Refining C3 Context-Classification Criteria for Low-Income and Minority Populations

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16. Abstract

Suburban arterial corridors are often problematic for pedestrians and bicyclists, particularly when traveling through lower-income and minority areas. This study examined the safety performance of more than 200 miles of surface arterials in the state of Florida to understand the conditions where enhanced designed criteria may be warranted. Because signalized intersections were expected to have crash characteristics difference from the corridor as a whole, the corridors were divided into signalized intersections and the segments between them. While longer crossing distances proved problematic at intersections, the primary factor determining pedestrian and bicyclist crash risk proved to be the presence of “high-risk” land uses, defined as grocery stores, gas stations, convenience stores, community shopping centers, and fast-food restaurants. The injury and death of pedestrians and bicyclists rises as a direct function of the number of these “high-risk” uses present along corridor segments and at signalized intersections. Detailed analyses of high-crash locations revealed that the majority of crashes can be attributed to specific developmental configurations. For intersections, nearly all of the high-crash intersections have a nearby grocery store or big box store serving as an anchor for other “high-risk” uses. Hazardous corridors typically took one of two forms. The first were commercial arterials traveling through gridded street networks that employ two-way stop control on the minor street, resulting in unprotected crossing locations. The second were corridors characterized as “transitional highways,” where the broader urbanization of the region resulted in high risk uses located along formerly rural arterials. This study concludes by recommending that suburban commercial arterial thoroughfares, currently classified as C3C under FDOT’s context classification system, be reclassified as “problematic.” Where high-risk uses are present, these streets should be redesigned into more urban configurations that support the street’s embedded access functions. Over the longer term, local land use codes need to be modified to prevent these high risk uses from locating along suburban arterial corridors.

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EXECUTIVE SUMMARY

Pedestrian and bicyclist crashes are disproportionately likely to occur on suburban arterials, particularly when they are located in lower-income and minority communities. To develop guidance on when enhanced design criteria may be warranted along suburban arterial corridors, this study examined pedestrian and bicycle crashes occurring between 2017 and 2020 along 222 miles of arterial thoroughfares in major metropolitan areas throughout the State of Florida. Because signalized intersections, particularly at the confluence of two major arterials, are likely to have unique crash characteristics, these corridors were broken down into signalized intersections and "corridor segments," defined as the sections located between signalized intersections and which may include driveways and unsignalized intersections. In total, this study examined 334 corridor segments and 489 intersection locations, with these locations examined separately. Risk factors were examined through a two-layered approach. The first used descriptive statistics and negative binomial regression models to understand design and developmental factors that influence the incidence of pedestrian and bicycle crashes, injuries, and deaths, while the second entailed detailed analyses of high- and low-crash locations to understand whether specific developmental patterns might be contributing to this risk.

While additional lanes and wider medians, features associated with longer crossing distances, were associated with increased pedestrian and bicyclist crash risk at intersections, the core safety problem was not so much street design as land use. Crash incidence increases as a direct and linear function of the number of "high-risk" land uses at intersections and along corridors, with high-risk uses defined as the number of grocery stores, gas stations, convenience stores, pharmacies, commercial shopping centers, and fast food restaurants. Indeed, nearly all of the observed variation in pedestrian and bicycle crashes can be explained as a direct function of the number of these uses that are present.

Examinations of high- and low-crash locations revealed that nearly all of the high-crash intersection locations took "anchor-outparcel" configurations, with a grocery or big box store anchoring a series of secondary household-supporting uses. High-crash corridor segments, by contrast, took one of two forms. The first were commercial arterials traveling through gridded street networks that employed two-way stop control on minor streets, resulting in a cluster of unprotected crossing locations. The second were corridors characterized as "transitional highways," where the broader urbanization of the region resulted in high-risk uses located along formerly rural highways.

This study concludes by recommending that all corridors meeting FDOT's C3C designation be reclassified as "problematic." Once these high-risk uses locate along an arterial corridor, they result in the creation of urban travel patterns, with these uses serving destination ends for pedestrian and bicycle trips, particularly in areas with concentrations of lower-income populations. Addressing this risk requires either that the street be redesigned into more urban configurations better able to safely support pedestrian and bicycle travel, or that these land uses be eliminated from the corridor. Over the longer term, local land use codes need to be modified to relocate these uses onto lower speed streets, either by incentivizing responsible development

patterns, or by withholding state transportation funding from jurisdictions promoting hazardous development patterns along arterial corridors.

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1. INTRODUCTION: PEDESTRIAN AND BICYCLE SAFETY ALONG C3 SUBURBAN CORRIDORS

Lower-income and minority populations are disproportionately at risk of being injured or killed while walking or bicycling when compared to their more affluent counterparts. Recent research sponsored by the Florida Department of Transportation (Dumbaugh et al., 2021) examined the temporal distribution of crashes involving different population cohorts in lower-income areas, as well as the environmental risk factors that may contribute to this risk. For children, crashes clustered on weekdays before and after school; for working-age adults, these clustered during the late afternoon and early evening, and for older adults, these tended to cluster between and immediately after the morning and evening commute periods. This study further sought to identify the environmental risk factors that may be contributing to crash incidence among these groups. Crashes tended to cluster in environments containing five-or-more lane streets, supermarkets, shopping centers, and restaurants.

The Florida Department of Transportation has developed a context classification system to ensure that streets are designed in harmony with the built and natural environment. The context classification system is scaled from C1-Natural to C6-Urban Core, based on the intensity of development along the corridor (see Figure 1). The identification of a street's Context Classification can then be used to identify the likely users of the corridor, as well as to provide guidance on appropriate street geometry and intersection control applications.

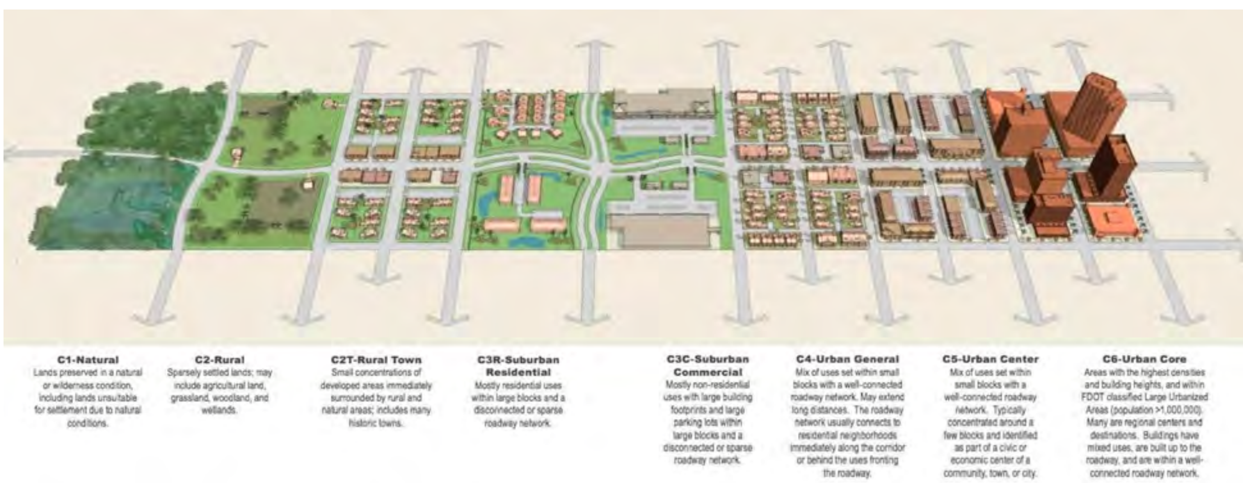


Figure 1: Context Classification System

While this approach works well for environments on either end of the development spectrum, the middle zone, C3 Suburban, has proven problematic, particularly for lower-income and minority populations. Indeed, the most problematic locations for lower-income and minority populations identified in our earlier study all contained C3 Suburban Arterials. This is perhaps unsurprising; C3 corridors are typically designed for higher-speed mobility functions. In affluent environments, where most utilitarian travel is accomplished by automobile, this should pose no particular problem. But the presence of C3 corridors in lower-income environments can result in people attempting to access practical destinations by foot or bicycle in environments that may not allow them to do so safely. Correspondingly, this study seeks to better understand the nature of pedestrian and bicycle crash risk on C3 corridors and provide guidance on when enhanced design criteria may be warranted. This study has three primary objectives:

1. The identification of contextual factors that may place lower-income pedestrians and bicyclists at increased risk along C3 corridors.
2. Estimation of the effects that specific design and developmental features of C3 corridors have on crash incidence, thereby allowing for the prioritization of safety-related countermeasures.
3. The identification of threshold values that may serve as a trigger for reconsidering design treatments along C3 corridors.

To achieve these objectives, this study conducted a comprehensive, multi-disciplinary review of the literature on pedestrian and bicyclist safety among lower-income populations, and proceeded to examine pedestrian and bicyclist crash risk on arterial corridors throughout the state. The study applied a three-tiered approach. The first entails a detailed statistical analysis of arterial corridors throughout the state to identify the design and developmental factors that may be leading to the death and injury of pedestrians and bicyclists. The second entails the identification of threshold values where alternate design treatments may be needed. It then proceeds to conduct detailed evaluations of high and low-crash locations in order to better clarify the specific risk factors. The sections below detail this analysis, while the literature review can be found in Appendix A.

