Collaborative Sciences Center for ROAD SAFETY

FINAL REPORT

# The Influence of the Built Environment on Crash Risk in Lower-Income and Higher-income Communities

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**16. Abstract**

This report presents the findings of a study that uses negative binomial regression models to examine differences in the relationship between the built environment and crash incidence for block groups in Orange County, Florida. It finds notable differences in the modelled variables between these income groupings, both in the magnitude and the direction of effects. First, while urban arterials are a risk factor for lower- and higher-income block groups alike, their negative effect on safety is profoundly greater in lower-income environments. For higher income communities, each additional mile of urban arterial is associated with a 9% increase in total and KAB crashes, though it did not have a statistically meaningful relationship with pedestrian crashes. For lower-income communities, each mile of urban arterial is associated with a nearly 30% increase in total and KAB crashes, as well as a 19% increase in pedestrian crashes. This study further finds that "livability" features have different safety effects in high-income and low-income communities. While it is widely presumed that the presence of sidewalks and sidewalk buffers enhance safety, the results of this study suggest that the relationship between these features and traffic safety is more complicated. For more affluent areas, which contain residents who are less dependent on walking as a primary means of transportation, sidewalk buffers were found to be associated with significant increases in total, injurious, and pedestrian collisions alike, while the presence of sidewalks was associated with a significant increase in injuries involving all road users. For lower income communities, sidewalks and sidewalk buffers were not significantly related to increases in crashes or injuries; indeed, the increased presence of these features tended to be associated with reductions in injurious and pedestrian crashes. Finally, race proved to have an important role on crash risk. While the percentage of white residents was not meaningfully associated with crash risk in more affluent block groups, race emerges as an important factor for understanding crash risk in lower-income communities, with higher concentrations of non-white residents being associated with significant increases in total, injurious, and pedestrian-related crashes. This report concludes by discussing the likely causes and broader implications of these findings.

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# List of Abbreviations and Acronyms

ACS: American Community Survey

AMI: Area Median Income

CDC: Centers for Disease Control and Prevention

FLHSMV: Florida Highway Safety and Motor Vehicles

FDOT: Florida Department of Transportation

FGDL: Florida Geographic Data Library

GIS: Geographic Information System

HHS: U.S. Department of Health & Human Services

KAB Crashes: Fatal-and-Injury Crashes

MSA: Metropolitan Statistical Area

NHTSA: National Highway Traffic Safety Administration

TANF: Temporary Assistance for Needy Families

VMT: Vehicle Miles Traveled

# Executive Summary

Studies of the environmental factors influencing crash risk typically use income as a control variable, finding that income is negatively correlated with crash incidence. Nonetheless, there has been little examination into the environmental factors that may influence crash risk in lower-income communities themselves. While lower-income communities may experience higher rates of traffic-related crashes, injuries, and deaths, it is not clear the environmental factors associated with crash risk are the same for lower-income populations as they are for the population as a whole.

This study thus seeks to understand the environmental factors that influence crash incidence in lower-income communities in Orange County, Florida, as well as whether the factors associated with crash risk in these communities differ from the factors affecting more affluent communities and the population as a whole. This study uses three sets of negative binomial regression models: one for the Orange County region as a whole, a second for lower-income communities defined as block groups with median household income of $40,000 or less, and a third for higher-income communities defined as block groups with median household incomes of greater than $65,000.

While previous research has consistently identified income as a significant factor in understanding community-level crash risk, the results of this study suggest that income has a far more complex relationship to crash incidence than previously supposed--one that appears to be compounded by issues of race. First, urban arterials are far more problematic for lower-income communities than for more affluent ones. Each mile of urban arterial was associated with a 9% increase in total and KAB crashes in affluent communities, while they were associated with nearly a 30% increase in these same crash types in lower-income areas. Further, while the presence of arterials in affluent communities had little effect on pedestrian collisions, each additional mile of urban arterial was associated with a 20% increase in pedestrian collisions in less affluent areas.

Design elements typically regarded as “livability” features further had divergent effects for low-income and high-income block groups. In high-income block groups, higher percentages of streets with sidewalks were associated with significant increases in KAB crashes, while the presence of pedestrian buffers, such as on-street parking and the presence of street trees and utility poles placed along planting strips, were associated with significant increases in total, KAB, and pedestrian crashes alike. This was not the case in lower-income areas where sidewalks and sidewalk buffers tended to be associated with fewer KAB and pedestrian collisions, though not at statistically significant levels. As discussed in this report, we suspect that these results are likely explained by the different manner in which these features may influence overall levels of pedestrian activity.

While race did not have a statistically-meaningful relationship to crash incidence in higher-income block groups, the percentage of whites in lower-income block groups was significantly associated with reductions in total, KAB, and pedestrian crashes. Stated another way, racial disparities exacerbate the crash risk already experienced by lower-income communities. Like other facets of U.S. society, the relationships between traffic safety and the built environment appears to be strongly intertwined with broader issues of racial and income inequality. This study thus attempts to begin to disentangle these issues and concludes with a call for greater consideration to the manner in which the design of the built environment may exacerbate, or prevent, inequalities associated with race and income.

# Introduction

Traffic crashes are a leading cause of preventable death in the United States (Botchwey et.al., 2014; CDC, 2010; Mokdad, Marks, Stroup, & Gerberding, 2004, 2005). Racial minorities and low-income neighborhoods are disproportionately represented in traffic-related death and injury, particularly as pedestrians. According to the Centers for Disease Control and Prevention, from 2001 to 2010, pedestrian fatality rates for black and Hispanic men (3.73 and 3.93 per 100,000 people, respectively) were nearly twice the rate as that for white men (1.78 per 100,000 people) (CDC, 2013).

It is well-known that socio-economic status (SES) is a predictor of crash risk, with lower-income, minority, and less-educated persons being disproportionately likely to be injured or killed in a traffic crash (CDC, 2013). Nonetheless, that there has been little focused examination into the nature of crash risk in lower-income environments. The relationship between income and crash incidence is usually accounted for in safety research as a control measure when examining other crash risk factors, such as those associated with roadway geometry or the characteristics of the built environment, rather than a specific focus of concern in its own right. When treated in such a manner, the crash risk associated with the presence of lower-income and minority populations is treated as simply a background condition, with the crashes associated with the presence of these populations being typically attributed to the characteristics of lower-income crash victims, such as their inability to afford a car (increasing the odds they will walk or cycle) or their inability to afford newer and more crashworthy vehicles. This approach thus treats design-level factors as affecting all populations equally with little consideration given to whether these populations may experience unique risk factors that differ from those of more affluent populations.

While higher rates of walking or the use of older vehicles may certainly be factors that influence crash risk affecting lower-income households, the reliance on such explanations simplifies what is almost certainly a far more complex phenomenon. Lower-income households have fewer housing and transportation options and are economically segregated into environments where lower-cost housing options are available. Public services and street design in these neighborhoods may be inferior to those found in more affluent communities. This perspective presumes that the environmental risk factors for the population as a whole can be applied to understand the risk factors affecting lower-income communities specifically, a perspective that may overlook the unique features of these communities or their residents that may make them disproportionately likely to experience a crash event. This study seeks to fill this void in the safety literature by examining the environmental factors associated with crash incidence in lower-income communities in Orange County, Florida, and comparing them against those of more affluent communities, as well as against the entire population of Orange County.

# Literature Review

## Economic and Demographic Contributors of Crash Risks

As discussed above, studies have repeatedly found that the presence of lower-income populations are associated with increases in crash frequency and severity (Abdalla, Raeside, Barker, & McGuigan, 1997; Baker, Braver, Chen, Li, & Williams, 2002; Chichester, Gregan, Anderson, & Kerr, 1998; Cottrill & Thakuriah, 2010; Graham, Glaister, & Anderson, 2005; Hippisley-Cox, Groom, & Kendrick, 2002; Rifaat, Tay, & de Barros, 2010; Roberts & Powers, 1996; Valverde & Jovanis, 2006). Areas with concentrations of lower-income residents often have higher percentages of female-led households with children, lower levels of educational attainment, higher percentages of racial minorities, and higher percentages of immigrants.

One hypothesis of why lower income neighborhoods have higher crash risks is that low-income residents are less likely to own cars, or even if they do, are often required to share them among multiple household members (Blumenberg & Manville, 2004; King, Smart, & Manville, 2019; Murakami & Young, 1997). Further, the cars in use by lower-income households are often older (Blumenberg & Haas, 2002; County of Los Angeles, 2000; Murakami & Young, 1997; Ong & Houston, 2002), or in need of repair and maintenance (Cervero, Sandoval, & Landis, 2002). All these result in an increased likelihood that these residents will walk, bike, or take public transit to meet their transportation needs, thereby increasing their exposure as pedestrians. Additionally, households without an automobile are likely to have very-low household incomes and to be African American (Blumenberg & Manville, 2004).

Much of the literature in travel behavior and crash risk analysis has focused on teens, seniors, males, and school-aged children. Crashes relating to teens are often attributed to the risk-taking behavior of young adults when driving due to lack of maturity and self-discipline. These behaviors often manifest as speeding, texting, racing, or other distractions while driving. Such behaviors are especially prevalent in males, with the percentage of male residents in a community being positively associated with increased crash risk (Evans, 2004; Hippisley-Cox, et al., 2002; Rifaat et al., 2010).

Senior populations may also be disproportionately exposed to traffic-related deaths and injuries. They are more cautious when on the road, and far less likely than younger populations to be involved in crashes associated with irresponsible or reckless driving, such as single-vehicle, run-off-roadway crashes, crashes involving excessive speeds, or crashes involving a driver following another vehicle too closely (Hakamies-Blomqvist 2004; Federal Highway Administration 1993). Nonetheless, safety problems for older adults, particularly as motorists, emerge at intersections. Declines in visual acuity associated with aging lead older adults to underestimate available gaps in oncoming traffic, and thus to attempt turning maneuvers in front of oncoming vehicles (Hakamies-Blomqvist 2004; Hallmark and Mueller 2004; Smiley 2004; Straight 1997). The tendency to misjudge traffic gaps is further evidenced by police citations at crash locations, with drivers older than sixty-five being twice as likely to be cited for failing to yield to oncoming traffic than are younger drivers (Matthias, De Nicholas, and Thomas 1996). The problem with identifying safe gaps in oncoming traffic is exacerbated by higher vehicle operating speeds. Older drivers are generally able to identify safe gaps in traffic when oncoming vehicles are traveling at speeds of 30 miles per hour or less, but they have increasing difficulty doing so when vehicles are traveling at higher speeds (Chandraratna, Mitchell, and Stamatiadis 2002; Scialfa et al. 1991; Staplin 1995).

## Behavioral Risk Factors for Low-income Populations

Among the myriad risk factors of traffic crashes, behavioral factors have been well documented in psychological studies, particularly the risk-taking behavior of adolescents in driving. Risk-taking behaviors related to driving, such as non-use of seat belts, riding with a drunk driver, and driving under the influence of alcohol, have been found clustering in the same adolescent individuals, mostly among the less privileged in terms of income (Petridou et al., 1997). The manifestation of socioeconomic divergence of these types of risky behaviors is mostly during the adolescent years, if not before. This is consistent with the inequalities in morbidity and mortality by social class (Black, 1980; Syme & Berkman, 1976) and the concentration of various risk-taking behavior among underprivileged teens (Bachman, Johnston, & O'Malley, 1987; Charlton & White 1995; CDC, 1989; Neff & Burge, 1995; Senf & Price, 1994). However, in a study of self-reported safe driving behavior which asked participants about seat belt use, speed limit compliance, and abstaining from drinking and driving, the researchers found that there is no single high-risk group that violates all three safety rules (Shinar, Schechtman, & Compton, 2001). Females are the only group that follow all three safety behaviors, with educated women being particularly more likely to use seat belts. Most survey respondents indicated avoidance of drinking and driving, regardless of age, gender, education and income differences. This is interesting since adolescents have been shown to adopt more risky driving behaviors than other age cohorts. This may be due to the gap between self-awareness and actual behavior.

For pedestrians, 60% of fatal crashes occur while pedestrians attempt to cross a street (NHTSA, 2003). Research has indicated that drivers behave differently when yielding to pedestrians crossing a street, for example, drivers of expensive cars are less likely to yield to pedestrians than those with low-status cars (Piff et al., 2012). Yielding to pedestrians is often viewed by many drivers as a courtesy or privilege, rather than compliance with established motor vehicle laws. Drivers are more likely to yield to disabled individuals (Harrell, 1992), women (Goddard, Kahn & Adkins, 2014), or people who are similar to their own age (Rosenbloom, Nemrodov & Eliyahu, 2006). In Oregon, all intersections are treated as crosswalks and drivers are required to yield to pedestrians. However, many drivers do not yield to crossing pedestrians at unmarked intersections, compared to marked crosswalks. Further, drivers are less likely to yield to black male pedestrians than other cohorts (Goddard, Kahn & Adkins, 2014).

