1.1 miles from the victim's home, while another found that half of pedestrian injuries occur within 1 mile from home, with 22% occurring in their home census tract, and another 22% occurring in a tract bordering their own (Anderson et al., 2012). For children and those over 65 years of age, over half of pedestrian injury crashes occur within half a mile of their home (Anderson et al., 2012).

In the following section, we discuss analysis characteristics of pedestrian-equity related safety analysis that examined crash location characteristics. Most of the studies opted to identify analysis zones, primarily census tracts or block groups, and tabulate pedestrian crash data to those zones. For example, the number of pedestrian crashes, injury crashes, or fatalities that occurred within the boundary of a block group, which could then be compared to available census data. In order to incorporate other transportation system data, the analysis might similarly tabulate values for the specified geographic area – for example the length of or percentage of roads within the zone that are arterials or residential streets, the number of intersections within the zone or the link-node ratio (ratio of segments to intersections), the average AADT of road segments within the zone, the proportion of roads with sidewalks, the number of crosswalks, etc.

An alternative approach to zonal analysis is to utilize network features, such as intersections or street segments, or individual crash locations, as analysis zones. Studies that used this approach tended to assign demographic or land use values to segments, intersections, or crash locations based on proximity or assigning the value of the tract or block group in which the feature was located. For example, Dai and Jaworski broke the road network into 100-meter-long segments, and assigned pedestrian crashes to its nearest segment. They then took point-location built environment features, including transit stops, stores/restaurants, bars, and summed the number accessible to any given segment within a 0.5-mile walk, and assigned census tract derived variables (including population density, income, and others) to a segment based on being located within the tract (Dai & Jaworski, 2016).

4.2 ECOLOGICAL PEDESTRIAN CRASH STUDIES REVIEW

4.2.1 Overview

The research team identified 22 studies looking at spatial characteristics of pedestrian crashes published between 2000 and 2020, with priority given for studies published between 2010 and 2020 (earlier studies were included if they were deemed foundational to the topic area based on citations from multiple subsequent studies). An overview of key study and model details is provided in Table . Of the 22 studies, seven included a focus on some aspect of equity, typically looking at pedestrian crash outcomes and differences by income or race/ethnicity, although age was also considered. However, 18 of the 22 studies included income or race / ethnicity variables in their analysis, allowing for equity-related findings based on those variables to be considered. A full list of significant variables relating to pedestrian crashes is included in the Appendix in Table A-1.

Table 4.1 Pedestrian Crash Studies Overview

Study	Geography	Time-frame	Analysis Zone	Dependent Variable(s)	Model type
Abdel-Aty et al 2013	Hillsborough and Pinellas counties, FL	2005 to 2006	1479 traffic analysis zones, 1338 block groups and 457 census tracts.	total crashes (n=87,718); severe crashes (7106); pedestrian crashes (1665)	Poisson-lognormal models in a Bayesian framework
Apardian and Smirnov 2020	Toledo region (urbanized part of region, with least dense, by population, quintile of CT removed), OH and MI	2007 to 2016	124 Census Tracts	pedestrian crashes (1284)	expanded Poisson regression framework to include spatial effects
Chakravarthy et al 2010	Orange County, CA	2000 to 2004	577 census tracts	pedestrian collisions (4222, with 4524 pedestrians involved)	negative binomial regression
Chimba et al 2014	Statewide, Tennessee	2003 to 2009	primarily census tract	5,360 pedestrian crashes; 2,558 bicyclist crashes	Negative Binomial (NB) regression
Clifton et al 2009	Baltimore City, MD	2000 to 2004	crash location (with 1/4-mile buffer)	pedestrian crash injury severity (fatality, injury, no injury); >4500 ped crashes	Ordered probit model
Cottrill and Thakuriah 2010	Chicago metro, IL	2005	1832 census tracts	pedestrian involved vehicle crashes (4886)	Poisson; Comparison of crash rates (injury, fatal, non-injury) in EJ vs non EJ tracts
Dai and Jaworski 2016	DeKalb County, Georgia	2000–2007	network: 100-meter segments	pedestrian crashes (1047)	bivariate correlation; multivariate analysis based on negative binomial regression
DiMaggio 2015	New York City, NY	2001 to 2010	1908 census tracts	140,834 pedestrian and bicyclist injuries	Bayesian hierarchical spatial models using integrated nested Laplace approximations