2. EXAMINING ENVIRONMENTAL RISK FACTORS ON C3 CORRIDORS

2.1 Database Development

This study sought to understand factors associated with variations in crash risk on C3 corridors. To identify corridors for inclusion in this study, the research team examined all surface arterials in the four major metropolitan areas throughout the state (Miami-Fort Lauderdale-West Palm Beach, Tampa-St. Petersburg, Orlando, and Jacksonville). Specifically sought were those that included both high- and low-income areas along their length, and which had variations in geometric and roadway design along its length, thus allowing this study to identify trends and patterns emerging from the data. Ultimately, 10 state routes were selected. For Pinellas, Pasco, and Hillsborough counties in the Tampa–St. Petersburg–Clearwater metro area, selected segments are from State Routes 55, 580 and 595. For Orange County in the Orlando–Kissimmee–Sanford metro area, selected segments are from State Routes 50 and 600. Finally, for Broward and Palm Beach counties in the Miami–Fort Lauderdale–West Palm Beach metro area, selected segments are from State Routes 802, 809, 816, 817, and 838. Alternate route and other name designations for these routes are listed in Table 1.

Table 1: State Highways Examined in This Study

County	Route	Other Designations
Pasco/Pinellas	SR 55	US 19, 34th St.
	SR 595	US 19 Alt., Pinellas Ave, Palm Harbor Blvd. Bayshore Blvd., Edgewater Dr., Myrtle Ave., Missouri Ave., Seminole Blvd., Bay Pines Blvd., Tyrone Blvd., 5th Ave.
Hillsborough	SR 580	Dale Mabry Hwy., West Busch Blvd.
Orange	SR 50	Colonial Drive
	SR 600	Orange Blossom Trail, Mills Ave. Orlando Ave., US 17, US 441
Broward	SR 816	Oakland Park Blvd.
	SR 817	University Dr.
	SR 838	Sunrise Blvd.
Palm Beach	SR 809	Military Trail
	SR 802	Lake Worth Rd.

Route Segmentation

We first obtained spatial data defining the line geography for each route from the FDOT Roadway Characteristics Inventory. The following set of rules was determined to govern the division of these selected route geographies into smaller segments for analysis and modelling.

- Major intersections were defined as signalized intersections at the junction of two or more roadways.
- Major intersection segments were clipped to include 250 feet of additional roadway on either side of the intersection.
- Corridor segments were clipped to exclude 250 feet from major intersections.

- Ramps, overpasses, and other special features were designated as "other" type segments, distinct from intersections and corridor segments.
- Segments less than 250 feet in total length were discarded

To carry out this ruleset we first visually examined each route through a specially prepared interface which overlayed the FDOT intersection and signal inventories on OpenStreetMap. The mile markers for major intersections and locations of special features were manually entered into a spreadsheet along each route. Once complete, these spreadsheets were input into a custom Python script which clipped route geographies into smaller segments by interpolating points based on beginning and ending mile markers, and merging geographies where specified in the ruleset above, outputting a spatial database of "corridor segment", "intersection", and "other" type segments. This resulted in a dataset containing information for 334 corridor segments, and 489 intersections. The final mileage and counts of corridor segments and intersections are shown in Table 2.

Table 2: Counts and Length of Segments on Selected Routes

		Intersections		Corridor Segments	
County	**Route**	**Count**	**Length (miles)**	**Count**	**Length (miles)**
Pasco/Pinellas	SR-55	56	5.3	38	30.2
	SR-595	57	5.4	38	26.8
Hillsborough	SR-580	48	4.5	37	20.4
Orange	SR-50	58	3.3	38	19.3
	SR-600	53	5.0	26	10.3
Broward	SR-816	33	3.1	22	8.1
	SR-817	52	4.9	40	16.2
	SR-838	36	3.4	22	8.8
Palm Beach	SR-809	77	7.3	61	32.6
	SR-802	19	1.8	12	5.4
	Total	489	44	334	178.1

Data Aggregation

Further data collection consisted of matching or spatially joining segments with data from four sources: the FDOT Roadway Characteristics Inventory, the US Census American Community Survey, Florida Department of Revenue land use parcels, and Signal 4 Analytics crash events, each of which will be described in more detail below.

The *FDOT Roadway Characteristics Inventory* indicates through line geography different values for variables on different sections of roadway. Variables for which we aggregated data were Average Annual Daily Traffic (AADT), number of lanes, speed limit, and characteristics of medians, shoulders, sidewalks, and bike lanes. Python scripting was written to match roadway IDs and mile markers of our segments to the appropriate values of these variables. In cases where a segment crossed multiple sections with different values for a given variable, a weighted average would be used based on the proportion (p) of the segment within each value (v) area:

$$W = \Sigma(\mathrm{p_n} \times \mathrm{v_n})$$

For example, if 25% of a corridor segment was located along an area of road with 64,000 recorded AADT, and 75% of that same segment was located along an area of road with 42,000 recorded AADT, the weighted average for that segment would 47,500:

$$(.25 \times 64{,}000) + (.75 \times 42{,}000) = 47{,}500$$

This method of weighting was used for numeric variables including AADT, lanes, speed limit, and various widths. For the categorical variable of median type, a set of binary variables was generated indicating if for each observed segment a given type of median exists.

To add social and demographic variables we used data from the *US Census 2018 American Community Survey 5 Year Estimates* at the block group unit of geography. We collected the following variables: population, population density, income, poverty, race, ethnicity, nativity, housing tenure, housing units, mode of commute, number of vehicles. Because we are interested in characteristics of the immediate surrounding area, our scripting first adds a buffer of 250 feet to each segment and then calculates the proportion of the buffered segment area that lay in each surrounding Census Block Group. As above, in cases with multiple surrounding Census blocks we calculated weighted averages.

Our data on surrounding land uses is *2018 parcel data from the Florida Department Revenue*. This dataset represents land uses according to the DOR code classification system which categorizes residential, commercial, industrial, agricultural, and governmental land uses across 99 categories. To measure land uses our scripting first adds a buffer of 250 feet for each segment and then tallies the land uses within that area for the DOR categories including: gas stations, supermarkets, regional shopping centers, community shopping centers, fast food, restaurants, bars, hotels, and schools. In examining this data, we noted a problem in which different counties applied different categories to gas stations. Palm Beach and Broward counties classified them as "Service Stations", Hillsborough County classified them as "Supermarkets", and Orange, Pasco, and Pinellas counties classified them as "Stores, Single Story". To overcome these differences, we generated a combined variable of "Groceries and Gas Stations" which is used in our analyses.

Finally crash data was accessed through *Signal Four Analytics (S4A), a project of the Geoplan Center at the University of Florida*. We downloaded all geolocated crash events data for Pasco, Pinellas, Hillsborough, Orange, Palm and Broward counties from 2017 to 2020. For tallying crashes occurring along segments, a small buffer of 100 feet was added to each corridor segment to ensure our scripting captured crashes on both sides of wide arterial roads, especially as line geographies were sometimes not well aligned to the actual roadway. For intersection segments the buffered area used to capture crashes represents a 250 feet radius around the intersection centroid. For each segment, our script first tallies the total crashes of all types across five different severity levels: Fatal, Incapacitating Injury, Non-Incapacitating Injury, Possible Injury, and No Injury. Secondly for each of the following crash types the script tallies total crashes as well counts for the five severity levels: Angle, Animal, Bicycle, Head On, Left Turn, Off Road, Other, Pedestrian, Rear End, Right Turn, Rollover, Sideswipe, Unknown.

Income Groups

Comparing the effects of segment characteristics on crash outcomes between lower and higher income communities requires a process by which segments are assigned to low income, middle income, or high-income groups. Our first strategy to do this was to compare the weighted average median household income value which was calculated for each segment by the process described in the previous subsection, against the county area median income (AMI). However, we found that because many arterial roads cut in between lower and higher income communities—often acting as divider between them—our weighted averages tended to skew towards middle income values that did not reflect the real presence of lower income individuals. Therefore, we instead stored the lowest and highest median household income values for each segment and compared these against AMI to determine low- or high-income status per the following ruleset:

- Segments passing through a Census block group with a household median income level below 50% of AMI for the county are designated low income.
- Segments passing through a Census block group with a household median income level above 120% of the AMI for the county are designated high income.

The disadvantage of this approach is that a small number of segments were categorized as both low and high income. In group comparisons, we exclude these observations. In total, we identified 96 of the 334 corridor segments as low income, 125 as middle income, and 98 as high income. Among intersections, we identified 142 of the 489 as low income, 197 as middle income, and 133 as high income (Table 3).

Table 3: Counts of Segments by Route and Income Group

		Intersection Segments			Corridor Segments		
County	**Route**	**Low**	**Mid**	**High**	**Low**	**Mid**	**High**
Pasco/Pinellas	SR-55	30	18	7	20	10	6
	SR-595	22	26	6	14	17	4
Hillsborough	SR-580	9	15	21	7	10	17
Orange	SR-50	13	40	2	13	24	1
	SR-600	13	26	11	5	14	4
Broward	SR-816	17	9	7	8	7	7
	SR-817	6	18	27	4	16	19
	SR-838	8	14	14	2	11	9
Palm Beach	SR-809	15	25	34	16	14	28
	SR-802	9	6	4	7	2	3

Crash Data

Finally, geo-located information on pedestrian and bicycle crashes was collected from Signal 4 Analytics and spatially assigned to the corridors. These data were aggregated to the intersection and segment in three ways. The first is the total count of pedestrian and bicycle crashes. Because death and injuries are the safety measures of particularly concern, we further examined the sum of KAB and KSI crashes as well. KAB crashes are defined as crashes involving a fatality (K), incapacitating injury (A), or non-incapacitating injury (B), while KSI—killed or severely injured—crashes are those involving a death or incapacitating injury.