Although lower incomes are associated with lower rates of vehicle ownership, Koekemoer et al. (2017) suggests that other factors, such as inadequate road infrastructure and "negligent behavior" may also explain why lower income areas tend to have higher crashes and injuries. "Negligent behavior" indicates a weak understanding of safety while crossing the streets or sharing the roads with conflicting transportation modes. Inadequate infrastructure, unsafe cars, and/or "negligent behavior" might help explain the increased motorist casualties in New Jersey (Noland et al., 2013). A few other studies have explained why pedestrians, particularly young pedestrians in poor neighborhoods, are associated with increased injury risks (e.g. Lyons et al., 2008; Guyer, Talbot, & Pless, 1985). Risk is attributed to the lack of safe play spaces, housing in close proximity to busy traffic flows, immature cognitive behavior, higher crime rates, lower vehicle ownership rates, and greater physical, social, and psychological stress.

## The Built Environment and Crash Risk

In addition to socioeconomic and behavioral characteristics, the built environment has an important role in crash incidence. A key factor is the presence of urban arterial roadways. More miles of arterial roadway have been associated with more total crashes (Alluri et al., 2017; Dumbaugh & Rae, 2009; Hadayeghi et al., 2007; Lovegrove & Sayed, 2006; Tasic & Porter, 2016; Wang, Jin, Abdel-Aty, Tremont, & Chen, 2012), more injury crashes (Alluri et al., 2017; Dumbaugh & Rae, 2009; Hadayeghi et al., 2007; Ladron de Guevara et al., 2004), and more fatal crashes (Alluri et al., 2017; Dumbaugh & Rae, 2009; Hadayeghi et al., 2007; Ladron de Guevara et al., 2004; Tasic & Porter, 2016). Pedestrian crashes have also been positively related to the preponderance of arterials (Eluru, Yasmin, Bhowmick, & Rahman, 2016; Tasic & Porter, 2016; Wang, Yang, Lee, Ji, & You, 2016). Other measures of arterial presence, such as arterial density (Huang et al., 2010), or percentage of the street network comprised of arterial roads (Jiang, Abdel-Aty, Hu, & Lee, 2016; Khondakar, Sayed, & Lovegrove, 2010; Osama & Sayed, 2017), have also been positively associated with crashes.

Higher traffic volumes are not only found on freeways and arterial roads, but also in areas with higher population and employment densities. Therefore, certain types of land uses, such as commercial and office uses, often increase the traffic flow in an area. Traffic crashes in commercial areas often happen in parking lots, entrances and intersections with sidewalks and/or bike lanes. Dumbaugh and Rae (2009) found that the presence of commercial land uses on arterial roads increases total, fatal, and injury crashes. Hadayeghi et al. (2007) found that the acreage of commercial, residential, and industrial land was positively correlated with total crashes and severe crashes. Likewise, Jermprapai and Srinivasan (2014) discovered a higher number of all levels of severity of pedestrian crashes in zones with a higher proportion of commercial or industrial land. Mohamed et al. (2014) found that both injury and fatal crashes increase with the percentage of residential and commercial land in a city or township. Ukkusuri et al. (2011) likewise uncovered that zones with greater industrial, commercial, and open land have more pedestrian crashes. Wier et al. (2009) also found that pedestrian crashes increase with the presence of commercial uses.

The presence of sidewalks and bike lanes, while often presumed to be safety features, have been found to have a mixed effect on crash incidence. Studies on pedestrian crashes revealed that the presence of more sidewalks often is positively associated with such crashes (Cai, Abdel-Aty, Lee, & Eluru, 2017; Eluru, Yasmin, Bhowmick, Rahman, et al., 2016; Nashad et al., 2016). This counterintuitive finding is likely attributable to the effects of exposure; areas with more sidewalks and bicycle facilities likely have more pedestrians and cyclists, and thus more opportunities for collisions, although few studies have meaningfully distinguish between pedestrian risk and pedestrian exposure (Merlin, Guerra, and Dumbaugh, 2020).

Intersections are often found to be a risk factor, as intersections are locations where multiple streams of traffic cross, creating traffic conflict and thus opportunities for traffic collisions. The number of intersections in an area is positively correlated with crashes in most, but not all, instances. In two papers, Abdel-Aty et al. (M. A. Abdel-Aty, Siddiqui, Huang, & Wang, 2011; M. Abdel-Aty et al., 2013) find that the number of intersections is correlated with total, severe, peak-hour, pedestrian and cyclist crashes. Dumbaugh and Rae (2009) find that the number of four-or-more leg intersections in a block group is positively correlated with total and injury crashes but negatively associated with fatal crashes. Hadayeghi et al. (2007) uncover positive correlations between the number of intersections and both total and severe collisions. A number of authors have discovered a positive correlation between intersection counts and pedestrian crashes (Jermprapai & Srinivasan, 2014; Siddiqui & Abdel-Aty, 2012; Ukkusuri, Miranda-Moreno, Ramadurai, & Isa-Tavarez, 2012). Yu and Zhu (2016) reported that the number of intersections is positively correlated with vehicular crashes. In a contrary finding, Ouyang and Beijeri (2014) found a negative correlation between intersection count and total, pedestrian, cyclist, injury, and fatal crashes in Census Block Groups of Miami-Dade County. Intersection density is sometimes positively (Huang, Abdel-Aty, & Darwiche, 2010; Nashad et al., 2016; Osama & Sayed, 2016) and sometimes negatively associated with crashes (Jonsson, 2005; Quistberg et al., 2015). Considered as a whole, the number of intersections in a community has an uncertain effect on crash frequency and severity. Crashes at intersections are influenced by factors such as approach speeds, the number of approaching lanes, and the types of intersection control devices in use. When considered in aggregate over larger geographic areas, as in done in studies of the relationship between the built environment and crash incidence, variations in the design and operation of intersections likely explains the divergence in the study results.

Built environment factors that are correlated with crashes are commonly found in low-income areas. For example, Li (2011) found that in the South Florida region, U.S. Highway 1, Interstate I-95, and Florida's Turnpike divide the region into three distinctive sections, where I-95 and Florida's Turnpike often go through disadvantaged areas. In these lower income areas, industrial land uses are often prevalent, with a large amount of multi-family units and smaller houses. Sidewalks are often found in central city areas, where there is often a distinct divide between the lower income areas and the higher income areas. All these could possibly contribute to increased crash risks in low-income neighborhoods and communities.

# Study Area: Orange County, Florida

This study examines traffic crashes occurring at the block group level in Orange County, Florida between 2014 and 2016. Orange County, in which the City of Orlando is located, was selected for its representative racial and ethnic diversity. Based on 2018 estimates from the U.S. Census Bureau, Orange County had a population of almost 1.4 million, of which 32% are Hispanic or Latino, and 23% of which are Black/African-American. While 68% of the population identifies as white alone, the percentage of whites of non-Hispanic descent is 40%, making the county a majority-minority region. As this study is focused on the crash incidence of low-income communities, it focuses on non-freeway streets exclusively.

The following data sources were used in this analysis:

1) Traffic crash data from Florida Department of Transportation.
2) Land use data from Florida Geographic Data Library.
3) Socioeconomic data from the U.S. Census Bureau 2013-2017 5-year American Community Survey (ACS) data.
4) Data on subsidized housing data from the U.S. Department of Housing and Urban Development.

## Defining "Low-Income Communities"

The first step in this analysis was to define a "low-income community." Because of our reliance on census geography for information on household income, this study uses census block groups as its unit of analysis. This study then needed to define which block groups would be classified as being "low-income." To do so, it uses the 2015 income limits defined by the United Department of Housing and Urban Development for Orange County, Florida, presented in Table 1, below. When considering the average value of 1-4 person households (as the average household size was 2.78, and the average family size was 3.5 during 2013-2017), the income limit for low income in the Orlando-Kissimmee-Sanford MSA was about $39,675. We rounded the limit to $40,000. Therefore, the low-income block groups are defined for the purposes of this study as those with an average median income of less than or equal to $40,000. During 2013-2017 median household income in Orange County, Florida was $51,586. In FY 2016, the HUD AMI (Area Median Income) was $57,800 for Orange County, which was an adjusted value from the median household income based on inflation and other factors. When a household makes more than 120% of the AMI the household will usually not be qualified for any government assistance. Therefore, 120% of the AMI was used as an upper threshold of moderate and lower middle income. In this study, we use $65,000 as the threshold, when realistically considering both the median household income and the AMI calculated by HUD. Any block groups with higher than $65,000 are considered middle to upper-middle and high-income neighborhoods. Figure 1, below, shows the income distribution, by block group, for the study area.

*Table 1. 2015 HUD Adjusted Home Income Limits for Orlando MSA*

| Limits | 1 Person | 2 Person | 3 Person | 4 Person | 5 Person | 6 Person | 7 Person | 8 Person |
|---|---|---|---|---|---|---|---|---|
| Extremely Low Income | $12,250 | $14,000 | $12,750 | $17,500 | $18,900 | $20,300 | $21,700 | $23,100 |
| Very Low Income | $20,450 | $23,350 | $26,250 | $29,150 | $31,500 | $33,850 | $36,150 | $38,500 |
| Low Income | $32,700 | $37,350 | $42,000 | $46,650 | $50,400 | $54,150 | $57,850 | $61,600 |

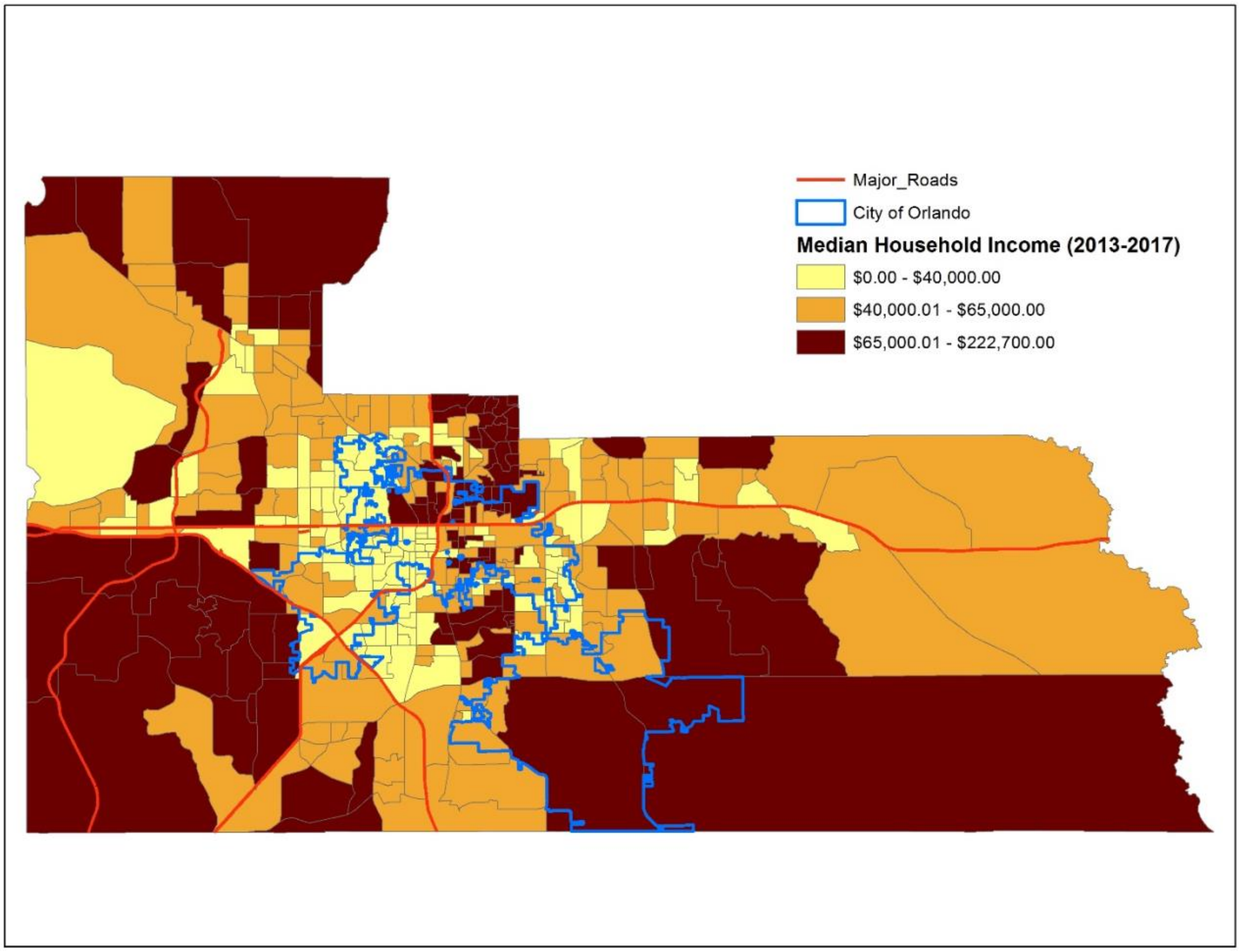


*Figure 1. Median Household Income in Orange County, Florida (ACS, 2013-2017)*

## Study Area Characteristics

The American Community Survey (ACS) 2013-2017 five-year estimates are used to obtain the demographic information for the study area. The percentage minority population indicates percentage population who are not white in a block group. Percentage population not speaking English at home was used as a proxy for immigration status since citizenship and naturalization statuses were not available for the dataset.