Study	Geography	Time-frame	Analysis Zone	Dependent Variable(s)	Model type
Dumbaugh and Li 2010	San Antonio-Bexar County metropolitan region, TX	2003 to 2007	block group	Vehicle-pedestrian crashes (3,108); Motorist crashes; Multiple-vehicle crashes; Fixed-object crashes; Parked-car crashes; Vehicle-cyclist crashes	negative binomial regression models
Guerra et al 2019	Philadelphia region, PA	2010 to 2014	intersections and segments (~250,000); census tracts (998)	total reported collisions (247,997) total serious injuries total traffic fatalities pedestrian-involved collisions pedestrian serious injuries pedestrian fatalities	multilevel negative binomial models with the lme4 package
Hu, Zhang and Shelton 2018	Houston, TX	2010 to 2016	2,286 traffic light controlled-intersections, 18,882 stop sign controlled-intersections and 57,204 non-controlled intersections	90 ped/cyclist fatalities, 1,802 ped/cyclist injuries 2,060 ped/cyclist non-injury crashes.	Global Colocation Quotient; Local Colocation quotient
Jermprapai and Srinivasan 2014	Statewide, Florida	2005 to 2009	census block group (11,442)	32,917 pedestrian-involved crashes 9,551 pedestrian injury crashes 2,553 pedestrian fatality crashes 11,992 nighttime crashes	negative binomial regression models

Study	Geography	Time-frame	Analysis Zone	Dependent Variable(s)	Model type
Kim 2019	Los Angeles county, CA	2015 to2017	intersections (80,108)	pedestrian collisions by age group	multinomial logistic (MNL) regression
La Scala 2000	San Francisco, CA	1990	149 census tracts	ped-vehicle injuries (1227); ped-vehicle injuries, ped alcohol involved (102)	regression model that provided a statistical correction for spatial autocorrelation
Lin et al 2019	Broward and Palm Beach County, FL	2011 to 2014	census block group (812 low income bg) with 100 ft buffer	pedestrian crashes severe injury pedestrian crashes	negative binomial (Poisson-Gamma) regression model
Loukaitou-Sideris et al 2007	Los Angeles city, CA	1994 to 2001	860 census Tract	density of pedestrian collision incidents in each census tract (25,683 total ped collisions)	Ordinary least squares regression model
Mansfield et al 2018	National	2012 to 2016	50,027 urban census tracts 22,711 rural census tracts	pedestrian fatalities with geo-coordinates (25,615)	negative binomial (NB) models with random effects; zero-inflated negative binomial (ZINB) models with CSA-level random effects; ZINB mixed model (ZINBMM) with random parameters
Moudon et al 2011	King County, WA	1999 to 2004	Individual (ped involved in crash) 757 on state routes and 2457 on city routes	state route - injury severity (five class KABCO); state route - injury severity (two class KA BCO); city route - injury severity (five class KABCO); city route - injury severity (two class KA BCO)	Binary logistic regression (unordered model) - two option dependent variable (fatal/incapacitating vs minor or no injury) ordinal logistic regression (ordered model) - five option dependent variable (fatal, incapacitating, non-incapacitating, possible injury, no injury)

Study	Geography	Time-frame	Analysis Zone	Dependent Variable(s)	Model type
Ukkusuri 2012	New York City, NY	2002 to 2006	zip code; census tract	severe ped injury crashes; fatal ped crashes; total pedestrian crashes (census tract only)	Poisson and negative binomial (NB) regression model;
Wier at al 2009	San Francisco, CA	2001 to 2005	176 census tracts	4039 vehicle-pedestrian injury collisions	Ordinary least squares regression model
Yu 2014	Austin, TX	2008 to 2012	162 census tracts	percentages of workers (aged 16 years or older) who walk; percentages of workers (aged 16 years or older) who bike; yearly pedestrian crash-rate per street mile; yearly bicyclist crash-rate per street mile	Path models
Yu 2015	Austin, TX	2008 to 2012	140 census tracts	1407 pedestrian–vehicle crashes (KA v BCO severity)	single-level ordered logistic model and the multi-level ordered logistic model single-level binomial logistic model and the multi-level binomial logistic model Order logistic models were utilized to explore the five KABCO categories of injury severity, while binomial logistic models were applied to examine fatal/high and no injury/low pedestrian injury severity categories.