2.2 Descriptive Analysis

Segment and Intersection Crash Incidence

Of the 76,186 crashes considered in this study, shown in Table 4, roughly one-third (24,909) occurred along corridor segments, while two-thirds (51,277) occurred at intersections. Considered as a whole, crashes occurring at intersections tended to be less severe than those occurring along corridor segments, with such crashes being only half as likely to result in an injury, and markedly less likely to result in a fatality. Nevertheless, because of the greater overall number of intersection crashes, more total injuries occur at intersection locations than along corridor segments. Considered on a per mile basis, intersections are the spatial location where an overwhelming share of total, injurious, and fatal crashes occur.

Table 4: Crash Incidence at Corridor Segment and Intersection Locations

All Crashes	**Corridor Segment**	**Intersection**	**Relative Hazard (vs. Corridor)**
Total Crashes	24,909	51,277	n.a.
Total Fatal Crashes	177	113	n.a.
Total KSI Crashes	819	958	n.a.
Total KAB Crashes	2,945	4,623	n.a.
Total Crashes per Mile	140.53	1,108.47	688.77%
Total Fatal Crashes per Mile	1.00	2.44	144.62%
Total KSI Crashes per Mile	4.62	20.71	348.19%
Total KAB Crashes per Mile	16.62	99.94	501.48%

As with total crashes, pedestrian crashes were more likely to occur at intersections than along corridor segments (Table 5). Despite the incidence of more total pedestrian crashes at intersection locations, there are fewer total fatal and killed or seriously injured (KSI) pedestrian crashes at intersections than along corridors segments, a factor likely attributable to differences in impact speeds, as vehicles often decelerate or stop at intersections, particularly for turning maneuvers. Nonetheless, on a per mile basis, fatal and injurious crashes are between 2 and 4 times more likely to occur at intersections than along corridor segments.

As shown in Table 6, crashes occurring along corridor segments appear to be more problematic for bicyclists than for motorists or pedestrians. For bicyclists, corridor segments reported slightly fewer crashes than intersection locations, but a greater number of deaths and serious injuries. We suspect the heightened risk along corridor segments might be attributable to inadequately buffered bicycle facilities, which may result in bicyclists getting struck by passing vehicles, or which may require bicyclist to merge into the travel lane to avoid debris located along the curb.

Table 5: Pedestrian Crash Incidence at Corridor Segments and Intersection Locations

Pedestrian Crashes	Corridor Segment	Intersection	Relative Hazard
Total Ped Crashes	424	609	n.a.
Fatal Ped Crashes	65	36	n.a.
KSI Ped Crashes	147	137	n.a.
KAB Ped Crashes	290	362	n.a.
Ped Crashes per Mile	2.39	13.16	450.34%
Fatal Ped Crashes per Mile	0.37	0.78	112.21%
KSI Ped Crashes per Mile	0.83	2.96	257.10%
KAB Ped Crashes per Mile	1.64	7.83	378.29%

Table 6: Bicycle Crash Incidence at Corridor Segment and Intersection Locations

Bicycle Crashes	Corridor Segment	Intersection	Relative Hazard
Total Bicycle Crashes	387	447	n.a.
Fatal Bicycle Crashes	13	4	n.a.
KSI Bicycle Crashes	66	55	n.a.
KAB Bicycle Crashes	196	219	n.a.
Bicycle Crashes per Mile	2.18	9.66	342.57%
Fatal Bicycle Crashes per Mile	0.07	0.09	17.90%
KSI Bicycle Crashes per Mile	0.37	1.19	219.30%
KAB Bicycle Crashes per Mile	1.11	4.73	328.12%

While pedestrian and bicycle crashes comprise only a small share of the total crashes that occurred, these crashes are disproportionately likely to result in a death or injury. As shown in Table 7, pedestrian and bicycle crashes only account for 3% of crashes occurring along corridor segments, and 2% of intersection crashes, but nonetheless they accounted for 44% of the deaths occurring along corridor segments, and 35% of the deaths occurring at intersection locations. Similarly, pedestrian and bicycle crashes result in more than a quarter of all KSI crashes occurring along corridor segments and 20% of all KSI crashes at intersections. These statistics confirm the relative hazard collisions pose for pedestrians and bicyclists, who lack the protection enjoyed by motor vehicle occupants.

Table 7: Pedestrian and Bicycle Crashes as a Share of Total Crashes

	Corridor Segment	Intersection
Pct. of Total Crashes	3.3%	2.1%
Pct. of Fatal Crashes	44.1%	35.4%
Pct. of KSI Crashes	26.0%	20.0%
Pct. of KAB Crashes	16.5%	12.6%

Socio-Demographic Differences

Income is strongly tied to other socio-demographic elements and, unsurprisingly, large and significant differences exist between the lowest and highest incomes for nearly every socio-economic variable (Tables 8 and 9). Low-income locations are characterized by higher levels of poverty, higher concentrations of black residents, and more rental units compared to both the highest and middle-income locations. Low-income locations are more densely populated than high-income locations, and transit commuting is highest in low-income locations, which also have the highest level of zero vehicle households. Notably, along high-income areas, about one in ten workers are working from home, which is nearly double that of low-income locations.

Table 8: Differences in Socio-Demographic Means for Intersection Locations by Income

	High (n=133)	**Mid (n=197)**	**Low (n=142)**	**p. Low vs High**	**p. Low vs Mid**
Population Per Sq. Mi.	3,731	4,619	5,145	0.00	0.14
Median HH Income ($)	89,395	53,524	38,523	0.00	0.00
Poverty Individual (%)	7.8	14.8	22.0	0.00	0.00
Race White (%)	80.2	67.5	57.8	0.00	0.05
Race Black (%)	10.0	21.2	33.4	0.00	0.01
Race Indigenous (%)	0.3	0.3	0.3	0.24	0.71
Ethnicity Hispanic (%)	19.1	27.9	20.7	0.88	0.00
Foreign Born (%)	21.3	24.3	23.2	0.92	0.22
Rented Units (%)	31.0	44.9	51.7	0.00	0.00
Vacant Units (%)	12.1	12.6	17.3	0.00	0.00
Multifamily Units (%)	31.0	35.7	39.7	0.00	0.27
Drive Commute (%)	85.6	88.6	85.7	0.46	0.00
Transit Commute (%)	1.2	2.4	4.3	0.00	0.00
Bike Commute (%)	0.6	0.7	0.9	0.00	0.17
Walk Commute (%)	1.4	1.2	2.3	0.00	0.00
WFH (%)	10.1	5.5	4.8	0.00	0.00
No Vehicle HHs (%)	1.8	3.6	5.9	0.00	0.00

p-values according to Wilcoxon Rank Sum Tests

Differences in Crash Incidence by Income Group

As shown in Tables 10 through 13, intersections and corridor segments in low-income areas have a consistently higher incidence of crashes than high- or middle-income locations. However, the magnitude of these differences is far larger between low- and high-income locations than between low- and middle-income locations. Among all types of crashes, which includes multiple vehicle and single vehicle crashes (Table 10), intersections in low-income locations have report 50% more KSI crashes per mile compared to high-income locations. Disparities were even larger for KSI crashes along corridor segments, where low-income segments had an 85.7% more KSI crashes per mile than high-income segments (Table 9). For all injurious or fatal (KAB) crashes, intersections and corridor segments show nearly the same disparity between low- and high-income locations (44.2% higher for intersections and 42% higher for corridor segments), and again show less disparity between low- and middle-income locations (14% higher for intersections and 4% higher for corridor segments).

Table 9: Differences in Socio-Demographic Means for Corridor Segments by Income

	High (n=98)	**Mid (n=125)**	**Low (n=96)**	**p. Low vs High**	**p. Low vs Mid**
Population Per Sq. Mi.	3,707	4,589	4,635	0.01	1.00
Median HH Income ($)	91,183	53,915	41,555	0.00	0.00
Poverty Individual (%)	7.6	14.5	20.0	0.00	0.00
Race White (%)	79.5	66.2	65.3	0.00	0.61
Race Black (%)	10.8	21.4	25.4	0.00	0.68
Race Indigenous (%)	0.3	0.3	0.4	0.19	0.97
Ethnicity Hispanic (%)	19.6	29.0	25.6	0.16	0.12
Foreign Born (%)	21.5	25.2	23.7	0.76	0.28
Rented Units (%)	28.3	43.8	48.9	0.00	0.06
Vacant Units (%)	11.6	12.5	15.6	0.00	0.01
Multifamily Units (%)	28.4	36.4	34.4	0.04	0.40
Drive Commute (%)	86.0	89.3	86.9	0.20	0.00
Transit Commute (%)	1.0	2.2	3.1	0.00	0.01
Bike Commute (%)	0.5	0.6	0.9	0.00	0.13
Walk Commute (%)	1.4	1.3	2.0	0.00	0.00
WFH (%)	9.8	5.1	5.4	0.00	0.80
No Vehicle HHs (%)	1.6	3.2	5.0	0.00	0.00

p-values according to Wilcoxon Rank Sum Tests

Table 10: All Crash Incidence in Intersection Locations by Income

	High (n=133)	**Mid (n=197)**	**Low (n=142)**	**Rel. Hazard Low vs. High**	**Rel. Hazard Low vs. Mid**
Total Crashes	12,185	21,153	16,285	n.a.	n.a.
Fatal Crashes	23	43	46	n.a.	n.a.
KSI Crashes	198	414	317	n.a.	n.a.
KAB Crashes	1,014	1,908	1,561	n.a.	n.a.
Total Crashes per Mile	968.5	1,135.0	1,212.3	25.2%	6.8%
Fatal Crashes per Mile	1.8	2.3	3.4	87.3%	48.4%
KSI Crashes per Mile	15.7	22.2	23.6	50.0%	6.2%
KAB Crashes per Mile	80.6	102.4	116.2	44.2%	13.5%