Table 2 indicates that about 33.9% of the households are non-White racial minorities and 30.6% of the households speak a language other than English at home. This indicates that the population in the county is diverse. Percentage of the population with the age under 18 is about 17.8% and the senior population is about 13.4%. Strikingly, 43% of the population older than 25 years are college educated and 24.1% of the total population are enrolled in certain types of schools, including K-12 schools, colleges and universities. These imply that the population in the study area is well educated.

## Crash Distribution in Orange County

Three years (2014-2016) of crash data were retrieved from FDOT's Unified Basemap Repository (UBR) to use in this study. Crash data in the UBR are available in GIS shapefiles, including crashes on-system (i.e., maintained by state) and off-system (i.e., maintained by city/county) roads in Florida. First, crashes from both on-system and off-system roads were combined, and then based on crash location field such as county, crashes in Orange County were identified. Using information on the category of roads where a crash occurred, an additional step was taken to filter out crashes that occurred on freeways and interstates. The remaining crashes were then mapped to census block groups in Orange County. An additional issue is how to address crashes occurring on the boundaries of block groups, many of which separated by major roadways. To address the boundary issue, we used the near analysis function in ArcGIS. Table 2, below, presents the descriptive statistics for the study area.

*Table 2. Descriptive Statistics of Crashes and Demographic Attributes at the Block Group Level*

| Variable | Mean | Std. Dev | Min | Max |
|---|---|---|---|---|
| **Crash Variables** | | | | |
| Total Crashes | 195 | 227 | 1 | 2,041 |
| Total Crashes per 10 Acres | 44 | 49 | 1 | 464 |
| Crashes with Injury or Fatality | 38 | 42 | 0 | 318 |
| Crashes with Injury or Fatality per 10 Acres | 8 | 8 | 0 | 52 |
| Pedestrian Crashes | 4 | 5 | 0 | 65 |
| Pedestrian Crashes per 10 Acres | 1 | 2 | 0 | 21 |
| Cyclist Crashes | 4 | 4 | 0 | 31 |
| Cyclist Crashes per 10 Acres | 1 | 1 | 0 | 11 |
| | | | | |
| ***Demographic Variables*** | | | | |
| Median Household Income ($) | $56,855.3 | $31,539.3 | 0 | $222,700.0 |
| Total Population | 3,450 | 3,722 | 85 | 31,526 |
| % Minority (Non-White) Population | 33.9% | 25.9% | 0 | %100.0 |
| % Hispanic Population | 24.5% | 18.5% | 0 | 89.4% |
| % Population not Speaking English at Home | 30.6% | 18.1% | 0 | 86.5% |
| % Households without Cars | 8.0% | 9.7% | 0 | 57.0% |
| % Population (>=25 years old) with a College Degree | 43.0% | 19.9% | 5.8% | 96.2% |
| % Households under Poverty | 16.5% | 13.0% | 0 | 92.7% |
| % Population Enrolled in Schools | 24.1% | 9.6% | 0 | 75.3% |
| % Households with Children (< 18 years old) | 17.8% | 8.2% | 0 | 52.2% |
| % Households with Seniors (>65 years old) | 13.4% | 8.5% | 0 | 74.3% |
| % Commuters Using Transit | 3.2% | 5.7% | 0 | 38.0% |
| % Commuters Walking | 1.6% | 3.1% | 0 | 30.4% |
| % Commuters Biking | 0.8% | 2.1% | 0 | 23.0% |

Since the size of census block groups is determined by population, there are significant variations in block group size. In order to compare the relative crash risk in each of these block groups, we normalized crashes by land area, with the crash incidence of block groups measured as the number of crashes per 10 acres. Figures 2 and 3 show the number of crashes per 10 acres, by block group, for the region as a whole and lower-income areas, respectively. As evidenced in the comparison, the majority of lower-income block groups correspond with many of the areas reporting the highest numbers of crashes, particularly along the I-4 and Colonial Drive corridors. Figure 4 shows the distribution of fatal and injurious crashes, which follows the same general pattern as total crashes, by which shows a greater concentration of deaths and injuries near downtown and along the I-4 and Colonial Drive corridors.

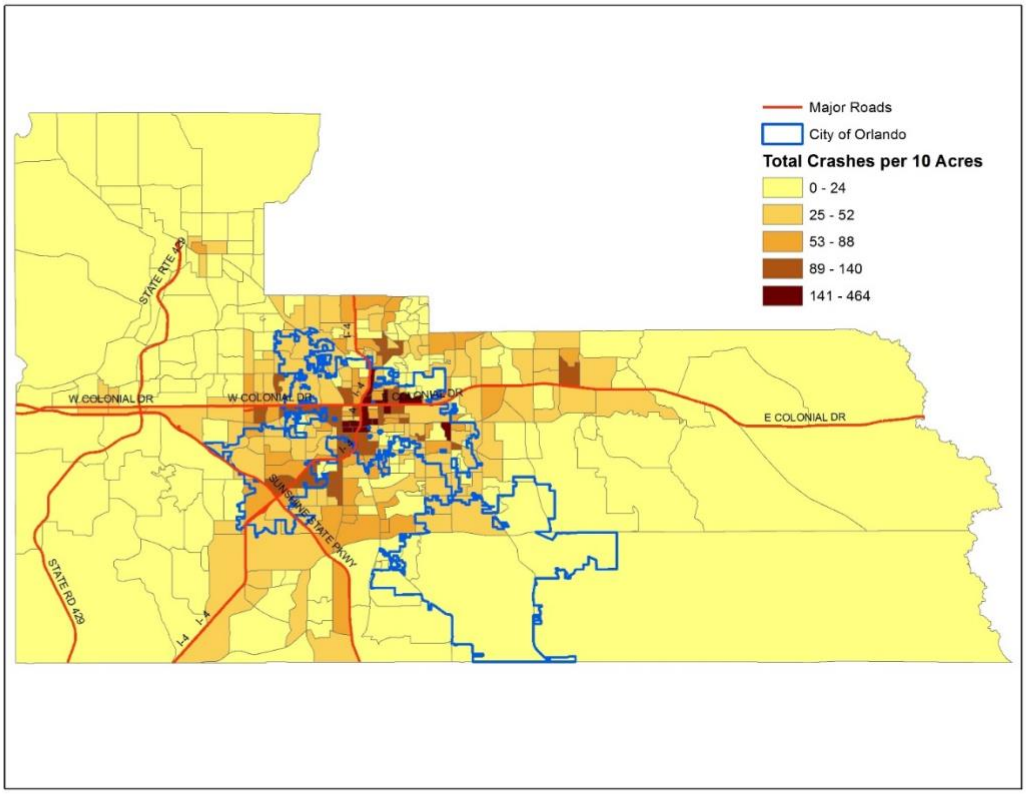


*Figure 2. Total Crashes by Land Area in Orange County, Florida (2014-2016)*

These trends are more clearly defined in Table 3 which shows the distribution of crashes by household income. The low-income category is further divided to three subcategories, and the moderate to lower middle income is divided into two subcategories, and the middle to upper middle and high income is divided into two additional categories. One striking observation is that low income block groups have 26.5% of the total population, residing in 9.1% of the land area, and accounting for 30.8% of the total crashes, 41.6% of the pedestrian crashes, and 38.5% of the cyclist crashes. Among the low-income group, block groups with an income between $25,000 and $40,000 have the largest number of crashes. By contrast, middle- to upper-income block groups comprise 31.2% of the total population and reside in 49.7% of the land area, yet experience only 20.6% of the total crashes.

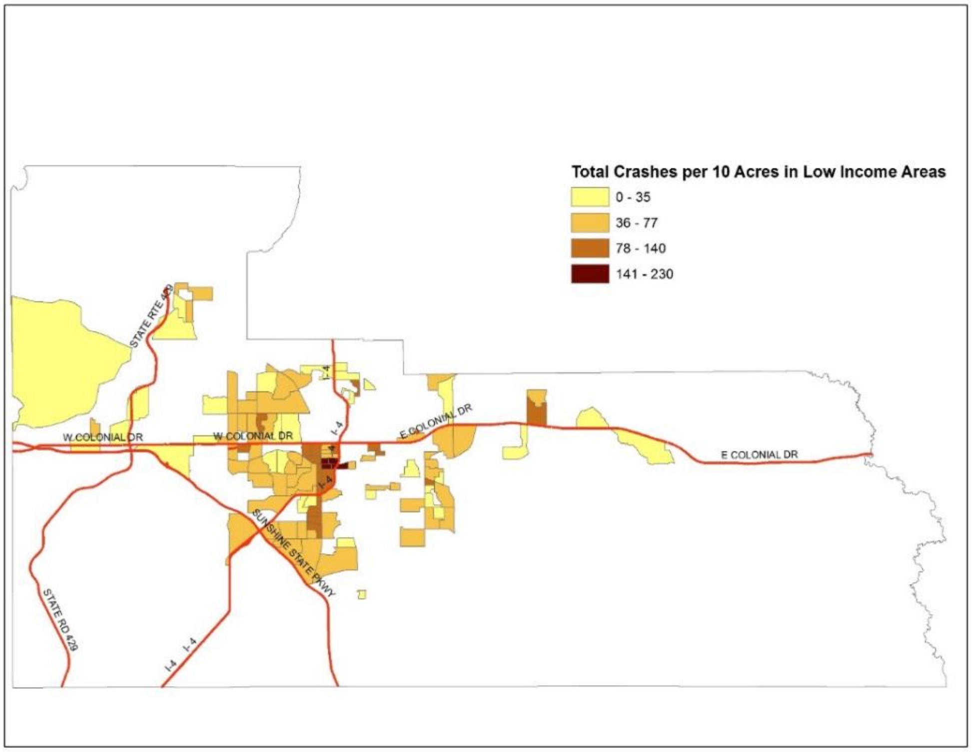


*Figure 3. Total Crashes per 10 Acres in Low-income Block Groups*

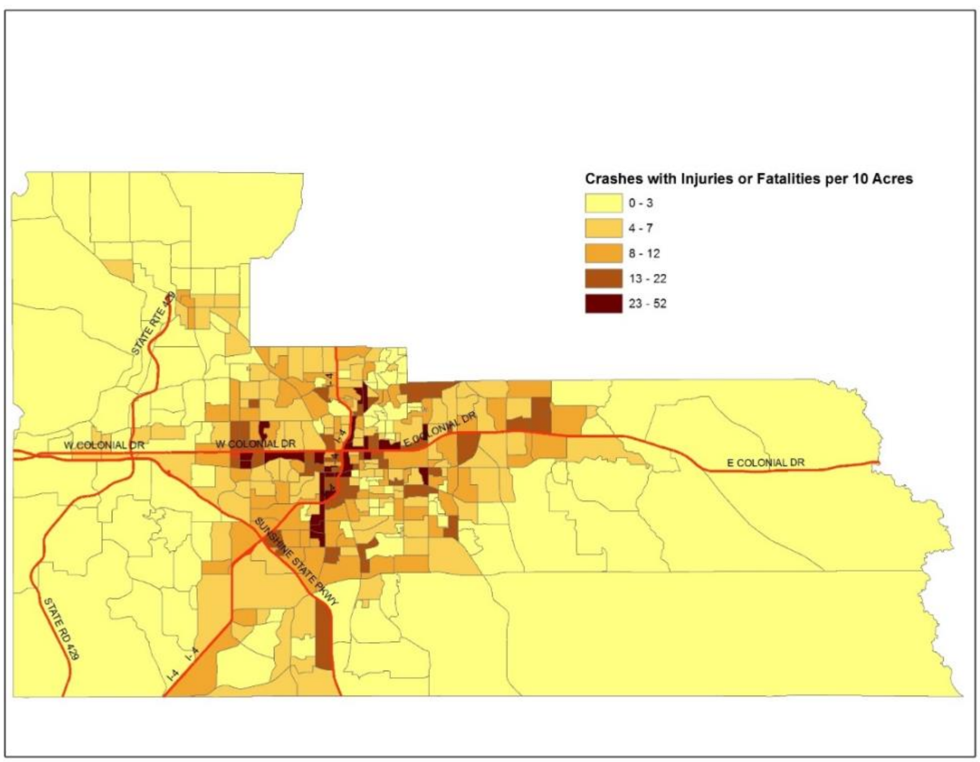


*Figure 4. Injurious and Fatal Crashes per 10 Acres*

*Table 3. Key Crash Statistics, by Median Household Income*

| Income Category | Median Household Income | Block Groups | Land Area (Acres) | Population | Total Crashes | Crashes with Injury or Fatality | Pedestrian Crashes |
|---|---|---|---|---|---|---|---|
| **Low Income** | **<=$40,000** | **115** | **4,867.8 (9.1%)** | **341,703 (26.5%)** | **22,495 (30.8%)** | **4,425 (31.5%)** | **591 (41.6%)** |
| *Extremely Low Income* | 0 - $15,000 | 9 | 199.3 (0.2%) | 6,132 (0.3%) | 1,057 (0.9%) | 176 (0.7%) | 29 (1.3%) |
| *Very Low Income* | $15,000.01 - $25,000 | 17 | 511.9 (0.5%) | 37,630 (1.7%) | 3,262 (2.6%) | 619 (2.6%) | 116 (5.2%) |
| *Low Income* | $25,000.01- $40,000 | 89 | 4,156.6 (4.1%) | 297,941 (13.3%) | 18,176 (14.7%) | 3630 (15.3%) | 446 (19.8%) |
| **Moderate and Lower Middle Income** | **$40,000.01 - $65,000** | **154** | **22,142.1 (41.2%)** | **545,864 (42.3%)** | **35,450 (48.6%)** | **6,679 (47.6%)** | **631 (44.4%)** |
| *Moderate Income* | $40,000.01 - $50,000 | 63 | 9,882.3 (9.6%) | 238,531 (10.7%) | 15,481 (12.5%) | 2,931 (12.4%) | 252 (11.2%) |
| *Lower Middle Income* | $50,000.01 - $65,000 | 91 | 12,259.8 (12.0%) | 307,333 (13.7%) | 19,969 (16.2%) | 3,748 (15.8%) | 379 (16.8%) |
| **Middle to Upper Middle and High Income** | **>$65,000** | **105** | **26,689.3 (49.7%)** | **402,649 (31.2%)** | **15,040 (20.6%)** | **2,939 (20.9%)** | **199 (14.0%)** |
| *Middle to Upper Middle Income* | $65,000.01 - $120,000 | 91 | 26,056.1 (25.4%) | 377,530 (16.9%) | 14,195 (11.5%) | 2,773 (11.7%) | 188 (8.4%) |
| *High Income* | >120,000 | 14 | 633.2 (0.6%) | 25,119 (1.1%) | 845 (0.7%) | 166 (0.7%) | 11 (0.5%) |
| Total | | **374** | **53,699.2** | **1,290,216** | **72,985** | **14,043** | **1,421** |

# The Influence of the Built Environment on Crash Risk in Lower-Income and Higher-income Communities

Studies of the environmental factors influencing crash risk typically use income as a control variable, finding that income is negatively correlated with crash incidence. Nonetheless, there has been little examination into the environmental factors that may influence crash risk in lower-income communities themselves. While lower-income communities may experience higher rates of traffic-related crashes, injuries, and deaths, it is not clear that the environmental factors associated with crash risk are the same for lower-income populations as they are for the population as a whole.