4.2.2 Geographies

The geographic focus of the studies included a focus on the city, county, metro, state and national levels. Eight of the studies were of mid to large cities (including Los Angeles, New York 2x, San Francisco 2x, Austin, Houston, and Baltimore); two were of large metro areas (Chicago and Philadelphia); two were of mid-size metro areas (Toledo and San Antonio); six of the studies focused on county level (including Hillsborough and Pinellas counties, FL, Orange County, CA, Broward and Palm Beach County, FL, King County, WA, Los Angeles county, CA, and DeKalb County, GA); two were at the state level (Florida and Tennessee); and one was a national study.

4.2.3 Crash data timespan and source

Most of the studies included multiple years of crash data, with 10 of the studies using five years of crash data, five using one to four years of crash data and seven using six to ten years. 17 of 22 studies used crash data from state crash databases, while two used FARS data and three used city DOT data.

4.2.4 Dependent Variables

Studies were included on the basis of having some pedestrian safety related dependent variable; however, how the studies specified the variable, and the inclusion of multiple variables differed from study to study.

Nineteen looked at the number or density of pedestrian involved crashes; ten looked at injury-specific crashes, often focusing on severe injury; and eight looked at pedestrian fatalities. Eight studies looked at multiple levels of crashes (e.g. looking at pedestrian crashes and injuries) - of those five constructed separate models for each level, while three studies constructed models that examined tiered crash severity. In addition to these pedestrian crash outcomes, a few included additional outcome variables, including nighttime pedestrian crashes, pedestrian alcohol involved crashes, and walk commute rate.

4.2.5 Analysis zone level

Most studies used geographic areas as analysis zones, which allowed the overlay of socio-demographic, land-use and certain transportation related variables over crash locations. Most frequently the census tract (CT) was the chosen analysis zone, used by 14 of the 21 studies. Four used block groups (BG), one used transportation analysis zone (TAZ), and one used zip code. One study included the CT, BG and TAZ to compare the effectiveness of each approach. Six studies used the actual crash location and applied either a buffer, or used the nearest intersection or segment.

4.2.6 Modeling approach

The most common modeling approach was to employ a negative binomial regression, employed by 9 of 22 studies, or a Poisson regression, employed by 4 of 22 studies. Other modeling approaches included ordinary least squares (2), binary and ordinal logistic regression (2), multinomial logistic regression, ordered probit, and path models, and colocation quotient analysis.

4.2.7 Socio-economic characteristics variables

All but two studies included some socio-economic variables in their analysis; with the most frequently used variables being income, age, race/ethnicity, and education.

- 17 studies considered either income or proportion of residents below or near poverty level, with 12 accounting for median income and 8 accounting for the proportion of residents below (or near) the poverty level. In one case, the income variable was excluded from the analysis due to multicollinearity with another variable.

- 13 studies considered age, with the most frequently used variables being the proportion of residents under or over some age (e.g. under 16 or over 65), while one used median age.

- 9 studies looked at race or ethnicity. Some selected a single minority group based on local demographics, for example the proportion of residents who are Black (6 studies), proportion who are Latino/Hispanic (6 studies), or proportion who are Asian (2 studies). Two studies looked at overall proportion of BIPOC population.

- 8 studies looked at education, typically including the proportion of the adult population with a high school diploma.

Other socioeconomic demographics included 5 studies with proportion who do not speak English (or speak it well), 4 studies with proportion of population employed (or unemployed); 4 with proportion of population with a car; as well as gender (3), homeownership (2), housing value (2), and household composition in terms of single or living alone (2).

4.2.8 Individual (crash-involved) characteristics

Aside from the dependent variables measures of severity, four studies included other crash record information about the individual(s) involved in the crash. These include the pedestrian's age and gender, as well as certain characteristics of the crash such as pedestrian action and substance-involved.