Table 11: All Crash Incidence along Corridor Segments by Income

	High (n=98)	**Mid (n=125)**	**Low (n=96)**	**Rel. Hazard Low vs. High**	**Rel. Hazard Low vs. Mid**
Total Crashes	6,029	9,836	8,075	n.a.	n.a.
Fatal Crashes	21	74	79	n.a.	n.a.
KSI Crashes	153	341	294	n.a.	n.a.
KAB Crashes	651	1196	959	n.a.	n.a.
Total Crashes per Mile	121.2	146.9	156.8	29.4%	6.7%
Fatal Crashes per Mile	0.4	1.1	1.5	263.6%	38.8%
KSI Crashes per Mile	3.1	5.1	5.7	85.7%	12.1%
KAB Crashes per Mile	13.1	17.9	18.6	42.4%	4.2%

These baseline differences in crash risk become increasingly pronounced when considering pedestrian and bicyclist crashes. At intersections, low-income locations had 134% more pedestrian crashes per mile than high-income locations. For KSI pedestrian crashes this difference increases to 203% (Table 12). Low-income corridor segments had 151% more pedestrian crashes per mile than high-income ones and 214% more KSI pedestrian crashes (Table 13). Lower-income locations also report more bicycle crashes per mile than high-income ones, experiencing 43% more crashes at intersections and 82% more crashes along corridor segments (Table 14 and 15).

Table 12: Pedestrian Crash Incidence in Intersection Locations by Income

	High (n=133)	**Mid (n=197)**	**Low (n=142)**	**Rel. Hazard Low vs. High**	**Rel. Hazard Low vs. Mid**
Total Ped. Crashes	91	270	227	n.a.	n.a.
Fatal Ped. Crashes	8	13	14	n.a.	n.a.
KSI Ped. Crashes	17	59	55	n.a.	n.a.
KAB Ped. Crashes	48	162	139	n.a.	n.a.
Total Ped. Crashes per Mile	7.2	14.5	16.9	133.6%	16.6%
Fatal Ped. Crashes per Mile	0.6	0.7	1.0	63.9%	49.4%
KSI Ped. Crashes per Mile	1.4	3.2	4.1	203.0%	29.3%
KAB Ped. Crashes per Mile	3.8	8.7	10.3	171.2%	19.0%

Table 13: Pedestrian Crash Incidence along Corridor Segments by Income

	High (n=98)	**Mid (n=125)**	**Low (n=96)**	**Rel. Hazard Low vs. High**	**Rel. Hazard Low vs. Mid**
Total Ped. Crashes	65	170	169	n.a.	n.a.
Fatal Ped. Crashes	9	26	30	n.a.	n.a.
KSI Ped. Crashes	20	59	65	n.a.	n.a.
KAB Ped. Crashes	49	117	114	n.a.	n.a.
Total Ped. Crashes per Mile	1.3	2.5	3.3	151.3%	29.2%
Fatal Ped. Crashes per Mile	0.2	0.4	0.6	222.1%	50.0%
KSI Ped. Crashes per Mile	0.4	0.9	1.3	214.1%	43.2%
KAB Ped. Crashes per Mile	1.0	1.7	2.2	124.8%	26.7%

Table 14: Bicycle Crash Incidence in Intersection Locations by Income

	High (n=133)	**Mid (n=197)**	**Low (n=142)**	**Rel. Hazard Low vs. High**	**Rel. Hazard Low vs. Mid**
Total Bicycle Crashes	84	220	128	n.a.	n.a.
Fatal Bicycle Crashes	0	2	2	n.a.	n.a.
KSI Bicycle Crashes	9	26	18	n.a.	n.a.
KAB Bicycle Crashes	41	105	67	n.a.	n.a.
Total Bicycle Crashes per Mile	6.7	11.8	9.5	42.7%	-19.3%
Fatal Bicycle Crashes per Mile	0.0	0.1	0.1	n.a.	38.7%
KSI Bicycle Crashes per Mile	0.7	1.4	1.3	87.3%	-4.0%
KAB Bicycle Crashes per Mile	3.3	5.6	5.0	53.1%	-11.5%

Table 15: Bicycle Crash Incidence along Corridor Segments by Income

	High (n=98)	Mid (n=125)	Low (n=96)	Rel. Hazard Low vs. High	Rel. Hazard Low vs. Mid
Total Bicycle Crashes	71	177	134	n.a.	n.a.
Fatal Bicycle Crashes	0	5	8	n.a.	n.a.
KSI Bicycle Crashes	7	29	29	n.a.	n.a.
KAB Bicycle Crashes	34	87	71	n.a.	n.a.
Total Bicycle Crashes per Mile	1.4	2.6	2.6	82%	-2%
Fatal Bicycle Crashes per Mile	0.0	0.1	0.2	n.a.	108%
KSI Bicycle Crashes per Mile	0.1	0.4	0.6	300%	30%
KAB Bicycle Crashes per Mile	0.7	1.3	1.4	102%	6%

Street Design Conditions by Income Group

It is tempting to attribute the increased incidence of pedestrian and bicycle crashes on arterials in lower-income areas to differences in street design. Yet, as shown in Tables 16 and 17, the average differences in street geometry between low-income and high-income areas is negligible. Lower-income areas have slightly higher average traffic volumes and more intersections and driveways, while affluent areas are more likely to have planted medians and wider sidewalks.

Table 16: Differences in Road Network Means for Intersection Locations by Income

	High (n=133)	Mid (n=197)	Low (n=142)	p Low vs High	p Low vs Mid
AADT	38,498	42,229	43,680	0.00	0.27
Intersections/Driveways	1.9	1.8	2.3	0.00	0.00
Lanes	5.5	5.7	5.6	0.27	0.80
Speed Limit (Mph)	43.6	43.6	42.1	0.15	0.00
Median Width (Ft)	23.8	22.7	21.6	0.09	0.12
Has Raised Paved Median	0.5	0.7	0.6	0.15	0.51
Has Raised Vegetative Median	0.5	0.4	0.4	0.22	0.66
Sidewalk Combined Width (Ft)	11.6	11.0	10.7	0.02	0.60
Sidewalk Combined Buffer (Ft)	14.1	12.3	14.0	0.19	0.32
Sidewalk Coverage (%)	96.0	92.4	92.8	0.66	0.64
Bike lane Coverage (%)	36.1	42.2	42.9	0.19	0.88
Shoulder Combined Outer Width (Ft)	11.6	10.2	11.7	0.10	0.74
Shoulder Combined Inner Width (Ft)	1.6	1.5	1.7	0.64	0.33

p-values according to Wilcoxon Rank Sum Tests

Table 17: Differences in Road Network Means for Corridor Segments by Income

	High (n=98)	**Mid (n=125)**	**Low (n=96)**	**p. Low vs High**	**p. Low vs Mid**
AADT	38,021	43,288	43,884	0.00	0.94
Intersections/Driveways	6.7	6.5	9.3	0.01	0.00
Lanes	5.6	5.7	5.7	0.55	0.73
Speed Limit (Mph)	44.6	44.9	43.3	0.22	0.01
Median Width (Ft)	23.5	22.6	21.7	0.11	0.14
Has Raised Paved Median	0.6	0.7	0.7	0.02	0.75
Has Raised Vegetative Median	0.7	0.8	0.7	0.47	0.11
Sidewalk Combined Width (Ft)	11.8	10.8	10.6	0.03	0.26
Sidewalk Combined Buffer (Ft)	16.7	13.7	17.3	0.48	1.00
Sidewalk Coverage (%)	93.9	91.5	91.5	1.00	0.72
Bike lane Coverage (%)	38.5	48.0	49.4	0.12	1.00
Shoulder Combined Outer Width (Ft)	12.0	11.3	13.8	0.82	0.47
Shoulder Combined Inner Width (Ft)	2.4	2.2	2.3	0.92	0.35

p-values according to Wilcoxon Rank Sum Tests

Land Use Differences by Income Group

While differences in street design were minor between low- and high-income locations, there are notable differences in land use (Tables 18 and 19). Low-income intersection locations have significantly more fast-food outlets, groceries and gas stations, with an average of 2.6 per intersection, compared to 1.48 in high-income locations, and 8 per corridor segment, compared to 3.1 in high-income locations. Additionally, low-income locations have the highest average number of auto sales and related land uses for both intersection locations (0.91 in low income compared to 0.17 in high income) and corridor segments (3.1 in low-income compared to 0.5 in high-income).