This study thus seeks to understand both the environmental factors that influence crash incidence in lower-income communities, as well as the factors associated with crash risk in these communities may differ from the factors affecting more affluent communities and the population as a whole. This study uses three sets of negative binomial regression models: one for all income groups in Orange County, a second for lower-income communities, defined as block groups with median household income of $40,000 or less, and a third for higher-income communities, defined as block groups with median household incomes of greater than $65,000.

To perform this analysis, three years (2014-2016) of crash data were retrieved from FDOT's Unified Basemap Repository (UBR). Crash data in the UBR are available in GIS shapefiles, including crashes on on-system (i.e., maintained by state) and off-system (i.e., maintained by city/county) roads in Florida. Crashes from both on-system and off-system roads were combined, and geospatially assigned for Orange County. Using information on the category of roads where a crash occurred, an additional step was taken to filter out crashes that occurred on freeways and interstates. The remaining crashes were then mapped to census block groups in Orange County. To avoid double-counting crashes, the near analysis function in ArcGIS was performed to assign crashes to the nearest census block groups. The number of crashes in each census block group was then counted for all crash-injury levels with pedestrian crashes, which have been found to be more prevalent in lower-income communities, specifically identified.

## Dependent Variables

Three sets of dependent variables were used for these analyses. The first is an examination of the total crashes occurring in each block group, which includes crashes of all severities, including fatal, incapacitating injury, non-incapacitating injury, possible injury, and property damage only crashes. To understand the nature of severe crashes, this study further summed KAB crashes, defined as fatal crashes (K), serious injury crashes (A), and possible injury crashes (B). For ease of writing, we use the terms injurious crashes and KAB crashes interchangeably in the sections that follow. Finally, we examined the number of crashes involving only pedestrians, as this is a crash type that overwhelmingly occurs in lower-income communities.

## Independent Variables

This study examines crashes as a function of the characteristics of the built environment. The variables used in these models, and their operational specifications, are as follows:

***Income (in thousands).*** While higher incomes have consistently been associated with the reduced incidence of traffic-related injury and death, we wondered whether this effect held true for all income levels, or whether population-level findings simply account for the improved safety of wealthy communities. For this study, income is the median household income of the census block group. This was converted to population in thousands of dollars to simplify the interpretation of the model coefficients.

***Population (in thousands).*** Areas with more people have more trips and thus more opportunities for crash events. As with income, these block-group level data from the American Community Survey are converted to thousands for ease of interpretation.

***% college educated.*** Previous research finds that higher levels of educational attainment are associated with reductions in crash incidence. The percentage of college-educated residents is included in this analysis to help ascertain the extent to which this relationship holds true across different income groups.

***% white population***. It has been found in previous research that non-whites are disproportionately represented in crash events. This variable is included to ascertain the extent to which race remains a risk factor in crash incidence when crash data are stratified by income and after accounting for the effects of the built environment.

***Miles of urban arterial***. Urban arterials are surface streets intended for higher-operating speeds and have consistently been found to be a crash risk factor. To calculate the mileage of urban arterials, we used GIS to identify the length of roadways classified as urban arterials within the block group boundaries, and then summed the length of the arterial segments located within each block group.

***# of commercial parcels.*** Commercial uses have been consistently analysed as a crash risk factor. This is attributed to the high number of trips they generate, for pedestrians and motorists alike, as well as because they often introduce driveways, and thus points of potential traffic conflict, into the system. The number of commercial parcels is the sum of unique parcels identified as being of commercial use.

***# of intersections.*** This variable is the total number of intersections within a block group, identified using the streets shapefile.

***% of streets with a sidewalk.*** Sidewalks have been found to generally to be associated with an increase in crash frequency and severity. Researchers have often attributed this finding to the fact that areas with sidewalks are likely to have more pedestrian activity and thus higher overall levels of exposure. This variable has not been examined for lower-income populations specifically who are more likely to be transportation disadvantaged and whose decisions to walk are therefore less likely to be affected by the presence or absence of sidewalks. This variable is the sum of the mileage of streets with a sidewalk on at least one side divided by the total mileage of streets in the block group.

***% of sidewalks with a buffer***. The Florida Department of Transportation further identifies whether a buffer is present between the vehicle travelway and sidewalks and shared paths. According to FDOT's classification, a buffer is defined as being a parking lane, a planting strip with objects such as trees and utility poles spaced less than 60 feet apart, or a guardrail. Such buffers are commonly regarded as being a pedestrian amenity as they physically separate pedestrians from vehicles traveling along a street. This variable is calculated as the miles of sidewalks buffered from oncoming traffic divided by the total miles of sidewalk in the block group.

A note on vehicle miles travelled: While we calculated VMT for the block group, we only had information on VMT for arterial streets. As such, this variable was highly collinear with arterial miles (R2 of 0.71). Since the focus of this effort is on the built environment, we included arterial miles, rather than VMT, into the models.

# Crash Incidence in Orange County

Our findings for Orange County region are consistent with previous research on the built environment and traffic safety. As shown in Tables 4, 5, and 6, below, our variables for income, and the percentage of white residents had the expected negative relationships with total crashes, KAB crashes, and pedestrian crashes, all at statistically significant levels. Similarly, more people, more miles of urban arterials, and more commercial parcels were all positively and significantly related to increases in all three crash types.

The presence of sidewalks and sidewalk buffers within a block group was consistently associated with increases in total, KAB, and pedestrian crashes. Both variables were associated with statistically-significant increases in total crashes, and the presence of sidewalk buffers was significantly-associated with increases in KAB crashes. This finding, while departing from the conventional wisdom that such elements are safety features, is nonetheless consistent with previous research which has speculated that these features are likely associated with increased pedestrian activity and thus increased pedestrian exposure. Finally, the number of intersections in a block group, which has had generally inconsistent relationships with crash incidence in previous research, proved to have no statistically-meaningful relationship to any of the three crash types examined in this study.

Considered as a whole, the consistency between these results and previous research suggests that the stratification of crash incidence by income should be useful for understanding the underlying risk factors that affect different income groups.

*Table 4. Total Crashes for All Block groups in Orange County*

| **Total Crashes** | **coeff.** | **std. err.** | **z** | **P(z)** | **95% Confidence Interval** | |
|---|---|---|---|---|---|---|
| Population (thousands) | 0.0581 | 0.0134 | 4.3300 | 0.0000 | 0.0318 | 0.0844 |
| Income (thousands) | -0.0110 | 0.0017 | -6.3200 | 0.0000 | -0.0144 | -0.0076 |
| % college educated | 0.0079 | 0.0030 | 2.6400 | 0.0080 | 0.0020 | 0.0137 |
| % white population | -0.0047 | 0.0018 | -2.5800 | 0.0100 | -0.0083 | -0.0011 |
| Miles of urban arterials | 0.2012 | 0.0277 | 7.2800 | 0.0000 | 0.1470 | 0.2554 |
| # of commercial uses | 0.0019 | 0.0007 | 2.8300 | 0.0050 | 0.0006 | 0.0033 |
| # of intersections | 0.0002 | 0.0005 | 0.4500 | 0.6550 | -0.0008 | 0.0013 |
| % of streets with a sidewalk | 0.0032 | 0.0015 | 2.2000 | 0.0280 | 0.0004 | 0.0061 |
| % of sidewalks with a buffer | 0.3749 | 0.1453 | 2.5800 | 0.0100 | 0.0901 | 0.6596 |
| Constant | 4.6710 | 0.1285 | 36.3500 | 0.0000 | 4.4192 | 4.9229 |

N = 374

Log likelihood = -2192.08

*Table 5. KAB Crashes for All Block Groups in Orange County*

| **KAB Crashes** | **coeff.** | **std. err.** | **z** | **P(z)** | **95% Confidence Interval** | |
|---|---|---|---|---|---|---|
| Population (thousands) | 0.0768 | 0.0130 | 5.9200 | 0.0000 | 0.0514 | 0.1023 |
| Income (thousands) | -0.0077 | 0.0018 | -4.2900 | 0.0000 | -0.0112 | -0.0042 |
| % college educated | -0.0013 | 0.0030 | -0.4500 | 0.6520 | -0.0072 | 0.0045 |
| % white population | -0.0036 | 0.0018 | -1.9700 | 0.0480 | -0.0073 | 0.0000 |
| Miles of urban arterials | 0.2118 | 0.0270 | 7.8600 | 0.0000 | 0.1590 | 0.2647 |
| # of commercial uses | 0.0016 | 0.0006 | 2.6600 | 0.0080 | 0.0004 | 0.0027 |
| # of intersections | 0.0000 | 0.0004 | 0.0000 | 0.9970 | -0.0008 | 0.0008 |
| % of streets with a sidewalk | 0.0020 | 0.0014 | 1.4200 | 0.1550 | -0.0008 | 0.0049 |
| % of sidewalks with a buffer | 0.3064 | 0.1405 | 2.1800 | 0.0290 | 0.0310 | 0.5818 |
| Constant | 3.1548 | 0.1279 | 24.6600 | 0.0000 | 2.9041 | 3.4056 |

N = 374

Log likelihood = -1578.27

*Table 6. Pedestrian Crashes for All Block Groups in Orange County*

| Pedestrian Crashes | coeff. | std. err. | z | P(z) | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| Population (thousands) | 0.0380 | 0.0159 | 2.3900 | 0.0170 | 0.0068 | 0.0691 |
| Income (thousands) | -0.0150 | 0.0029 | -5.1300 | 0.0000 | -0.0207 | -0.0092 |
| % college educated | 0.0059 | 0.0040 | 1.4900 | 0.1370 | -0.0019 | 0.0136 |
| % white population | -0.0069 | 0.0024 | -2.8200 | 0.0050 | -0.0116 | -0.0021 |
| Miles of urban arterials | 0.0807 | 0.0334 | 2.4200 | 0.0160 | 0.0153 | 0.1461 |
| # of commercial uses | 0.0024 | 0.0008 | 2.9600 | 0.0030 | 0.0008 | 0.0040 |
| # of intersections | 0.0004 | 0.0005 | 0.7000 | 0.4840 | -0.0007 | 0.0014 |
| % of streets with a sidewalk | 0.0027 | 0.0020 | 1.4000 | 0.1620 | -0.0011 | 0.0066 |
| % of sidewalks with a buffer | 0.2697 | 0.1924 | 1.4000 | 0.1610 | -0.1075 | 0.6468 |
| Constant | 1.5941 | 0.1674 | 9.5200 | 0.0000 | 1.2660 | 1.9221 |

N = 374

Log likelihood = -846.10

## Crash Incidence in Block Groups with Median Incomes of Greater than $65,000

Tables 7, 8, and 9 present the models for affluent block groups, defined in this study as block groups with median household incomes of greater than $65,000. As expected, the coefficients between income and crash incidence are markedly weaker for higher-income populations than for the population as a whole, and income proved to be significantly-related only to the incidence of total crashes. This suggests that as a community reaches a minimum level of affluence, the crash risk experienced by its population tends to be defined by other factors.