4.2.9 Street characteristics variables

- Nineteen of 21 studies included characteristics of the roadway or traffic.

- Twelve studies included a measure of the number, density or type of intersections.

- Thirteen studies included measures of roadway density (e.g. miles of roadway per square mile), classification (e.g. miles of arterials) or speed. Seven specifically focused on roadway density, sometimes in combination with the six that focused on classification. Six had measures of speed, usually posted speed limits, which were calculated either as an area-wide average speed, or the number or proportion of roads of varying speed limits.

- Nine studies include measures of AADT, often area-wide calculations of average AADT. Relatedly, 3 studies included a measure of the more person-based vehicle miles travel (VMT).

- Five studies looked at the number of lanes.

- Twelve studies looked at the number, density and/or configuration of intersections. Configurations included the number of 3-way or 4-way intersections, for example.

Notably, there was limited inclusion of pedestrian-oriented transportation infrastructure, with 6 studies including sidewalk completeness measures, and 2 studies including crosswalk presence or absence information.

4.2.10 Land use variables

Land use variables are often a potential proxy for the types of interactions that pedestrians or motorists will have on the nearby streets. Eighteen of the 22 studies included land use considerations in their analysis, generally looking at the proportion of land occupied by a certain use, or the presence or number of certain types of destinations, such as school or bars. The most commonly used land use variables were the presence of or proportion of land used by residential purposes (9 studies) and the proportion of land used by commercial purposes (9 studies). Three studies also looked at the proportion or presence of pedestrian-oriented commercial, while three looked at the presence of strip-style commercial, including big-box stores. Six studies looked at the proportion of land devoted to industrial purposes, and five looked at offices. Six looked at the presence of or proportion of land devoted to schools, and five that the presence of or proportion of land devoted to parks, open space or recreation. Five studies included other destination types, such as bars or restaurants, while three studies used measures of land use diversity in their models. Of studies looking at alcohol sales locations, locations with on-site sales, and bars or pubs in particular, were deemed to be more correlated with pedestrian crashes or injuries than off-premise sales locations, such as stores that sell beer, wine or liquor to go.

4.2.11 Activity/Exposure variables

Related to land use variables and street characteristics were variables that corresponded to potential exposure. Seventeen of 22 studies used population density, while eight of 22 used employment density or a comparable measure. Four studies used the proportion of workers who commute by walking or taking transit, and eight studies used the number of transit stops.

4.3 METHODS QUESTIONS / CONSIDERATIONS

The review of studies that incorporated sociodemographic data into pedestrian safety analyses revealed a number of important considerations for conducting such studies.

4.3.1 Analysis level

Choices about whether to conduct an analysis on a network level, such as at an intersection or segment level, or at a zonal level, such as at a census block group or tract, traffic analysis zone (TAZ), or alternatively at individual crash locations, merit consideration.

Zonal analyses may be more consistent with existing sociodemographic data formatting, particularly census data. Such analyses can be helpful in understanding the existence of potential inequities, as well as contributing or correlated factors. Choosing zones is also an important process, since larger zones may hide discrepancies within the zones. Further, since census tract or block group borders may be more likely to occur at major roads, and since areas at the fringe of a city or county might have different characteristics than other areas within the zone, understanding the implications of the border of the analysis zone is important.

In order to understand particular danger hotspots, as well as some specific infrastructural or situational contributors, a network approach may also be needed.

Beyond the type of analysis area, the overall scope of the analysis area may change depending on the study objective. Many studies will cover a large geography (e.g. an entire county, metro area, or state) and look for differences in safety outcomes based on differences in sociodemographic characteristics. Other analyses may focus on areas of known disadvantage to better understand the causes, correlations, and impacts of crashes in those areas. For example, a study might focus on identified environmental justice areas, and look at causes of crashes (e.g. Lin, 2019) or conduct case studies of high-crash locations (e.g. Loukaitou-Sideris 2007).