Table 18: Differences in Land Use Means for Intersection Locations by Income

	High (n=133)	**Mid (n=197)**	**Low (n=142)**	**p. Low vs High**	**p. Low vs Mid**
Groceries and Gas Stations	1.48	2.44	2.63	0.00	0.09
Community Shopping Centers	0.60	0.21	0.45	0.23	0.00
Regional Shopping Centers	0.03	0.01	0.01	0.37	0.74
Fast Food Restaurants	0.16	0.31	0.42	0.00	0.08
Restaurants	0.20	0.28	0.30	0.07	0.49
Hotels or Bars	0.05	0.16	0.08	0.16	0.17
Offices	3.05	1.39	1.14	0.20	0.32
Department Stores	0.07	0.05	0.05	0.68	0.71
Banks or Insurance	0.31	0.22	0.31	0.94	0.13
Auto Sales or Related	0.17	0.47	0.91	0.00	0.00
Repair Stores	0.00	0.02	0.04	0.03	0.40
Parks or Recreation	0.07	0.08	0.16	0.18	0.04
Schools	0.09	0.11	0.13	0.30	0.62
Hospitals	0.00	0.01	0.01	0.17	0.74
Industrial	0.08	0.29	0.44	0.00	0.13
Bus Stops	1.23	1.30	1.39	0.24	0.65

p-values according to Wilcoxon Rank Sum Tests

Table 19: Differences in Land Use Means along Corridor Segments by Income

	High (n=98)	Mid (n=125)	Low (n=96)	p. Low vs High	p. Low vs Mid
Groceries and Gas Stations	3.1	5.9	8.0	0.00	0.00
Community Shopping Centers	0.9	0.5	0.8	0.41	0.14
Regional Shopping Centers	0.0	0.0	0.0	0.33	0.22
Fast Food Restaurants	0.5	1.0	1.0	0.00	0.51
Restaurants	0.8	1.0	1.1	0.01	0.45
Hotels or Bars	2.8	3.3	0.7	0.00	0.10
Offices	9.5	5.2	5.4	0.75	0.15
Department Stores	0.1	0.1	0.2	0.12	0.22
Banks or Insurance	0.5	0.4	0.6	0.68	0.18
Auto Sales or Related	0.5	2.1	3.9	0.00	0.00
Repair Stores	0.0	0.1	0.5	0.00	0.00
Parks or Recreation	0.1	0.2	0.6	0.01	0.04
Schools	0.3	0.3	0.4	0.66	0.62
Hospitals	0.0	0.0	0.0	0.55	0.43
Industrial	0.5	1.8	2.1	0.00	0.25
Bus Stops	3.7	4.0	4.6	0.01	0.05

p-values according to Wilcoxon Rank Sum Tests

Comparing High and Low Crash Locations

We further sought to understand whether areas with higher concentrations of pedestrian deaths and injuries had different characteristics from areas where deaths and injuries did not occur, regardless of income. For the purposes of this analysis, a "hazardous" location is defined as one having two or more pedestrian and bicycle KSI crashes during the study period, while a "safer" location is defined as one that did not report a single KAB collision of either type.

Among road network variables, hazardous intersections tended to have more traffic, more driveways, lower speed limits, narrower sidewalks and shoulders, and they were less likely to include a raised vegetative median (Table 20), characteristics more likely to be found in lower-income areas than in more affluent ones. Along corridor segments, traffic was significantly higher at hazardous locations, which also reported more driveways and intersections, narrower shoulders, and greater sidewalk coverage (Table 21). Considered as whole, the more hazardous locations are not simply those that are lower-income, but instead those that have more constrained, "urban" street characteristics. As will be detailed below, this, in conjunction with the findings on land use detailed above, will go a long way towards explaining pedestrian and bicycle crash incidence on state arterials.

Table 20: Differences in Road Network Means for Intersection Locations by Crash Level

	2+ KSI (n=45)	**0 KAB (n=233)**	**p**
AADT	45,220	40,785	0.02
Intersections/Driveways	2.4	1.9	0.05
Lanes	5.8	5.5	0.25
Speed Limit (Mph)	41.7	43.7	0.03
Median Width (Ft)	22.3	22.4	0.69
Has Raised Paved Median	0.7	0.6	0.20
Has Raised Vegetative Median	0.3	0.5	0.01
Sidewalk Combined Width (Ft)	10.8	11.2	0.02
Sidewalk Combined Buffer (Ft)	9.8	14.2	0.93
Sidewalk Coverage (%)	97.9	92.4	0.07
Bike lane Coverage (%)	39.9	40.1	0.99
Shoulder Combined Outer Width (Ft)	8.8	11.9	0.01
Shoulder Combined Inner Width (Ft)	1.3	1.6	0.18

High crash designated as 2+ ped/bike KSI; p-values according to Wilcoxon Rank Sum Tests

Table 21: Differences in Road Network Means for Corridor Segments by Crash Level

	2+ KSI (n=87)	**0 KAB (n=150)**	**p**
AADT	42,611	41,733	0.17
Intersections/Driveways	8.5	6.0	0.00
Lanes	5.8	5.6	0.84
Speed Limit (Mph)	42.9	44.9	0.00
Median Width (Ft)	22.3	22.8	0.29
Has Raised Paved Median	0.7	0.7	0.31
Has Raised Vegetative Median	0.7	0.8	0.01
Sidewalk Combined Width (Ft)	11.1	11.0	0.38
Sidewalk Combined Buffer (Ft)	11.8	17.2	0.18
Sidewalk Coverage (%)	96.8	89.9	0.01
Bike lane Coverage (%)	41.2	40.5	0.69
Shoulder Combined Outer Width (Ft)	9.7	13.4	0.00
Shoulder Combined Inner Width (Ft)	1.8	2.4	0.00

High crash designated as 2+ ped/bike KSI per mile; p-values according to Wilcoxon Rank Sum Tests

Likewise, the land uses at high crash locations are more akin to those found in lower-income areas, rather than affluent ones. High-crash locations had more groceries and gas stations, as well as more community shopping centers, fast food, and auto sales or related land uses (Table 22). As with intersections, high crash segments were significantly more likely to have groceries and gas stations, community shopping centers, fast-food restaurants, and auto sales. They also reported significantly more restaurants, hotels or bars, and department stores (Table 23). As will be discussed later in this report, the increases in crash incidence experienced by lower-income populations is almost certainly not a feature of income alone, but instead a function of C3 corridors in lower-income areas having characteristics that are more urban than suburban.

Table 22: Differences in Land Use Means for Intersection Locations by Crash Level

	2+ KSI (n=45)	**0 KAB (n=233)**	**p**
Groceries and Gas Stations	3.2	1.7	0.00
Community Shopping Centers	0.4	0.2	0.04
Regional Shopping Centers	0.0	0.0	0.82
Fast Food Restaurants	0.7	0.2	0.00
Restaurants	0.2	0.2	0.93
Hotels or Bars	0.1	0.1	0.52
Office Buildings	0.5	1.9	0.07
Department Stores	0.1	0.0	0.19
Banks or Insurance	0.3	0.3	0.52
Auto Sales or Related	0.7	0.4	0.02
Repair Stores	0.0	0.0	0.82
Parks or Recreation	0.1	0.1	0.55
Schools	0.0	0.1	0.05
Industrial	0.4	0.3	0.65
Bus Stops	1.5	1.2	0.12

High crash designated as 2+ ped/bike KSI; p-values according to Wilcoxon Rank Sum Tests

Table 23: Differences in Land Use Means for Corridor Segments by Crash Level

	2+ KSI (n=87)	**0 KAB (n=150)**	**p**
Groceries and Gas Stations	7.7	3.9	0.00
Community Shopping Centers	0.9	0.5	0.03
Regional Shopping Centers	0.0	0.0	n.a.
Fast Food Restaurants	1.1	0.5	0.00
Restaurants	1.1	0.8	0.03
Hotels or Bars	3.6	2.1	0.01
Office Buildings	4.6	6.8	0.52
Department Stores	0.2	0.1	0.00
Banks or Insurance	0.5	0.5	0.85
Auto Sales or Related	3.4	1.2	0.00
Repair Stores	0.1	0.1	0.20
Parks or Recreation	0.1	0.2	0.90
Schools	0.4	0.3	0.54
Industrial	1.9	1.1	0.06
Bus Stops	4.8	3.3	0.00

High crash designated as 2+ ped/bike KSI per mile; p-values according to Wilcoxon Rank Sum Tests

2.3 Pedestrian and Bicycle Crash Models

To determine the effects of location characteristics on crash frequency while controlling for other factors, we constructed six negative binomial regression models. The negative binomial distribution is appropriate for modeling count data as an alternative to Poisson regression in the case of overdispersion, although both approaches gave us similar results. We use three different crash frequency variables to account for differences in incidence and severity: total pedestrian and bicycle crashes, KAB pedestrian and bicycle crashes, and KSI pedestrian and bicycle crashes. The independent variables for all six models are the same, consisting of average annual daily traffic (AADT), number of lanes, median width, speed limit, the presence of raised planted median, population density, median household income, percent black population, and numbers of fast food restaurants, community shopping centers, groceries/gas stations, and bus stops. While our descriptive analyses showed the importance of intersections and driveways, this was excluded from model specifications due to its strong correlation with land use variables, especially fast food and grocery/gas stations which are included in our specification. For the corridor segment models, segment length is included as control variable to account for the influence of differing lengths may have on crash frequency. In our discussion of results, we exponentiate coefficients (e^{β}) to create odds ratios (OR) which allows us to discuss the effects of independent variables on frequency outcomes in percentage terms.

Intersection Models

Tables 24 and 25 show the descriptive statistics for the variables used in our intersection models. Table 24 shows the crash statistics for 489 intersections in our dataset and Table 25 presents the descriptive statistics for our independent variables. There were an average of 2.16 pedestrian or bicycle crashes per intersection during the four-year study period, while the number of KAB and KSI crashes averaged 1.19 and 0.39, respectively. Pedestrian crashes at intersections were more common than bicycle crashes for all severity levels.