*Table 7. Total Crashes in Block Groups with Median Incomes of Greater than $65,000*

| Total Crashes | coeff. | std. err. | z | P(z) | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| Population (thousands) | 0.0684 | 0.0210 | 3.2500 | 0.0010 | 0.0272 | 0.1096 |
| Income (thousands) | -0.0077 | 0.0028 | -2.7400 | 0.0060 | -0.0133 | -0.0022 |
| % college educated | -0.0010 | 0.0066 | -0.1500 | 0.8840 | -0.0138 | 0.0119 |
| % white population | -0.0049 | 0.0078 | -0.6300 | 0.5270 | -0.0201 | 0.0103 |
| Miles of urban arterials | 0.0887 | 0.0336 | 2.6300 | 0.0080 | 0.0227 | 0.1546 |
| # of commercial uses | 0.0032 | 0.0017 | 1.9200 | 0.0550 | -0.0001 | 0.0064 |
| # of intersections | 0.0000 | 0.0005 | 0.1100 | 0.9150 | -0.0009 | 0.0010 |
| % of streets with a sidewalk | 0.0042 | 0.0028 | 1.5100 | 0.1310 | -0.0013 | 0.0097 |
| % of sidewalks with a buffer | 0.8793 | 0.3163 | 2.7800 | 0.0050 | 0.2593 | 1.4992 |
| Constant | 4.9401 | 0.6777 | 7.2900 | 0.0000 | 3.6118 | 6.2684 |

N = 105

Log likelihood = -572.89

*Table 8. KAB Crashes in Block Groups with Median Incomes Greater than $65,000*

| **KAB Crashes** | **coeff.** | **std. err.** | **z** | **P(z)** | **95% Confidence Interval** | |
|---|---|---|---|---|---|---|
| Population (thousands) | 0.0693 | 0.0196 | 3.5300 | 0.0000 | 0.0308 | 0.1077 |
| Income (thousands) | -0.0037 | 0.0029 | -1.3000 | 0.1950 | -0.0094 | 0.0019 |
| % college educated | -0.0122 | 0.0064 | -1.9000 | 0.0580 | -0.0248 | 0.0004 |
| % white population | -0.0077 | 0.0075 | -1.0300 | 0.3050 | -0.0223 | 0.0070 |
| Miles of urban arterials | 0.0886 | 0.0301 | 2.9500 | 0.0030 | 0.0296 | 0.1475 |
| # of commercial uses | 0.0026 | 0.0013 | 1.9500 | 0.0510 | 0.0000 | 0.0052 |
| # of intersections | 0.0002 | 0.0004 | 0.6000 | 0.5510 | -0.0006 | 0.0011 |
| % of streets with a sidewalk | 0.0054 | 0.0027 | 2.0100 | 0.0440 | 0.0001 | 0.0106 |
| % of sidewalks with a buffer | 0.7505 | 0.2949 | 2.5400 | 0.0110 | 0.1725 | 1.3286 |
| Constant | 3.7723 | 0.6441 | 5.8600 | 0.0000 | 2.5099 | 5.0347 |

N = 105

Log likelihood = -397.10

*Table 9. Pedestrian Crashes for Block Groups with Median Incomes Greater than $65,000*

| **Pedestrian Crashes** | **coeff.** | **std. err.** | **z** | **P(z)** | **95 Confidence Interval** | |
|---|---|---|---|---|---|---|
| Population (thousands) | 0.0714 | 0.0233 | 3.0600 | 0.0020 | 0.0256 | 0.1171 |
| Income (thousands) | -0.0050 | 0.0049 | -1.0200 | 0.3070 | -0.0145 | 0.0046 |
| % college educated | -0.0007 | 0.0099 | -0.0700 | 0.9440 | -0.0200 | 0.0186 |
| % white population | 0.0148 | 0.0115 | 1.3000 | 0.1950 | -0.0076 | 0.0373 |
| Miles of urban arterials | -0.0055 | 0.0401 | -0.1400 | 0.8910 | -0.0840 | 0.0731 |
| # of commercial uses | 0.0043 | 0.0017 | 2.5400 | 0.0110 | 0.0010 | 0.0077 |
| # of intersections | 0.0002 | 0.0005 | 0.5300 | 0.5990 | -0.0006 | 0.0011 |
| % of streets with a sidewalk | 0.0016 | 0.0038 | 0.4100 | 0.6800 | -0.0059 | 0.0091 |
| % of sidewalks with a buffer | 0.8624 | 0.4002 | 2.1600 | 0.0310 | 0.0781 | 1.6468 |
| Constant | -0.9178 | 0.9899 | -0.9300 | 0.3540 | -2.8580 | 1.0224 |

N = 105

Log likelihood = -174.47

Like the population as a whole, the number of commercial uses in a block group were again associated with statistically-significant increases in all three crash types, while the miles of urban arterials were associated with increases in total crashes. Interestingly, the miles of arterials in higher-income block groups not only ceases to have a statistically-significant relationship with pedestrian collisions, but also experiences a reversal in the direction of the coefficient. This may be attributable to differences in exposure; given the choice between driving or walking in environments with urban arterials, more affluent residents may simply elect to forego walking, thus reducing the incidence of pedestrian collisions in these environments. Nonetheless, the percentage of streets with sidewalks is associated with significant increases in KAB collisions, while the percentage of sidewalks that are buffered from oncoming traffic is associated with significant increases in total, KAB, and pedestrian crashes alike. In the latter case, these relationships proved to be remarkably strong, with a 1% increase in the number of streets with a sidewalk buffer corresponding to an 87% increase in total collisions, a 75% increase in KAB collisions, and a 92% increase in pedestrian collisions.

Another notable finding is that the percentage of whites residing in a block group ceases to have a statistically meaningful relationship with total, KAB, or pedestrian crashes. This suggests that residing in a more affluent community may offset any crash risk associated with racial inequities. Higher levels of educational attainment were associated with slight reductions in all three crash types, but the relationship proved to be significant only for KAB crashes.

# Crash Incidence in Block Groups with Median Incomes of $40,000 or Less

Tables 10, 11, and 12, present the model results for lower-income block groups, defined as block groups with median household incomes of $40,000 and less. As with the models for higher-income block groups, median household income and the number of intersections again prove to be comparatively unimportant as explanatory variables, while the number of people residing in a block group is again associated with significant increases in crash incidence.

*Table 10. Total Crashes in Block Groups with Median Incomes of $40,000 or Less*

| **Total Crashes** | **coeff.** | **std. err.** | **z** | **P(z)** | **95% Confidence Interval** | |
|---|---|---|---|---|---|---|
| Population (thousands) | 0.0970 | 0.0315 | 3.0800 | 0.0020 | 0.0352 | 0.1588 |
| Income (thousands) | -0.0075 | 0.0067 | -1.1200 | 0.2620 | -0.0207 | 0.0056 |
| % college educated | 0.0062 | 0.0053 | 1.1700 | 0.2440 | -0.0042 | 0.0167 |
| % white population | -0.0049 | 0.0022 | -2.1900 | 0.0290 | -0.0092 | -0.0005 |
| Miles of urban arterials | 0.2878 | 0.0514 | 5.6000 | 0.0000 | 0.1870 | 0.3885 |
| # of commercial uses | 0.0028 | 0.0012 | 2.2500 | 0.0250 | 0.0004 | 0.0052 |
| # of intersections | 0.0005 | 0.0013 | 0.4100 | 0.6820 | -0.0020 | 0.0031 |
| % of streets with a sidewalk | 0.0016 | 0.0022 | 0.7600 | 0.4480 | -0.0026 | 0.0059 |
| % of sidewalks with a buffer | 0.2420 | 0.2587 | 0.9400 | 0.3500 | -0.2650 | 0.7490 |
| Constant | 4.2988 | 0.2241 | 19.1800 | 0.0000 | 3.8596 | 4.7380 |

N = 115

Log likelihood = -667.31

Nonetheless, the remaining variables differ in notable ways from those of higher-income block groups. First, race proved to be far more important for understanding crash incidence in lower-income communities than in higher-income ones. While the percentage of whites residing in a block groups did not have statistically-meaningful relationships with any of the crash types in higher income block groups, it was significantly related to the reduced incidence of total, KAB and pedestrian collisions in lower-income groups. Stated another way, areas with higher concentrations of non-white residents experience significantly greater levels of overall crash risk.

Urban arterials proved to be particularly problematic in lower-income block groups, being not only significantly associated with increases in all three crash types, but also reporting coefficients for total and KAB crashes that are more than three times greater than those of higher income populations. For pedestrian collisions, which were not influenced by the presence of arterials in high-income communities, each additional mile of urban arterial was associated with a 21% increase in pedestrian collisions. While the presence of sidewalk buffers proved to be associated with strong increases in the incidence of total, injurious, and pedestrian collisions for higher-income block groups, they were generally associated with reductions in injurious and pedestrian crashes in lower-income areas and, moreover, though not at conventional levels of statistical significance.

*Table 11. KAB Crashes in Block Groups with Median Incomes of $40,000 or Less*

| KAB Crashes | coeff. | std. err. | z | P(z) | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| Population (thousands) | 0.1394 | 0.0328 | 4.2500 | 0.0000 | 0.0752 | 0.2036 |
| Income (thousands) | -0.0019 | 0.0070 | -0.2700 | 0.7880 | -0.0156 | 0.0119 |
| # school-aged children | -0.0046 | 0.0056 | -0.8200 | 0.4120 | -0.0156 | 0.0064 |
| % White | -0.0038 | 0.0023 | -1.6500 | 0.1000 | -0.0082 | 0.0007 |
| Miles of urban arterials | 0.2987 | 0.0533 | 5.6000 | 0.0000 | 0.1942 | 0.4032 |
| # of commercial uses | 0.0023 | 0.0013 | 1.8000 | 0.0720 | -0.0002 | 0.0048 |
| # of intersections | -0.0004 | 0.0013 | -0.2700 | 0.7870 | -0.0030 | 0.0022 |
| % of streets with a sidewalk | -0.0006 | 0.0022 | -0.2600 | 0.7980 | -0.0050 | 0.0038 |
| % of sidewalks with a buffer | -0.3999 | 0.2733 | -1.4600 | 0.1430 | -0.9355 | 0.1357 |
| Constant | 2.8696 | 0.2408 | 11.9200 | 0.0000 | 2.3977 | 3.3415 |

N = 115

Log likelihood = -487.55

*Table 12. Pedestrian Crashes in Block Groups with Median Incomes of $40,000 or Less*

| Pedestrian Crashes | coeff. | std. err. | z | P(z) | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| Population (thousands) | 0.1302 | 0.0387 | 3.3600 | 0.0010 | 0.0543 | 0.2060 |
| Income (thousands) | -0.0024 | 0.0085 | -0.2800 | 0.7770 | -0.0190 | 0.0142 |
| % college educated | -0.0151 | 0.0070 | -2.1400 | 0.0320 | -0.0289 | -0.0013 |
| % white population | -0.0073 | 0.0027 | -2.6400 | 0.0080 | -0.0126 | -0.0019 |
| Miles of urban arterials | 0.2102 | 0.0568 | 3.7000 | 0.0000 | 0.0990 | 0.3215 |
| # of commercial uses | 0.0017 | 0.0014 | 1.2100 | 0.2280 | -0.0011 | 0.0045 |
| # of intersections | -0.0005 | 0.0014 | -0.3300 | 0.7440 | -0.0033 | 0.0024 |
| % of streets with a sidewalk | -0.0009 | 0.0026 | -0.3600 | 0.7210 | -0.0061 | 0.0042 |
| % of sidewalks with a buffer | -0.3992 | 0.3229 | -1.2400 | 0.2160 | -1.0321 | 0.2337 |
| Constant | 1.5843 | 0.2777 | 5.7100 | 0.0000 | 1.0400 | 2.1285 |

N = 115

Log likelihood = -280.57

# Discussion

To date, the research on traffic safety and the built environment has treated income largely as a control variable, if it is a factor that is considered at all. These studies have consistently found that income is negatively correlated with total, injurious, and fatal crashes, a finding that is attributed to the ability of more affluent households to afford newer, more crashworthy vehicles that are more likely to have collision-avoidance systems. Nonetheless, there has been little formal examination into how, if at all, the risk factors affecting lower-income and higher-income communities may differ.

This study has sought to fill this void by providing a comparison of the unique risk factors for higher-income and lower-income block groups in Orange County, Florida. While this study's findings for the risk factors for the County as a whole are consistent with previous studies that have examined the relationship between traffic safety and the built environment, there are notable differences when one examines the risk factors for lower-income and higher-income block groups. Table 13 compares the model coefficients and significance levels for all modelled variables.