4.3.2 Injury severity and non-injury collisions

In most cases, the dependent variable will be a safety measure such as the number of pedestrian collisions, pedestrian injuries, severe injuries or fatalities. One option is to independently model pedestrian collisions, injuries, severe injuries and fatalities, or some combination thereof. Alternatively, a model may consider severity, ranging from non-injury to fatality, when modeling crashes. One author noted that, in some cases, pedestrian falls or non-vehicle involved pedestrian injuries, may not be included in road injury statistics, (Aldred, 2018), which could leave the equity implications of this potentially important issue unknown.

4.3.3 Exposure variables

Exposure is important to understanding the rate at which crashes occur (for example the number of crashes per mile or trip). Intuitively, the more walking activity that occurs, the more pedestrian crashes one would expect, which is consistent with analyses finding more pedestrian crashes, nominally speaking, in dense urban centers dominated by walking than in rural areas with few walking trips taking place. Exposure variables help to shed light on the rates at which crashes occur and is a clearer measured of overall risk. To the degree that prior studies have incorporated exposure variables into sociodemographic pedestrian safety analyses, they have tended to consider variables associated with increased pedestrian activity, such as population or jobs density, and transit stops or activity.

Several considerations of exposure are necessary to better understand the meaning of safety and crash numbers. More recent crowd-source and passive data sets, such as StreetLight activity data, may be able to provide more defined exposure information, including more about the types of trips, trip timing, and more. Further, "exposure" and "risk" are not always the same thing, with some types of activities potentially causing greater risk. For example, Aldred (2018) points to the challenge of how should to assess the contribution of a "distracted pedestrian" (e.g. using a mobile phone at the time of a crash) when you don't know the number of people using mobile phones while walking overall (Aldred, 2018).

It is also important to note here that simply controlling for exposure is not enough. As documented previously in this review, certain populations are more dependents on walking and transit. Even if those populations were subject to the same "rate" of pedestrian crashes or fatalities, a higher nominal number of such events would still be concerning from an equity perspective.

Multicollinearity, particularly of socio-economic variables with each other, and socio-economic variables with land use or transportation variables was a noted concern in a number of the studies reviewed. We may know that certain groups are more likely to experience pedestrian crashes, injuries and fatalities. However, it is harder to isolate the contribution to that relationship of specific characteristic, along with how that characteristic relates to other socioeconomic characteristics. One consideration will be the extent to which people are subject to road or land use conditions that increase pedestrian risk.

4.3.4 Urban versus rural differences

There is likely a need to evaluate risk and exposure differently for different areas, including urban areas and rural areas, as well as suburbs. Special consideration is need for areas on the urban/suburban or urban/rural fringe. For example, Guerra et al found that "higher population densities are generally associated with higher numbers of pedestrian-involved collisions and injuries in the suburbs, but fewer in Philadelphia" (Guerra et al., 2019), Another study found that for block groups, population density was negatively associated with pedestrian crashes, while for counties, population was positively associated with pedestrian crashes, suggesting that lower density areas in higher density counties may be the most dangerous places (Jermprapai & Srinivasan, 2014).

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APPENDIX A

Table A-1 Significant Variables in Pedestrian Crash Models Reviewed

Study	**Significant Variables in modeled results for** pedestrian crashes “CR”; pedestrian injuries “INJ”; severe pedestrian crashes “SEV”; pedestrian fatalities “FAT”; pedestrian crash severity “severity”
Abdel-Aty et al 2013	Log of roadway length with 25 mph PSL (CR+, TAZ model only) Log of roadway length with 35 mph PSL(CR+ TAZ, BG models) Log of roadway length with 65 mph PSL(CR- CT model) Log of total number of intersection (CR+) Log of population age 0–15 (CR- CT, TAZ) Density of children (K to 12th grade)(CR+ TAZ) Proportion minority population(CR+) Log of vehicle miles traveled (CR+) Log of no of workers: travel time 15–19 min (CR+ TAZ) Log of no of workers: commute by public transport(CR+) Log of no of workers: commute by walking(CR+)
Apardian and Smirnov 2020	Percentage of black population (CR+) Percentage of population that owns housing (versus rent) (CR-) Median house value (CR-) Percentage of population under the age of 5 (CR-) Percentage of population aged 65 or older (CR-) Population(CR+)
Chakravarthy et al 2010	% Poverty; (CR+) % Near poverty (<185% of poverty level); (CR+) % Age 0 to 14; (CR+) % Age 65+; (CR-) W/o High School diploma; (CR+) Speak language other than Eng at home (Speak English very well); (CR+) Speak language other than Eng at home (Speak English less than very well) (CR+) population density (CR+)
Chimba et al 2014	Number of Lanes(CR+) Speed Limit: 30 to 35mph (CR+) Speed Limit: 40 to 55mph (CR+) Presence of a School Zone(CR+) White Population (%) (CR-) Black Population (%) (CR+) Latino Population (%)(CR+) Population from 20 to 64years of Age (%)(CR+) Mean Household Income ($) (CR+) Households with Income below $25000 (%) (CR-) Population in Labor Force (%) (CR+) Population below Poverty Level (%) (CR+) Housing units with No vehicles (%) (CR+) Housing units with 1 vehicle (%)(CR+) Housing units with 2 or more vehicles (%)(CR-)