Table 24: Intersection Crashes: Descriptive Statistics

	Min.	**Max.**	**Mean**	**Std. Dev.**
Pedestrian and Bicycle Crashes	0.00	20.00	2.16	2.66
KAB Pedestrian and Bicycle Crashes	0.00	9.00	1.19	1.57
KSI Pedestrian and Bicycle Crashes	0.00	4.00	0.39	0.73
Pedestrian and Bicycle Crashes Per Mile	0.00	211.42	22.83	28.13
KAB Pedestrian and Bicycle Crashes Per Mile	0.00	95.14	12.56	16.61
KSI Pedestrian and Bicycle Crashes Per Mile	0.00	42.28	4.15	7.75
Pedestrian Crashes	0.00	15.00	1.25	1.84
KAB Pedestrian Crashes	0.00	7.00	0.74	1.16
KSI Pedestrian Crashes	0.00	4.00	0.28	0.63
Pedestrian Crashes per Mile	0.00	158.56	13.16	19.43
KAB Pedestrian Crashes per Mile	0.00	74.00	7.83	12.31
KSI Pedestrian Crashes per Mile	0.00	42.28	2.96	6.71
Bicycle Crashes	0.00	7.00	0.91	1.32
KAB Bicycle Crashes	0.00	5.00	0.45	0.80
KSI Bicycle Crashes	0.00	3.00	0.11	0.36
Bicycle Crashes Per Mile	0.00	74.00	9.66	13.95
KAB Bicycle Crashes Per Mile	0.00	52.85	4.73	8.46
KSI Bicycle Crashes Per Mile	0.00	31.71	1.19	3.85

Model Results for Total Pedestrian and Bicycle Crashes at Intersections

Table 26 shows the results for total pedestrian and bicycle crashes at intersection locations. The strongest positive effect in the model comes from the fast-food land use variable. Each fast-food outlet is associated with a 30% increase in intersection pedestrian and cyclist crashes (OR=1.3). The number of groceries and gas stations are also associated with an increase in crashes. Collectively, this indicates that auto-oriented land uses at intersections are contributing factors to intersection pedestrian and cyclist crash rates. Population density and income are also strongly correlated with crash incidence, with each additional thousand persons per square mile in surrounding areas is associated with a 7% increase in intersection pedestrian and bicycle crashes

(OR=1.07), and each additional thousand dollars of average median household income is associate with a 1% decrease (OR=0.99).

Table 25: Descriptives for Intersection-level Independent Variables

	Min.	Max.	Mean	Std. Dev.
AADT (000)	5.60	85.60	41.42	13.30722
Lanes	1.86	8.00	5.58	1.042393
Median Width (Ft)	0.00	60.00	22.51	8.055365
Speed Limit (Mph)	25.00	55.00	43.09	5.114828
Raised, Planted Median	0.00	1.00	0.44	0.497
Population Per Sq. Mi. (000)	0.32	16.40	4.50	2.3407
Median HH Income ($000)	18.82	173.73	59.20	24.2353
Race White (%)	0.42	98.57	68.33	23.38246
Race Black (%)	0.00	97.95	21.65	23.03433
Race Hispanic (%)	0.00	73.91	23.06	16.5791
Fast Food Restaurants	0	3	0.31	0.647
Community Shopping Centers	0	33	0.4	1.615
Groceries and Gas Stations	0	16	2.227	2.07927
Bus Stops	0	7	1.3088	1.07921

Table 26: Model Results for Total Pedestrian and Bicycle Crashes at Intersections

	Coef.	Std. Err.	z	p	Odds Ratio
AADT (000)	0.003	0.005	0.66	0.511	1.003
Lanes	0.077	0.069	1.12	0.264	1.080
Median Width (Ft)	0.034	0.009	3.96	0.000	1.035
Speed Limit (Mph)	-0.043	0.014	-3.04	0.002	0.958
Raised, Planted Median	-0.425	0.111	-3.82	0.000	0.654
Population Per Sq. Mi. (000)	0.064	0.024	2.69	0.007	1.066
Median HH income ($000)	-0.007	0.003	-2.56	0.010	0.993
Race Black (%)	0.004	0.002	1.84	0.066	1.004
Fast Food Restaurants	0.261	0.075	3.51	0.000	1.298
Community Shopping Centers	0.064	0.037	1.75	0.081	1.066
Groceries and Gas Stations	0.099	0.026	3.84	0.000	1.104
Bus Stops	0.079	0.047	1.67	0.095	1.082
Constant	0.894	0.577	1.55	0.122	2.445

Among road network variables, the number of lanes and AADT were not statistically significant for total pedestrian and bicycle crashes. Median width proved to be positively associated with pedestrian and bicycle crashes at intersections, though this is almost attributable to the fact that wider medians are associated with more turn lanes, and thus longer crossing distances and greater opportunities for conflicts between pedestrians and motor vehicles. While median widths are associated with more crashes, the presence of a raised, planted median is associated with 35% fewer pedestrian and cyclist crashes (OR=0.65). An analysis of satellite imagery, discussed in Section 3 of this report, showed that raised, planted medians are typically an indicator of affluent suburban environments, which typically have little roadside development. Thus, the reduction in crash incidence is likely not solely attribute to these features serving as a refuge island, but is instead indicative of areas with lower pedestrian and bicycle traffic volumes and thus lower overall exposure. We were initially surprised to find that higher speed limits were associated with fewer pedestrian and bicycle crashes, though this too is a result of differences in developmental context; locations with higher posted speed limits tend to be located in less intensely developed areas that have few driveways and little roadside development.

Model Results for KAB Pedestrian and Bicycle Crashes at Signalized Intersections

Results for the model on KAB pedestrian and bicycle crashes at intersections are very similar to the results for total crashes, with only minor differences in the magnitude of effects (Table 27). The size of the effect of fast food on KAB crashes was smaller, while the effect from household income on KAB outcomes was slightly larger.

Table 27: Model Results for KAB Pedestrian and Bicycle Crashes at Intersections

	Coef.	**Std. Err.**	**z**	**p**	**Odds Ratio**
AADT (000)	0.003	0.006	0.53	0.593	1.003
Number of Lanes	0.081	0.079	1.02	0.306	1.084
Median Width (feet)	0.037	0.010	3.71	0.000	1.038
Speed Limit (MPH)	-0.053	0.017	-3.15	0.002	0.948
Raised, Planted Median	-0.352	0.127	-2.77	0.006	0.703
Population Per Sq. Mi. (000)	0.063	0.027	2.35	0.019	1.065
Median HH income ($000)	-0.009	0.003	-2.73	0.006	0.991
Race Black (%)	0.004	0.003	1.46	0.145	1.004
Fast Food Restaurants	0.197	0.083	2.37	0.018	1.218
Community Shopping Centers	0.064	0.035	1.84	0.065	1.066
Groceries and Gas Stations	0.097	0.028	3.50	0.000	1.102
Bus Stops	0.080	0.055	1.45	0.147	1.083
Constant	0.755	0.656	1.15	0.250	2.128

Model Results for KSI Pedestrian and Bicycle Crashes at Intersections

Our final model examined KSI pedestrian and bicycle crashes at intersection (Table 28). Compared to the previous two models, there are a few notable differences. Population density no longer has a meaningful effect on KSI crashes, while the number of a lanes now has a positive and significant effect on crash frequency, with each additional lane increasing KSI pedestrian and bicycle crashes by 42% (OR = 1.42). Finally, the effect of fast-food restaurants is largest in the KSI model, with each additional intersection fast food outlet increasing KSI pedestrian and bicycle crashes by 36% (OR = 1.36). Other effects, including income and groceries and gas stations are present and comparable to those in the previous models.

Table 28: Model Results for KSI Pedestrian and Bicycle Crashes at Intersections

	Coef.	Std. Err.	z	p	Odds Ratio
AADT (000)	0.001	0.009	0.09	0.932	1.001
Lanes	0.349	0.132	2.65	0.008	1.418
Median Width (Ft)	0.039	0.015	2.65	0.008	1.040
Speed Limit (Mph)	-0.068	0.025	-2.70	0.007	0.934
Raised, Planted Median	-0.388	0.181	-2.14	0.032	0.678
Population Per Sq. Mi. (000)	0.000	0.000	0.47	0.639	1.000
Median HH income ($000)	-0.012	0.005	-2.31	0.021	0.988
Race Black (%)	0.006	0.004	1.58	0.113	1.006
Fast Food Restaurants	0.309	0.106	2.91	0.004	1.362
Community Shopping Centers	0.050	0.034	1.47	0.143	1.051
Groceries and Gas Stations	0.099	0.038	2.58	0.010	1.104
Bus Stops	0.085	0.080	1.05	0.292	1.089
Constant	-0.904	1.002	-0.90	0.367	0.405

Corridor Segment Models

Descriptive statistics for crashes along the 334 corridor segments examined in this study are shown in Table 29, while descriptive statistics for our independent variables are shown in Table 30. There was an average of 2.43 total pedestrian or bicycle crashes for each corridor segment over the four-year study period, 1.46 KAB crashes, and 0.39 KSI crashes. As with intersections, pedestrian crashes were more common than bicycle crashes at all severity levels.