*Table 13. A Comparison of Risk Factors for High-Income and Low-Income Block Groups*

| Variable | High Income | | | Low Income | | |
|---|---|---|---|---|---|---|
| | Total | KAB | Pedestrian | Total | KAB | Pedestrian |
| Population (thousands) | 0.0684*** | 0.0693*** | 0.0714** | 0.0970** | 0.1394*** | 0.1302*** |
| Income (thousands) | -0.0077** | -0.0037 | -0.0050 | -0.0075 | -0.0019 | -0.0024 |
| % college educated | -0.0010 | -0.0122 Ψ | -0.0007 | 0.0062 | -0.0046 | -0.0151* |
| % white population | -0.0049 | -0.0077 | 0.0148 | -0.0049* | -0.0038Ψ | -0.0073** |
| Miles of urban arterials | 0.0887** | 0.0886** | -0.0055 | 0.2878*** | 0.2987*** | 0.2102*** |
| # of commercial uses | 0.0032 Ψ | 0.0026 Ψ | 0.0043* | 0.0028* | 0.0023Ψ | 0.0017 |
| # of intersections | 0.0000 | 0.0002 | 0.0002 | 0.0005 | -0.0004 | -0.0005 |
| % of streets with a sidewalk | 0.0042 | 0.0054* | 0.0016 | 0.0016 | -0.0006 | -0.0009 |
| % of sidewalks with a buffer | 0.8793** | 0.7505* | 0.8624* | 0.2420 | -0.3999 | -0.3992 |

Ψ $p \leq 0.1$
* $p \leq 0.05$
** $p \leq 0.01$
*** $p \leq 0.001$

## Commercial Uses and Urban Arterials

The presence of urban arterials and commercial uses were found to be risk factors for higher-income and lower-income communities alike. While the effects of commercial uses on crash incidence is roughly the same between lower-income and higher-income communities, as evidenced in their correlation coefficients, the presence of urban arterials has a profoundly more negative effect on lower-income communities than higher-income ones. In lower-income communities, each mile of urban arterial having a 300% larger effect on the incidence of total and injurious crashes in lower-income communities, and a staggering 3,800% larger effect on the incidence of pedestrian crashes. These facilities, while problematic for all road users, have a profoundly negative effect on lower-income populations specifically.

One possible explanation for the effects of these facilities is exposure; persons in lower-income communities are likely to be more reliant on walking to serve their trip objectives than those in more affluent ones, thus leading to greater opportunities to be involved in a collision. To test this, we re-ran the models using the number of residents walking to work, obtained from the American Community Survey. This variable did not have a statistically-meaningful relationship to pedestrian crashes for the more affluent block groups, but proved to be significantly-related, at the 90% confidence level, to pedestrian crashes in lower-income areas (See Table 14).

*Table 14. Revised Model for Pedestrian Crashes in Lower-income Block Groups, including Walking to Work*

| Pedestrian Crashes | coeff. | std. err. | z | P(z) | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| Population (thousands) | 0.1198 | 0.0388 | 3.0900 | 0.0020 | 0.0438 | 0.1958 |
| Income (thousands) | -0.0002 | 0.0085 | -0.0200 | 0.9850 | -0.0168 | 0.0165 |
| % college educated | -0.0193 | 0.0074 | -2.5900 | 0.0100 | -0.0339 | -0.0047 |
| % white population | -0.0071 | 0.0027 | -2.6200 | 0.0090 | -0.0124 | -0.0018 |
| Miles of urban arterials | 0.2032 | 0.0557 | 3.6500 | 0.0000 | 0.0941 | 0.3124 |
| # of commercial uses | 0.0020 | 0.0014 | 1.4200 | 0.1570 | -0.0008 | 0.0048 |
| # of intersections | -0.0008 | 0.0015 | -0.5500 | 0.5820 | -0.0036 | 0.0020 |
| % of streets with a sidewalk | -0.0005 | 0.0026 | -0.2100 | 0.8370 | -0.0057 | 0.0046 |
| % of sidewalks with a buffer | -0.4133 | 0.3189 | -1.3000 | 0.1950 | -1.0383 | 0.2118 |
| # of persons walking to work | 0.0034 | 0.0021 | 1.6500 | 0.1000 | -0.0006 | 0.0074 |
| Constant | 1.5875 | 0.2756 | 5.7600 | 0.0000 | 1.0473 | 2.1278 |

These findings suggest that the negative effects of arterials on lower-income populations may be a combination of two factors. The first is that the road users in lower-income block groups may be more likely to engage in risky behaviors than their counterparts in higher-income areas. While one may be tempted to infer this means that lower-income residents themselves are more likely to engage in high-risk behaviors, we should note that simply because a crash occurs in a lower-income block group does not mean that the involved parties are residents of the area. Indeed, previous research has found that persons driving expensive cars are less likely to yield for pedestrians than those driving more modest cars (Piff et al., 2012). As shown in Figure 3, lower-income communities tend to cluster along Colonial Drive, I-4, and the Sunshine State Parkway which are major commuting routes through the region. It is thus highly probable that some portion of the increased crash risk associated with arterials in lower-income areas is attributable to more affluent persons traveling through these areas (Cherry et. al., 2018). Nonetheless, in the absence of information on the residential locations of involved parties, we are unable to test this hypothesis.

A second factor is that arterials in lower-income communities may be designed or operated differently, with less consideration for safety, than those in more affluent communities. This disparity may come in a variety of forms, long distances between protected pedestrian crossings, and signal cycles that prioritize traffic progression over safety. Indeed, a study of signal coordination that included Orange County found that such applications to be associated with a 53% increase in intersection crashes (Guo, Wang, and Abdel-Aty, 2010). Given the limitations on our data, however, we can only speculate on the precise nature of these potential causes. Nonetheless, our findings strongly suggest that greater attention to the design and operation of arterial in lower-income communities is needed.

## Sidewalks and Sidewalk Buffers

For higher-income communities, the percentage of streets with sidewalks was positively associated with all crash types, and significantly so for KAB crashes. Further, the presence of sidewalk buffers in higher-income communities, defined by FDOT as parking lanes, guardrails, or planting strips placed between the sidewalk and the vehicle travelway, were found to be associated with positive and statistically-significant increases in total, injurious, and pedestrian collisions alike.

This was not the case for lower-income communities, however. What is of note is not so much that these variables failed to enter the models at significant levels, but that, in the case of both KAB and pedestrian crashes, they had a generally *negative* effect on crash incidence. For this reason, tables 7-12 report not only model coefficients and significance levels, but also the 95% confidence intervals of the estimates, which describe the overall effects of the variables.

Considering the results holistically, this suggests that income, as well as its associated effects on walking, should be considered when examining the relationship between pedestrian infrastructure and pedestrian crash incidence. For persons with higher incomes, walking is often a choice based on the ease of walking to destinations and the perceived comfort of the built environment. This is not only reflected in the results for pedestrian buffers, but also in the presence of commercial uses, which are associated with significant increases in pedestrian crashes. Similarly, the presence of arterials, which are high-speed, high-volume thoroughfares, and which are often unpleasant for pedestrians, had a generally negative (though not statistically-meaningful) association with pedestrian collisions. This implies that when presented with the choice to walk along unsafe facilities, affluent persons choose not to do so.

Lower-income households, who often have lower levels of car ownership, may not have this choice, resulting in their use, as pedestrians of arterial roadways and a corresponding increase in their risk of being injured or killed. Indeed, this is reflected by the significance of work trips on crash incidence for lower-income communities. Work trips are not optional and trip ends cannot be readily substituted for destinations located in safer environments. Under such conditions, sidewalk buffers are not simply features that encourage people to walk who might otherwise not do so. And indeed, in lower-income communities, the presence of these features is generally associated with reduction in pedestrian crashes (though only at an 80% level of statistical confidence).

Interestingly, the presence of sidewalks and sidewalk buffers in more affluent communities were found to be not only associated with increases in pedestrian collisions but with total and injurious collisions as well. While we did not model collisions involving motorists separately from total and injurious collisions, these findings suggest that, at least for more affluent areas, the presence of these features may result in more complex traffic environments that appear to increase the incidence of multiple-vehicle collisions. It would be useful for future research to examine how these features may influence rear-end, angle, and fixed-object crashes.

## Race and Income

Perhaps the most noteworthy finding is that race and income—and the cultural indicators they suggest—play a far more prominent role in understanding crash incidence than has previously been assumed. For affluent communities, while median income entered the model with the expected coefficients, it only proved to be significantly-related to total collisions. Race, by contrast, proved relatively unimportant as a risk factor in affluent communities. Nonetheless, more affluent communities tended to have higher shares of white residents than less affluent ones; on average, 83% of persons residing in more affluent block groups were white, and even the most diverse block group was 48% white (Table 15). By contrast, the residents of lower-income block groups, on average, were only 45% white, though the percentage of whites ranged from 0% to 100%.

*Table 15. Percentages of Whites in High-income and Low-income Communities*

| Income Group | Min | Max | Mean | Std. Dev |
|---|---|---|---|---|
| Lower-income | 0% | 100% | 45% | 29% |
| Higher-income | 48% | 100% | 83% | 11.3% |

This was not so for lower-income communities, where race proved to be significantly-related to increased crash risk for all three crash categories, indicating that racial inequities influence overall levels of crash risk.

Future research will need to establish the extent to which these differences may be attributable to socio-cultural factors that influence crash risk, or whether the environments in which non-white populations reside are designed with less regard for safety. We expect that the latter factor plays an important role. As shown in Figure 5, below, whites tend to be located near downtown Orlando, which has lower-operating speeds than much of the rest of the region, while non-white residents tend to be concentrated along Western Colonial Drive and in the area defined by I-4, Colonial Drive, and the Sunshine State Parkway, all of which are major commuting routes for the region.

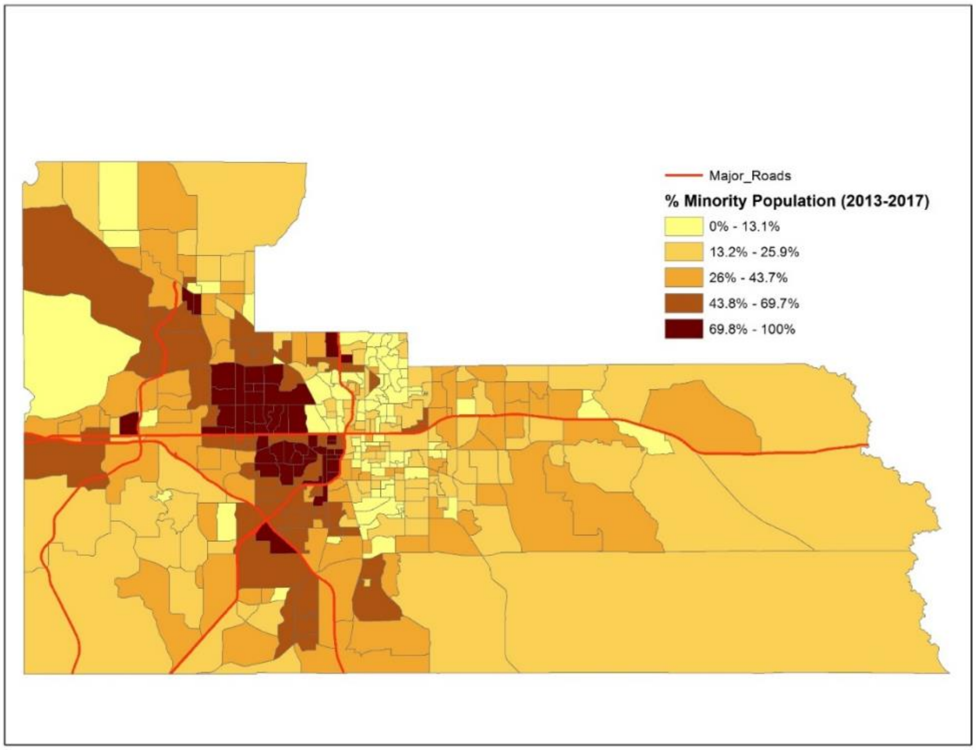


*Figure 5. Percentage of Non-white Residents in Orange County*

# Conclusions

While previous research has consistently identified income as a significant factor in understanding community-level crash risk, the results of this study suggest that income has a far more complex relationship to crash incidence than has been previously supposed. The first and perhaps most notable finding is that while urban arterials are a risk factor for all areas, their negative effect on safety is profoundly greater in lower-income environments. For higher income communities, each additional mile of urban arterial is associated with a 9% increase in total and KAB crashes, though it did not prove to have a statistically meaningful relationship with pedestrian crashes. For lower-income communities, each mile of urban arterials is associated with a nearly 30% increase in total and KAB crashes, and a 19% increase in pedestrian crashes. For Orlando/Orange County, which has been identified by Smart Growth America (2019) as being the most dangerous region for pedestrians in the United States, these findings strongly suggest that the region needs to pay explicit attention to the effects of arterial design in lower-income communities.

Race proved to have an important role on crash risk as well. While race did not prove to have much of a meaningful effect on crash incidence in more affluent areas, it was a significant predictor of crash risk in lower-income block groups. This suggests that as non-white households become more affluent, the crash risk in their communities tends to mirror that of more affluent whites. Nonetheless, race emerges as an important factor for understanding crash risk in lower-income communities, with higher concentrations of non-white residents being associated with significant increases in total, injurious, and pedestrian-related crashes. Broader societal issues related to race may well be influencing these results; a study examining driver yielding, for example, found that motorists were twice as likely to yield for white pedestrian than black ones (Goddard, Kahn, and Atkins, 2015). As such, racial bias may thus translate into increased crash risk in lower-income areas where non-white populations are concentrated.

Another important finding is that “livability” features were found to have different safety effects in high-income and low-income communities. A major objective of the planning and urban design professions is to reduce automobile use through the creation of “walkable” or “livable” communities. It is widely presumed that the creation of environments designed to encourage walking through the provision of sidewalks and sidewalk buffers enhance traffic safety. Yet the results of this study suggest that the relationship between these features and crash incidence is more complicated, particularly after accounting for differences in household income. For more affluent areas, which contain residents who are less dependent on walking as a primary means of transportation, the presence of sidewalks was associated with an increase in KAB crashes, while sidewalk buffers associated with an increase of total, injurious, and pedestrian collisions alike. We suspect that this is attributable to two factors. The first is that when presented with environments perceived to support walking, persons residing in affluent communities become more likely to walk, which would in turn increase their overall levels of exposure. Second, elements such as on-street parking, higher pedestrian volumes, and traffic associated with commercial uses may result in a more complex traffic environment, making collisions and injuries more likely to occur. Future research is needed to better understand these effects.