Study	**Significant Variables in modeled results for** pedestrian crashes “CR”; pedestrian injuries “INJ”; severe pedestrian crashes “SEV”; pedestrian fatalities “FAT”; pedestrian crash severity “severity”
	CBD, Commercial, Fringe & Industrial Land Use Residential, Public Use & Parks Land Use (CR+)
Clifton et al 2009	Daylight (CR+ SEV +) Pedestrian in crosswalk (CR-) Vehicle type – Emergency vehicle(+); trucks, vans and buses(SEV +) Ped characteristics (crash record): Age – Child (0–15 years) (CR+) Age – Adult (16–64 years) Age – Older (over 64 years) (SEV +) Sex (CR+ male) Clothing type (dark)(CR- SEV -) Signal disobedience(CR+) Substance present(CR+ SEV +) Number of bus stops in the 1=4 mile buffer(CR-) street connectivity - connected node ratio; (CR-)
Cottrill and Thakuriah 2010	Sum of AADT (CR+) Total miles of roads (CR-) Crime rate(CR+) Median household income (CR-) Percent with no cars(CR+) Transit Availability index (CR+) Pedestrian accessibility index (CR+) Total numbers of schools (no schools CR+)
Dai and Jaworski 2016	Gradient (CR-) senior population % in census tract (CR-) median income in census tract (CR-) linguistic isolation % in census tract (CR+) Number of public transit stops (CR+) population density (CR+) % taking transit to work (CR+) number of stores/restaurants (CR+) number of drinking places (CR+)
DiMaggio 2015	traffic density (vehicle KMT per sq km) (INJ+) average speed (INJ+) "social fragmentation index" composed of "proportion of total housing units in a census tract that were not owner occupied, the proportion of vacant housing units, the proportion of persons living alone, and the proportion of housing units into which an occupant recently moved" (INJ+) median household income (INJ-)
Dumbaugh and Li 2010	4-or-more-leg intersections (CR+) Arterial miles (CR+)

Study	**Significant Variables in modeled results for** pedestrian crashes “CR”; pedestrian injuries “INJ”; severe pedestrian crashes “SEV”; pedestrian fatalities “FAT”; pedestrian crash severity “severity”
	Net population density (CR+) Strip commercial uses (CR+) Big box stores (CR+) Pedestrian-scaled retail uses (CR-)
Guerra et al 2019	Street link-to-node ratio (CR INJ FAT -) AADT (CR INJ FAT +) Posted speed limits 35mph (CR INJ FAT +) Posted speed limits 45mph (CR +) Posted speed limits 55-65mph (CR INJ FAT +) Roadway segment length (in feet) (CR INJ FAT +) Length of limited access highways (in feet) (CR INJ -) Length of secondary highways (in feet) (CR INJ FAT +) Length of major arterials (in feet)(CR INJ FAT +) Proportion of black residents (CR +) Proportion of families in poverty (CR INJ +) Proportion of residents over 64 (CR +) Population density in City (FAT -) Population density in Suburbs (CR INJ FAT +) Employment density (CR +) Land use diversity index (INJ +)
Hu, Zhang and Shelton 2018	traffic light (FAT +)
Jermprapai and Srinivasan 2014	Number of intersections (CR SEV FAT NIGHT +) Median household income (CR SEV FAT NIGHT -) Poverty (%) (CR SEV NIGHT +) Population who do not speak English well (%) (CR SEV FAT NIGHT +) Population who graduated from high school (%) (CR SEV FAT -) Median age (years) (CR SEV NIGHT -) Population density CR SEV FAT NIGHT -) Total weekly work trips(CR SEV FAT NIGHT +) Length of bus route (m) (CR +) Number of transit stations (guided rail only) (CR+) Total number of educational facilities (CR SEV FAT NIGHT +) Residential area census block group (%) (NIGHT +) Commercial area census block group (%) (CR SEV FAT NIGHT +) Industrial area in census block group (%) (CR SEV FAT NIGHT +) Distance from big city (m)(CR SEV FAT NIGHT -) Census block group located in urban or urban cluster area? (CR + FAT -) Population density of county (people/m2) (CR SEV +) Median household income of county ($) (CR SEV FAT NIGHT +) Residential area in county (%) (CR SEV -) Commercial area in county (%) (NIGHT +)