Table 29: Crashes along Corridor Segments: Descriptive Statistics

	Min.	Max.	Mean	Std. Dev.
Pedestrian and Bicycle Crashes	0.00	22.00	2.43	3.32
KAB Pedestrian and Bicycle Crashes	0.00	15.00	1.46	2.17
KSI Pedestrian and Bicycle Crashes	0.00	9.00	0.64	1.11
Pedestrian and Bicycle Crashes Per Mile	0.00	46.53	5.12	6.94
KAB Pedestrian and Bicycle Crashes Per Mile	0.00	29.15	3.06	4.56
KSI Pedestrian and Bicycle Crashes Per Mile	0.00	13.08	1.33	2.39
Pedestrian Crashes	0.00	17.00	1.27	2.08
KAB Pedestrian Crashes	0.00	13.00	0.87	1.52
KSI Pedestrian Crashes	0.00	7.00	0.44	0.91
Pedestrian Crashes per Mile	0.00	32.80	2.69	4.55
KAB Pedestrian Crashes per Mile	0.00	29.15	1.85	3.39
KSI Pedestrian Crashes per Mile	0.00	10.74	0.92	1.96
Bicycle Crashes	0.00	13.00	1.16	1.72
KAB Bicycle Crashes	0.00	12.00	0.59	1.08
KSI Bicycle Crashes	0.00	3.00	0.20	0.48
Bicycle Crashes Per Mile	0.00	19.81	2.43	3.46
KAB Bicycle Crashes Per Mile	0.00	15.85	1.21	2.09
KSI Bicycle Crashes Per Mile	0.00	7.92	0.41	1.10

Table 30: Descriptives for Independent Variables along Corridor Segments

Variable	**Min.**	**Max.**	**Mean**	**Std. Dev.**
Segment Length (miles)	0.20	2.60	0.53	0.32
AADT (000)	7.06	85.50	41.79	13.86
Number of Lanes	2.00	8.00	5.63	1.06
Median Width (ft)	0.00	60.00	22.47	7.88
Speed Limit (MPH)	28.48	55.00	44.28	5.08
Raised, Planted Median	0.00	1.00	0.75	0.43
Population Per Sq. Mi. (000)	0.33	13.93	4.36	2.36
Median HH Income ($000)	18.04	169.50	61.48	25.79
Race White (%)	3.13	99.05	69.88	22.15
Race Black (%)	0.00	92.82	19.56	21.17
Race Hispanic (%)	0.96	76.64	24.70	17.14
Fast Food Restaurants	0.00	8.00	0.84	1.35
Community Shopping Centers	0.00	17.00	0.76	1.67
Groceries and Gas Stations	0.00	43.00	5.62	5.68
Bus Stops	0.00	21.00	4.16	3.31

Model Results for Total Pedestrian and Bicycle Crashes at Intersections

Table 31 shows the results total pedestrian and bicycle crashes along corridor segments. Population density has a particularly notable effect, with each additional thousand persons per square mile associated with a 10% increase in crash frequency (OR=1.10). The presence of a raised, planted median was associated with 29% decrease in pedestrian and cyclist crashes (OR=0.71) though, as discussed previously, we suspect part of this effect is attributable planted medians being located at affluent locations with little roadside development. Among land uses, fast food outlets and commercial shopping centers were each associated with a 10% increase in crash incidence (OR=1.10). We also find positive and significant effects for the number of groceries, gas stations, and bus stops. Finally, as with the intersection models, income has an inverse effect on pedestrian and bicycle crash frequency, with higher income segments reporting fewer crashes. Race again has no effect on pedestrian and cyclist crash frequency after accounting for income.

Table 31: Model Results for Total Pedestrian and Bicycle Crashes along Corridor Segments

	Coef.	**Std. Err.**	**z**	**p**	**Odds Ratio**
Segment Length (Mi)	0.051	0.285	0.18	0.858	1.052
AADT (000)	-0.007	0.006	-1.16	0.248	0.993
Lanes	-0.030	0.085	-0.35	0.725	0.970
Median Width (Ft)	0.023	0.011	2.01	0.044	1.023
Speed Limit (Mph)	-0.028	0.018	-1.57	0.116	0.972
Raised, Planted Median	-0.343	0.168	-2.04	0.042	0.710
Population Per Sq. Mi. (000)	0.099	0.032	3.10	0.002	1.104
Median HH income ($000)	-0.010	0.003	-3.38	0.001	0.990
Race Black (%)	-0.001	0.004	-0.42	0.677	0.999
Fast Food Restaurants	0.096	0.044	2.20	0.028	1.101
Community Shopping Centers	0.095	0.036	2.67	0.008	1.100
Groceries and Gas Stations	0.056	0.014	4.00	0.000	1.058
Bus Stops	0.059	0.025	2.35	0.019	1.061
Constant	1.577	0.744	2.12	0.034	4.840

Model Results for KAB Pedestrian and Bicycle Crashes along Corridor Segments
Results from the model of segment-level KAB pedestrian and bicycle crashes are presented in Table 32 and are similar to the model for total crashes along corridor segments. KAB pedestrian and bicycle crashes increase with increases in population density and the number of fast-food restaurants, shopping centers and groceries, and decrease with increases in income and the presence of a raised, planted median.

Table 32: Model Results for KAB Pedestrian and Bicycle Crashes along Corridor Segments

	Coef.	Std. Err.	z	p	Odds Ratio
Segment Length (Mi)	-0.013	0.325	-0.04	0.968	0.987
AADT (000)	-0.005	0.007	-0.67	0.504	0.995
Lanes	-0.055	0.096	-0.58	0.564	0.946
Median Width (Ft)	0.020	0.013	1.49	0.135	1.020
Speed Limit (Mph)	-0.002	0.020	-0.09	0.932	0.998
Raised, Planted Median	-0.388	0.191	-2.03	0.043	0.678
Population Per Sq. Mi. (000)	0.085	0.036	2.36	0.018	1.089
Median HH income ($000)	-0.006	0.004	-1.74	0.081	0.994
Race Black (%)	0.003	0.004	0.80	0.422	1.003
Fast Food Restaurants	0.092	0.050	1.83	0.067	1.096
Community Shopping Centers	0.074	0.039	1.88	0.060	1.077
Groceries and Gas Stations	0.059	0.016	3.74	0.000	1.061
Bus Stops	0.071	0.028	2.50	0.013	1.074
Constant	-0.224	0.860	-0.26	0.794	0.799

Model Results for KSI Pedestrian and Bicycle Crashes at Intersections
Our final model examines KSI pedestrian and bicycle crashes occurring along corridor segments (Table 33). This model again shows that population density has a strong, positive effect of KSI crashes, as do shopping centers and grocery stores. Higher incomes and the presence of a raised, planted median are associated with fewer KSI pedestrian and bicycle crashes.

Table 33: Model Results for KSI Pedestrian and Bicycle Crashes along Corridor Segments

	Coef.	Std. Err.	z	p	Odds Ratio
Segment Length (Mi)	0.195	0.384	0.51	0.611	1.215
AADT (000)	-0.013	0.009	-1.37	0.170	0.987
Lanes	0.071	0.118	0.60	0.548	1.074
Median Width (Ft)	0.034	0.017	2.06	0.040	1.035
Speed Limit (Mph)	-0.010	0.026	-0.39	0.697	0.990
Raised, Planted Median	-0.492	0.233	-2.11	0.035	0.611
Population Per Sq. Mi. (000)	0.091	0.045	2.01	0.044	1.095
Median HH income ($000)	-0.013	0.005	-2.79	0.005	0.987
Race Black (%)	0.003	0.005	0.60	0.549	1.003
Fast Food Restaurants	0.033	0.063	0.53	0.595	1.034
Community Shopping Centers	0.110	0.048	2.29	0.022	1.116
Groceries and Gas Stations	0.054	0.018	3.05	0.002	1.055
Bus Stops	0.054	0.034	1.61	0.108	1.055
Constant	-0.923	1.068	-0.86	0.388	0.397

2.4 Discussion

While pedestrian and bicycle crashes account for 3% of all crashes occurring on arterial corridors, they account for 35% of all deaths occurring at intersections and 44% of the fatalities occurring along corridor segments. The risk is particularly pronounced for lower-income areas, which experience two to three times the number of pedestrian and bicyclist deaths and serious injuries that occur in affluent areas. It is tempting to attribute the differences in crash risk to differences in street design, though the differences were small and not particularly significant. Of greater significance were differences in land use, with lower-income areas having far more fast food restaurants, groceries, and gas stations than their more affluent counterparts.

Findings from our negative binomial models reinforced the observation that crash risk is largely influenced by land use. For intersection locations, our model results showed that fast-food restaurants, groceries, and gas stations increase pedestrian and bicycle crashes at all severity levels. Additionally wider medians at intersections, which are the result of more left turn lanes and thus more traffic conflicts, are associated with increases in pedestrian and bicyclist crashes. This points to large intersections with abundant driveways in densely-populated areas as being the most dangerous for pedestrians and cyclists, environments which are far more common in lower-income environments than in affluent ones.

3. THRESHOLD ANALYSIS

The third component of this study sought to identify the conditions where enhanced street design criteria may be warranted along C3 corridors. The major finding from the previous phase of this analysis is that land use plays the defining role in the incidence of pedestrian and bicycle crashes, injuries, and deaths, with fast-food restaurants, groceries, gas stations, pharmacies, and shopping centers associated with increased pedestrian and bicycle crashes. While low-income populations were found to experience 2-3 times the number of pedestrian bicyclist deaths and injuries than more affluent locations, they also have 2-3 times the number of these “high-risk” land uses. Considered as a whole, it is not street design or income alone that matters, but instead how these elements interact with the adjacent land uses. This phase of the study thus focuses on the role of land use on pedestrian and bicyclist deaths and injuries.