For lower income communities, however, sidewalks and sidewalk buffers were not significantly related to increases in total or KAB crashes. Indeed, the increased presence of these features tended to be associated with an overall reduction in KAB and pedestrian crashes. We expect that this finding may also be understood, at least in part, as a function of exposure; in lower-income environments, which typically have lower-levels of automobile ownership and thus a higher propensity for walking, pedestrian trips are likely to be made regardless of the perceived comfort of the pedestrian environment. Whether sidewalks and buffers are present or absent likely makes little overall difference to overall pedestrian volumes. This conclusion is further supported by the divergent results relating to arterial thoroughfares. Arterials have a profoundly negative effect on pedestrian crashes in lower-income environments, undoubtedly as a result of the fact that persons residing in such environments, and for whom driving may not be an option, are forced to use them. In more affluent communities, their presence tended to be associated with fewer pedestrian crashes, though not at statistically-significant levels. Stated another way; when affluent persons have the choice regarding whether or not to walk along arterial thoroughfares, they appear to choose not to do so.

This is not to suggest that the provision of such infrastructure is undesirable, but instead that greater care needs to be given to their traffic safety impacts. Issues such as speed, intersection control, and commercial access need to be addressed thoughtfully; encouraging higher levels of pedestrian activity but failing to address the inherent safety problems such activity may create appears to result in the increased incidence of traffic-related crashes and injuries, at least for more affluent populations. For lower-income communities, greater attention needs to be given to the safety impacts of arterial design.

To date, there has been a general tendency to regard the built environment as having consistent safety impacts on all races and incomes alike. Yet, as detailed here, this cannot be presumed to be the case; traffic safety and the design of the built environment, like much of U.S. society, appears to be strongly intertwined with broader issues of racial and income inequality. We thus conclude with the observation that future safety research, and future transportation practice, needs to better account for the influence of race and income inequality on traffic safety.

# References


Abdalla, I., Raeside, R., Barker, D., & McGuigan, D. (1997). An investigation into the relationships between area social characteristics and road accident collision casualties. *Accident Analysis & Prevention*, 29(5), 583-593.

Abdel-Aty, M.A., Siddiqui, C, Huang, H., & Wang, X. (2011). Zonal level safety evaluation incorporating trip generation effects. *Transportation Research Record*, 2213, 20-28.

Abdel-Aty, M., Lee, J., Siddiqui, C., & Choi, K. (2013). Geographical unit based analysis in the context of transportation safety planning. *Transportation Research Part A: Policy and Practice*, 49, 62-75. Retrieved from http://dx.doi.org/10.1016/j.tra.2013.01.030

Alluri, P., Saha, D., Wu, W., Huq, A., Nafis, S., & Gan, A. (2017). *Statewide Analysis of Bicycle Crashes* (No. BDV29-977–23). Miami, FL.

American Association of State Highway and Transportation Officials (2018) *A Policy on the Geometric Design of Highways and Streets*. Washington DC: Author.

Anstey, K.J., Wood, J.M., Lord, S., & Walker, J.G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. Clinical Psychology, 25, 45-65.

Baker, S.P., Braver, E.R., Chen, L-H., Li, G., & Williams, A.F. (2002). Drinking histories of fatally injured drivers. *Injury Prevention*, 8(3), 221-226.

Bachman, J.G., Johnston, L.D., O'Malley, P.M. (1987). *Monitoring the Future: Questionnaire Responses from the Nation's High School Seniors, 1986*. Ann Arbor (Michigan): Univ. of Michigan.

Beck, L.F., Leonard, J.P., Stephen, C.D. (2007). Pedestrian fatalities, Atlanta metropolitan statistical area and United States, 2000-2004. *Journal of Safety Research*, 38(6), 613-616.

Black D. (1980). *Inequalities in Health: Report of a Research Working Group*. London: Department of Health and Social Security.

Blumenberg, E., & Haas, P. (2002). *The Travel Behavior and Needs of the Poor: A Study of Welfare Recipients in Fresno County*. San Jose, California: Mineta Transportation Institute, San Jose State University.

Blumenberg, E., & Manville, M. (2004). Beyond the spatial mismatch: Welfare recipients and transportation policy. *Journal of Planning Literature*, 19(2), 182-205.

Bonneson, J.A. (2010). *Highway Safety Manual*. Washington, D.C.: American Association of State Highway and Transportation Officials.

Botchwey, N.D., Falkenstein, R., Levin, J., Fisher, T., & Trowbridge, M. (2014). The built environment and actual causes of death: Promoting an ecological approach to planning and public health. *Journal of Planning Literature*, 30(3), 261-281.

Cai, Q., Abdel-Aty, M., Lee, J., & Eluru, N. (2017). Comparative analysis of zonal systems for macro-level crash modeling. *Journal of Safety Research*, 61, 157-166. https://doi.org/10.1016/j.jsr.2017.02.018

Carter, D.L., & Council, F.M. (2007). Factors contributing to pedestrian and bicycle crashes on rural highways. *Transportation Research Board*: 86th Annual Meeting.

CDC (Centers for Disease Control and Prevention). (1989). *National Adolescent Student Health Survey (NASHS)*, 1987. MMWR, 38, 147.

CDC (Centers for Disease Control and Prevention). (2010). *Teen Drivers: Fact Sheet. Injury Prevention & Control: Motor Vehicle Safety*. Retrieved from:

http://www.cdc.gov/MotorVehicleSafety/Teen_Drivers/teendrivers_factsheet.html.

CDC (Centers for Disease Control and Prevention). (2013). *Motor Vehicle Traffic-Related Pedestrian Deaths – United States, 2001-2010*. Retrieved from: https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6215a1.htm

Chandraratna, S., L. Mitchell, and N. Stamatiadis. (2002). Evaluation of the transportation safety needs of older drivers. Lexington: University of Kentucky.

Charlton, B.G., and White, M. (1995). Living on the margin: a salutogenic model for socio-economic differentials in health. *Public Health*, 109, 235–243.

Cherry, C., Hezaveh, A.M., Noltenius, M. Ph.D., Khattak, A., Merlin, L., Dumbaugh, E., Ragland, D. & Sandt, L. (2018). *Completing the Picture of Traffic Injuries: Understanding Data Needs and Opportunities for Road Safety*. Chapel Hill: Collaborative Sciences Center for Road Safety. https://www.roadsafety.unc.edu/wp-content/uploads/2018/11/CSCRS_R4_FinalReport.pdf. Accessed November 10, 2020.

Chichester, B., Gregan, J., Anderson, D., & Kerr, J. (1998). Associations between road traffic accidents and socio-economic deprivation on Scotland's west coast. *Scottish Medical Journal*, 43(5), 135-138.

Clifton, K.J., Burnier, C.V., & Akar, G. (2009). Severity of injury resulting from pedestrian–vehicle crashes: What can we learn from examining the built environment? *Transportation Research Part D: Transport and Environment*, 14, 425-436.

Cottrill, C.D., Thakuriah, P. (2010). Evaluating pedestrian crashes in areas with high low-income or minority populations. *Accident Analysis & Prevention*, 42, 1718-1728.

County of Los Angeles. (2000). *Assessing the Transportation Needs of Welfare-to-Work Participants in Los Angeles County*. Los Angeles: Urban Research Division, Chief Administrative Office.

Cervero, R., Sandoval, O., & Landis, J. (2002). Transportation as a stimulus of welfare-to-work—Private versus public mobility. *Journal of Planning Education and Research*, 22(1), 50-63.

DiMaggio, C. (2015). Small-Area Spatiotemporal Analysis of Pedestrian and Bicyclist Injuries in New York City. *Epidemiology*, 26(2), 247–254. https://doi.org/10.1097/EDE.0000000000000222

Dumbaugh, E., & Li, W. (2011). Designing for the safety of pedestrians, cyclists, and motorists in urban environments. Journal of the American Planning Association, 77(1), 69-88. https://doi.org/10.1080/01944363.2011.536101

Dumbaugh, E., & Rae, R. (2009). Safe urban form: Revisiting the relationship between community design and traffic safety. *Journal of the American Planning Association*, 75(3), 309-329. https://doi.org/10.1080/01944360902950349

Eluru, N., Yasmin, S., Bhowmick, T., & Rahman, M. (2016). *Enhancing Non-Motorized Safety by Simulating Non-Motorized Exposure Using a Transportation Planning Approach*. Retrieved from http://safersim.nads-sc.uiowa.edu/final_reports/UCF 1 Y3_Report.pdf

Elvik, R. (2000). How much do road accidents cost the national economy? *Accident Analysis & Prevention*, 32(5), 849-851.

Evans, L. (2004). *Traffic Safety – Science Serving Society*. Bloomfield Hills, Michigan.

Ewing, R., & Dumbaugh, E. (2009). The built environment and traffic safety: A review of empirical evidence. *Journal of Planning Literature*, 23(4), 347-367.

Ewing, R., Schieber, R.A., & Zegeer, C.V. (2003). Urban sprawl as a risk factor in motor vehicle occupant and pedestrian fatalities. *American Journal of Public Health*, 93,1541-1545.

Federal Highway Administration. 1993. *Traffic maneuver problems of older drivers: Final technical report* (Report FHWARD-92-092). Washington, DC: U.S. Department of Transportation.

Goddard, T., Kahn, K.B., & Adkins, A. (2015). *Racial Bias in Driver Yielding Behavior at Crosswalks*. *Transportation research Part F: Psychology and Behavior*, 33, 1-6

Graham, D., Glaister, S., & Anderson, R. (2005). The effects of area deprivation on the incidence of child and adult pedestrian casualties in England. *Accident Analysis & Prevention*, 37, 125-135.

Graham, D., & Glaister, S. (2003). Spatial variation in road pedestrian casualties: The role of urban scale, density, and land-use mix. *Urban Studies*, 40(8), 1591-1607.

Guo, F., Wang, X., and Abdel-Aty, A (2010). Modeling signalized intersection safety with corridor-level spatial correlations. *Accident Analysis and Prevention*, 2, 84-92.

Guyer, B., Talbot, A.M., Pless, I.B. (1985). Pedestrian injuries to children and youth. *Pediatric Clinics of North America*, 32(1), 163-174.

Hadayeghi, A., Shalaby, A. S., & Persaud, B. N. (2007). Safety Prediction Models: Proactive Tool for Safety Evaluation in Urban Transportation Planning Applications. Transportation Research Record: Journal of the Transportation Research Board, (2019), pp 225-236. Retrieved from: http://dx.doi.org/10.3141/2019-27.

Hallmark, S. L., and K. Mueller. 2004. *Impact of left-turn phasing on older and younger drivers at high-speed intersections*. Ames: Iowa Department of Transportation.

Hakamies-Blomqvist, L. (2004). *Safety of older persons in traffic. In Transportation in an aging society: A decade of experience*. Washington, DC. National Academy of Sciences, Transportation Research Board.

Harrell, W.A. (1992). Driver response to a disabled pedestrian using a dangerous crosswalk. *Journal of Environmental Psychology*, 12(4), 345-354.

Hippisley-Cox, J., Groom, L., & Kendrick, D. (2002). Cross sectional survey of socioeconomic variations in severity and mechanism of childhood injuries in Trent 1992-7. *British Medical Journal*, 324, 1132-1138.

Huang, H., Abdel-Aty, M., & Darwiche, A. (2010). County-level crash risk analysis in Florida. *Transportation Research Record: Journal of the Transportation Research Board*, 2148, 27-37. https://doi.org/10.3141/2148-04

Institute of Transportation Engineers. (2008). *Designing walkable urban thoroughfares: A context sensitive approach*. Washington, DC: Author.

Jermprapai, K., & Srinivasan, S. (2014). Planning-level model for assessing pedestrian safety. *Transportation Research Record*, 2464, 109-117. https://doi.org/10.3141/2464-14

Jiang, X., Abdel-Aty, M., Hu, J., & Lee, J. (2016). Investigating macro-level hotzone identification and variable importance using big data: A random forest models approach. *Neurocomputing*, 181, 53-63. https://doi.org/10.1016/j.neucom.2015.08.097

Jonsson, T. (2005). Predictive models for accidents on urban links-A focus on vulnerable road users. *Bulletin/Lund Institute of Technology, Department of Technology and Society*, 226.

Khondakar, B., Sayed, T., & Lovegrove, G. R. (2010). Transferability of community-based collision prediction models for use in road safety planning applications. *Journal of Transportation Engineering*, 136(10), 871-880. Retrieved from http://dx.doi.org/10.1061/(ASCE)TE.1943-5436.0000153.

King, D.A., Smart, M.J., & Manville, M. (2019). The poverty of the carless: Toward universal auto access. Journal of Planning Education and Research, 1-18. https://doi.org/10.1177/0739456X18823252.

Koekemoer, K., Van Gesselleen, M., Van Niekerk, A., Govender, R., & Van As A.B. (2017). Child pedestrian safety knowledge, behaviour and road injury in Cape Town, South Africa. *Accident Analysis & Prevention*, 99, 202-209.