Study	**Significant Variables in modeled results for** pedestrian crashes “CR”; pedestrian injuries “INJ”; severe pedestrian crashes “SEV”; pedestrian fatalities “FAT”; pedestrian crash severity “severity”
Kim 2019	Note: Intersections where elderly pedestrian collisions primarily occurred (IEC) Intersections where younger pedestrian collisions primarily occurred (IEC) missing crosswalks (IYC +) permissive right turn lane and signal (IEC IYC -) raised median (IEC -) 3way intersection (IEC -) colored or decorated crosswalk (IYC -) primary road 5 or more lanes (IEC IYC +) sidewalks available (IEC IYC +) tree canopy shade (IEC -) parking lot (IEC IYC +) bus stop (IEC +) Residential land use % (IEC IYC -) Commercial land use% (IEC IYC +) Office land use% (IEC IYC +) Park and recreational land use%(IEC -)
La Scala 2000	Average daily traffic flow (INJ+) Persons age 0–15 (proportion) (INJ-) Persons unemployed (proportion) (INJ+) Males (proportion) (INJ+) High school graduate or higher (proportion)(INJ-) pop density Population per kilometer roadway (INJ+) Bars per kilometer roadway (CR ns; + Alc related CR)
Lin et al 2019	Count of intersections (CR SEV +) Count of traffic signals (CR SEV +) Number of bus stops per mile (CR SEV +) Proportion of lower-speed roads (%)(CR SEV -) Older ped 65 or over (Severity +) not in crosswalk (Severity +) ped darting/dashing (Severity +) impaired pedestrian (Severity +) aggressive driver (Severity +) dark not lighted condition (Severity +) dark lighted condition (Severity +) inclement weather (Severity +) low speed limit (Severity -) traffic control (Severity -) Proportion of older people (age 65) (%) (CR SEV -) Proportion of African American population (%) (CR +) Proportion of households with zero car (%) (CR SEV +)

Study	**Significant Variables in modeled results for** pedestrian crashes “CR”; pedestrian injuries “INJ”; severe pedestrian crashes “SEV”; pedestrian fatalities “FAT”; pedestrian crash severity “severity”
	Proportion of population less than high school (%) (CR SEV +) Population in thousands (CR SEV +) Proportion of commuters using public transit or biking (%)(CR +) Presence of Walmart stores in low-income BG (CR +) Number of discount department stores per sq. mi. (CR SEV +) Number of convenience stores per sq. mi. (CR +) Number of fast food restaurants per sq. mi. (CR SEV +) Number of grocery stores per sq. mi. (CR +) Number of barber shops per sq. mi. (CR +)
Loukaitou-Sideris et al 2007	AADT density (AADT aggregated to census tract) (CR+) % Hispanic (only socio-economic variable retained in regression) (CR+) Population density (CR+) Employment density (CR+) % vacant (CR-) % industrial (CR-) % office (CR-) % commercial (CR+) % high-density residential (CR+)
Mansfield et al 2018	Note: URB urban locations; RUR rural locations VMT density (thousand VMT/mi2) for: Interstates, freeways, and expressways (FAT URB+ RUR+) Non-access-controlled principal arterials (FAT URB+ RUR+) Minor arterials (FAT URB+ RUR+) Major collectors (FAT URB+ RUR+) Auto-oriented intersection (count/mi2) (FAT RUR+) Non-auto-oriented intersections (count/mi2) (FAT RUR+) Non-Hispanic Black % (FAT URB+ RUR+) Non-Hispanic Asian %(FAT URB+) Female, 45-54 (FAT URB-) Female, 55-64 (FAT URB-) Female, 65 or older (FAT URB-) Male, 18-24 (FAT URB-) Male, 45-54 (FAT URB+) Male, 55-64 (FAT URB+) Male, 65 or older (FAT URB+) Median household income (FAT URB-) Percent male (FAT RUR-) Residential population density (persons/mi2) (FAT URB-) Employment density (employees/mi2): Office employees/mi2 (FAT RUR-) Retail employees/mi2 (FAT RUR-)