Ladron de Guevara, F., Washington, S.P., & Oh, J., (2004). Forecasting crashes at the planning level: Simultaneous negative binomial crash model applied in Tucson, Arizona. *Transportation Research Record*, 1897, 191-199. https://doi.org/10.3141/1897-25.

LaScala, E.A., Gerber, D., Gruenewald, P.J. (2000). Demographic and environmental correlates of pedestrian injury collisions: A spatial analysis. *Accident Analysis & Prevention*, 32(5), 651-658.

Leaf, W.A., & Preusser, D.F. (1999). *Literature Review on Vehicle Travel Speeds and Pedestrian Injuries*. Washington, DC: US Department of Transportation, National Highway Traffic Safety Administration. Retrieved from: http://www.nhtsa.gov/ people/injury/research/pub/hs809012.html.

Lee, J., Abdel-Aty, M., Cai, Q., Wang, L., & Huang, H. (2018). Integrated modeling approach for non-motorized mode trips and fatal crashes in the framework of transportation safety planning. *Transportation Research Record: Journal of the Transportation Research Board*, 12p. Retrieved from: http://dx.doi.org/10.1177/0361198118772704

Lee, J., Abdel-Aty, M., & Jiang, X. (2015). Multivariate crash modeling for motor vehicle and non-motorized modesat the macroscopic level. Accident Analysis and Prevention, 78, 146-154. https://doi.org/10.1016/j.aap.2015.03.003

Loukaitou-Sideris, A., Liggett, R., & Sung, H.G. (2007). Death on the crosswalk: A study of pedestrian-automobile collisions in Los Angeles. *Journal of Planning Education and Research*, 26(3), 338-351.

Lovegrove, G.R., & Sayed, T.A. (2006). Using macrolevel collision prediction models in road safety planning applications. *Transportation Research Record*, 1950, 73-82. Retrieved from: http://dx.doi.org/10.3141/1950-09

Lucy, W.H. (2003). Mortality risk associated with leaving home: Recognizing the relevance of the built environment. *American Journal of Public Health*, 93,1564-1569.

Lyons, R.A., Towner, E., Christie, N., Kendrick, D., Jones, S.J., Hayes, M., Kimberlee, R., Sarvotham, T., Macey, S., Brussoni, M., Sleney, J., Coupland, C., Phillips, C. (2008). The advocacy in action study: A cluster randomized controlled trial to reduce pedestrian injuries in deprived communities. *Injury Prevention*, 14(2).

Merlin, L., Guerra, E. & Dumbaugh, E. (2020). Crash risk, crash exposure, and the built environment: A conceptual review. *Accident Analysis & Prevention*, 134, 1-9.

Mohamed, R., vom Hofe, R., & Mazumder, S. (2014). Jurisdictional spillover effects of sprawl on injuries and fatalities. *Accident Analysis & Prevention*, 72, 9-16. https://doi.org/10.1016/j.aap.2014.05.028

Mokdad, A.H., Marks. J.S., Stroup, D.F, & Gerberding, J.L. (2004). Actual causes of death in the United States, 2000. *Journal of the American Medical Association*, 291(10),1238-1245.

Murakami, E., & Young, J. (1997). *Daily Travel by Persons with Low Income*. Paper presented at the NPTS (National Household Travel Survey) Symposium (October 29-31, 1997).

National Association of City Transportation Officials (2013). *Urban street design guide*. Washington DC: Island.

Nashad, T., Yasmin, S., Eluru, N., Lee, J., & Abdel-Aty, M. A. (2016). Joint modeling of pedestrian and bicycle crashes Copula-based approach. *Transportation Research Record*, 2601, 119-127. https://doi.org/10.3141/2601-14

National Highway Traffic Safety Administration (NHTSA). (2003). Pedestrian roadway fatalities. *Annals of Emergency Medicine*, 42(4), 479-480.

Neff, J.A., Burge, S.K. (1995) Alcohol use, liberal conservative orientation and ethnicity as predictors of sexual behaviors. *Journal of Acquired Immune Deficiency Syndrome*, 8, 302-312.

Noland, R., Kleain, N.J., & Tulach, N.K. (2013). Do lower income areas have more pedestrian casualties? *Accident Analysis & Prevention*, 59, 337-345.

Noland, R., and M. A. Quddus. (2004). Spatially disaggregate analysis of road casualties in England. *Accident Analysis & Prevention*, 36(6), 973-984.

Noland, R., & Oh, L. (2004). The effect of infrastructure and demographic change on traffic-related fatalities and crashes: A case study of Illinois county-level data. *Accident Analysis & Prevention*, 36(4), 525-532.

Ong, P.M., & Houston, D. (2002). Transit, employment and women on welfare. *Urban Geography*, 23 (4), 344-364.

Osama, A., & Sayed, T. (2016). Evaluating the impact of bike network indicators on cyclist safety using macro-level collision prediction models. *Accident Analysis & Prevention*, 97, 28–37. https://doi.org/10.1016/j.aap.2016.08.010

Osama, A., & Sayed, T. (2017). Macro-spatial approach for evaluating the impact of socio-economics, land use, built environment, and road facility on pedestrian safety. *Canadian Journal of Civil Engineering*, 44(12), 1036–1044. https://doi.org/10.1139/cjce-2017-0145

Ouyang, Y., & Bejleri, I. (2014). Geographic Information System-based community-level method to evaluate the influence of built environment on traffic crashes. *Transportation Research Record*, 2432, 124-132. https://doi.org/10.3141/2432-15

Quddus, M. A. (2008). Modelling area-wide count outcomes with spatial correlation and heterogeneity: An analysis of London crash data. *Accident Analysis & Prevention*, 40(4), 1486-1497. https://doi.org/10.1016/j.aap.2008.03.009

Quistberg, D. A., Howard, E. J., Ebel, B. E., Moudon, A. V., Saelens, B. E., Hurvitz, P. M., Rivara, F. P. (2015). Multilevel models for evaluating the risk of pedestrian-motor vehicle collisions at intersections and mid-blocks. *Accident Analysis & Prevention*, 84, 99-111. https://doi.org/10.1016/j.aap.2015.08.013

Paulozzi, L.J. (2006). Is it safe to walk in the Sunbelt? Geographic variation among pedestrian fatalities in the United States, 1999-2003. *Journal of Safety Research*, 37, 453-459.

Petridou, E, Zavitsanos, X., Dessypris, N., Frangakis, C., Mandyla, M., Doxiadis, S., Trichopoulos, D. (1997). Adolescents in high-risk trajectory: Clustering of risky behavior and the origins of socioeconomic health differentials. *Preventive Medicine*, 26(2), 215-219.

Piff, P. K., Stancato, D. M., Mendoza-Denton, R., Keltner, D., & Coteb, S. (2012). Higher social class predicts increased unethical behavior. *Proceedings of the National Academy of Sciences of the United States of America*, 109, 11, 4086-4091.

Romano, E., Voas, R., & Tippetts, S. (2006). Stop sign violations: The role of race and ethnicity on fatal crashes. *Journal of Safety Research*, 37(1), 1-7.

Rifaat, S.M., Tay, R., and de Barros, A. (2010). Effect of street pattern on safety: Are policy recommendations sensitive to aggregations of crashes by severity? *Transportation Research Record: Journal of the Transportation Research Board*, No. 2147, Transportation Research Board of the National Academies, Washington.

Roberts, I., & Powers, C. (1996). Does the decline in child injury mortality vary by social class? A comparison of class specific mortality in 1981 and 1991. *British Medical Journal*, 313, 784-786.

Rosenbloom, T., Nemrodov, D., & Eliyahu, A.B. (2006). Yielding behavior of Israeli drivers: interaction of age and sex. *Perceptual and Motor Skills*, 103(2), 387-390.

Scialfa, C. T., L. T. Guzy, H. W. Leibowitz, P. M. Garvey, and R. A.Tyrrell. (1991). Age differences in estimating vehicle velocity. *Psychology and Aging 6*(1): 60-66.

Senf, J.H., & Price, C.Q. (1994). Young adults, alcohol and condom use: what is the connection? *Journal of Adolescence Health*, 15, 238-244.

Shinar, D., Schechtman, E., & Compton, R. (2001). Self-reports of safe driving behaviors in relationship to sex, age, education and income and US adult driving population. *Accident Analysis & Prevention*, 33(1), 111-116.

Siddiqui, C., & Abdel-Aty, M. (2012). Nature of modeling boundary pedestrian crashes at zones. *Transportation Research Record: Journal of the Transportation Research Board*, 2299, 31-40. https://doi.org/10.3141/2299-04

Siddiqui, C., & Abdel-Aty, M. (2016). Geographical boundary dependency versus roadway hierarchy in macroscopic safety modeling analysis with motor vehicle crash data. *Transportation Research Record*, (2601), 59-71. https://doi.org/10.3141/2601-08

Siddiqui, C., Abdel-Aty, M., & Huang, H. (2012). Aggregate nonparametric safety analysis of traffic zones. *Accident Analysis & Prevention*, 45, 317-325. https://doi.org/10.1016/j.aap.2011.07.019

Smiley, A. (2004). Adaptive strategies of older drivers. In *Transportation in an aging society: A decade of experience*, 36-43. Washington, DC. National Academy of Sciences, Transportation Research Board.

Staplin, L. 1995. Simulator and field measures of driver age differences in left-turn gap judgments. *Transportation Research Record: Journal of the Transportation Research Board 1485*, 49-55. Washington, DC: National Research Council.

Straight, A. (1997). *Community transportation survey*. Washington, DC: AARP.

Syme, L.S., Berkman, L.F. (1976). Social class, susceptibility and sickness. *American Journal of Epidemiology*, 104, 1-7.

Tasic, I., & Porter, R. J. (2016). Modeling spatial relationships between multimodal transportation infrastructure and traffic safety outcomes in urban environments. *Safety Science*, 82, 325-337.

Tay, R. (2008). Marginal effects of increasing ageing drivers on injury crashes. *Accident Analysis & Prevention*, 40(6), 2065-2068.

Trowbridge, M.J., & McDonald, N.C. 2008. Urban sprawl and miles driven daily by teenagers in the United States. *American Journal of Preventive Medicine*, 43, 202-206.

Ukkusuri, S., Hasan, S., & Aziz, H. M. A. (2011). Random parameter model used to explain effects of built-environment characteristics on pedestrian crash frequency. Transportation Research Record, 2237, 98-106. https://doi.org/10.3141/2237-11

Ukkusuri, S., Miranda-Moreno, L. F., Ramadurai, G., & Isa-Tavarez, J. (2012). The role of built environment on pedestrian crash frequency. *Safety Science*, 50(4), 1141-1151. https://doi.org/10.1016/j.ssci.2011.09.012

Valverde, J., & Jovanis, P. (2006). Spatial analysis of fatal and injury crashes in Pennsylvania. *Accident Analysis & Prevention*, 38(3), 618-625.

Wang, X., Jin, Y., Abdel-Aty, M., Tremont, P. J., & Chen, X. (2012). Macrolevel model development for safety assessment of road network structures. *Transportation Research Record: Journal of the Transportation Research Board*, 2280, 100-109. Retrieved from http://dx.doi.org/10.3141/2280-11

Wang, X., Yang, J., Lee, C., Ji, Z., & You, S. (2016). Macro-level safety analysis of pedestrian crashes in Shanghai, China. *Accident Analysis & Prevention*, 96, 12-21. https://doi.org/10.1016/j.aap.2016.07.028

Washington, S., Schalkwyk, I. Van, Mitra, S., Meyer, M., Dumbaugh, E., vsn Schalkwyk, I., Zoll, M. (2006). *Incorporating Safety into Long-Range Transportation Planning* (NCHRP Report No. 546). National Cooperative Highway Research Program. Tuscon, AZ: Transportation Research Board. https://doi.org/10.17226/13891

Wei, F., & Lovegrove, G. R. (2013). An empirical tool to evaluate the safety of cyclists: Community based, macro-level collision prediction models using negative binomial regression. *Accident Analysis & Prevention*, 61, 129-137. https://doi.org/10.1016/j.aap.2012.05.018

Wier, M., Weintraub, J., Humphreys, E.H., Seto, E., & Bhatia, R. (2009). An area-level model of vehicle-pedestrian injury collisions with implications for land use and transportation planning. *Accident Analysis & Prevention*, 41, 137-145.

Xu, P., & Huang, H. (2015). Modeling crash spatial heterogeneity: Random parameter versus geographically weighting. *Accident Analysis & Prevention*, 75, 16-25. https://doi.org/10.1016/j.aap.2014.10.020

Yu, C-Y. (2015). How differences in roadways affect school travel safety. *Journal of the American Planning Association*, 81(3), 203-220. https://doi.org/10.1080/01944363.2015.1080599

Yu, C-Y., & Xu, M. (2017). Local variations in the impacts of built environments on traffic safety. *Journal of Planning Education and Research*, 1–15. https://doi.org/10.1177/0739456X17696035

Yu, C-Y., & Zhu, X. (2016). Planning for safe schools: Impacts of school siting and surrounding environments on traffic safety. *Journal of Planning Education and Research*, 36(4), 476-486. https://doi.org/10.1177/0739456X15616460

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