Study	**Significant Variables in modeled results for** pedestrian crashes "CR"; pedestrian injuries "INJ"; severe pedestrian crashes "SEV"; pedestrian fatalities "FAT"; pedestrian crash severity "severity"
	Industrial, transportation and warehousing employees/mi2 (FAT RUR-) General services employees/mi2 (FAT URB- RUR-) Entertainment & food/accommodation services employees/mi2 (FAT URB+ RUR+) Activity mix index (unitless) (FAT URB+ RUR+)
Moudon et al 2011	Note CITY city roads; ST state roads light conditions (crash record) daylight (Severity CITY-) Average annual daily traffic in 0.5km buffer (AADT) (Severity ST- CITY+) pedestrian age (Severity CITY+) pedestrian inebriety (Severity ST+) driver inebriety (Severity CITY+) Median home value in 0.5km buffer (dollars) (Severity CITY+) Net residential density in 0.5km buffer (log) (Severity CITY+)
Ukkusuri 2012	Primary freeway length/total length (CR + FAT +) Local–rural road/length(CR - FAT -) Other thoroughfare/length (CR -) Five-lanes length/length (CR + FAT + with more lanes) 50–59 ft width/length (CR + with increase width) (FAT + over 60f width/length) 3 way intersections(CR - FAT -) 4 way intersections(CR + FAT +) 5 way intersections (CR +) All way stop(CR -) Population under 17 (proportion) (CR +) Population 65 + (proportion) (CR - FAT +) Population(CR + FAT +) % of transit or non-motorized users (CR + FAT +) # of subway stations(CR + FAT +) Residential land use/total (CR - FAT -) Commercial land use/total (FAT +) Industrial land use/total (CR + FAT +) Open land use/total land use (CR +) Total number of schools(CR + FAT +)
Wier at al 2009	Traffic volume (n, natural log, aggregated average daily traffic counts) (INJ+) Arterial streets, without public transit (%, street length) (INJ+) Age 65 and older (%, resident population) (INJ-) Living below the poverty level last year (%, resident population) (INJ+) Employee population (n) (INJ+)

Study	**Significant Variables in modeled results for** pedestrian crashes "CR"; pedestrian injuries "INJ"; severe pedestrian crashes "SEV"; pedestrian fatalities "FAT"; pedestrian crash severity "severity"
	Resident population (n) (INJ+) Neighborhood commercial (%, land area)(INJ+) Residential (%, land area) (INJ+) Land area (square miles)(INJ-)
Yu 2014	sidewalk completeness (CR+) street intersection density (CR-) % of white population (CR-) transit stop density (CR+) Resident density (CR+) Land use mix (CR+)
Yu 2015	Posted speed limit (Severity +) The crash occurred at an intersection (Severity -) Inclement weather (Severity -) Light condition - dark (Severity +) Traffic control device present (Severity -) Sidewalk density(Severity -) 4+ leg intersections (Severity -) Pedestrian age (Severity +) MV turning left (Severity -) Population density # of population/tract area (acres) (Severity +) # Transit stops (Severity -) % of commercial area in tract(Severity -) % of school area in tract (Severity +) % of park area in tract(Severity +)