3.1 Defining High-Risk Land Uses

Our statistical models revealed that pedestrian and bicyclist deaths and injuries were most strongly associated with the presence of five land uses: grocery store, gas stations, shopping centers, fast-food restaurants, and “single stores,” a designation that often includes gas stations, pharmacies, and convenience stores. For this analysis, we sought to understand the magnitude of the effect these uses had on pedestrian and bicyclist crashes. To do so, we created a variable called “high-risk uses,” defined as the sum of groceries, gas stations, shopping centers, single stores, and fast-food restaurants at each intersection and along each corridor segment. As detailed above, we divided the corridors in this study into intersections and corridor segments.

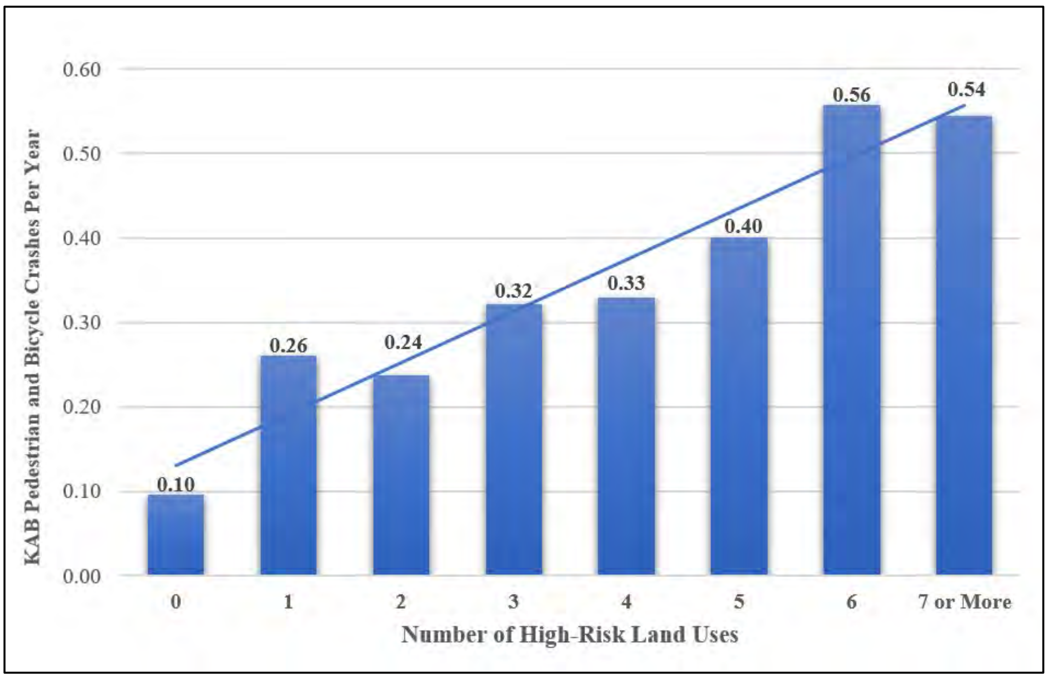
3.2 High-Risk Uses at Intersections

To gauge the effect of these high-risk uses on KAB and KSI crashes at intersections, we calculated the average number crashes occurring at intersections based on the number of high-risk uses that were present. As shown in Table 34, below, there were very few intersections with more than 7 such uses. Because the limited number of observations suggested that the averages were likely unreliable, we merged them into the category of 7 or more. Figure 2 plots the relationship between the number of high-risk uses and the number of deaths and injuries involving a pedestrian or a bicyclist. The relationship is extremely strong and almost perfectly linear. The number of high-risk uses near an intersection explains 92% of the variation in the average number of pedestrian and bicyclist injuries that occur, and the model is significant at the 0.000 level.

As shown in the regression equation, which can be used to predict likely crashes along C3 arterials in Florida, each additional high-risk use within 250’ of an intersection would be expected to result in 0.06 additional pedestrian or bicyclist injuries per intersection, per year. On average, locations with 3 high-risk uses would be expected to result in at least one pedestrian or bicyclist being injured or killed every 3 years, while a location with 6 such uses would be expected to experience one death or injury every 2 years.

Table 34: Summary Statistics for Pedestrian and Bicycles Crashes at Intersections

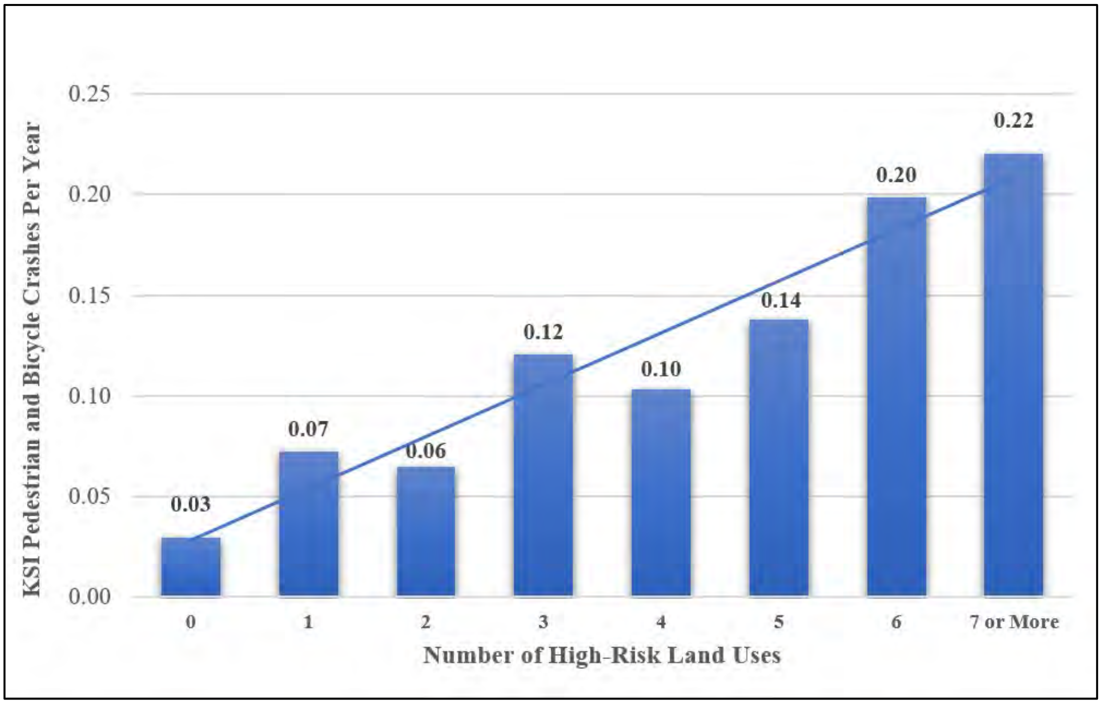
Number of High-Risk Uses	Number of Intersections	KAB Crashes Per Year	Avg. KAB Per Intersection, Per Year	KSI Crashes Per Year	Avg. KSI Per Intersection, Per Year
0	93	9	0.10	2.75	0.03
1	69	18	0.26	5	0.07
2	62	14.75	0.24	4	0.06
3	83	26.75	0.32	10	0.12
4	75	24.75	0.33	7.75	0.10
5	38	15.25	0.40	5.25	0.14
6	39	21.75	0.56	7.75	0.20
7	17	9.25	0.54	3.75	0.22
8	7	2.75	0.39	1	0.14
9	2	1.25	0.63	0.5	0.25
10	1	0	0.00	0	0.00
16	2	1	0.50	0	0.00
34	1	0.75	0.75	0.25	0.25



y = 0.133 * 0.06 (# High-Risk Uses)
R^2 = 0.92, F=68.60 (p=0.000)

Figure 2: KAB Pedestrian and Bicycle Crashes, Per Intersection, Per Year, by the Number of High-Risk Land Uses

Figure 3 presents the results for KSI crashes involving a pedestrian or a bicyclist each year. As with the KAB model, the relationship is strong and perfectly linear, with the number of high-risk uses again explaining 92% of the variation in the number of deaths and incapacitating injuries. The regression equation shows that each additional high-risk use can be expected to result in 0.026 deaths or serious injuries each year. While the number seems small, it is important to observe that a single high-risk use more than *doubles* the baseline likelihood of a death or serious injury. For locations with 6 or more such uses, one would expect at least one pedestrian or bicyclist to be killed or maimed every 5 years.



y = 0.026 * 0.026 (# High-Risk Uses)
R^2 = 0.919, F=68.041 (p=0.000)

Figure 3: KSI Pedestrian and Bicycle Crashes, Per Intersection, Per Year, by the Number of High-Risk Land Uses

3.3 High-Risk Uses along Corridor Segments

As with intersections, we sought to understand the magnitude of the effect of high risk uses on arterial corridor segments. Because the segments used in this analysis vary in length, it was necessary to normalize crashes and risk uses by segment length. Correspondingly, the risk of these features is measured as the number of pedestrian and bicyclist crashes per mile, per year, examined against the number of high-risk uses per mile (See Table 35).

Table 35: Summary Statistics for KAB and KSI Pedestrian and Bicycle Crashes Per Mile along Corridor Segments, Per Year, by the Number of High-Risk Land Uses

High Risk Uses Per Mile	KAB	KSI
0	0.21	0.05
0.01-4.99	0.38	0.17
5-9.99	0.68	0.24
10-14.99	0.45	0.26
15-19.99	1.10	0.60
20-24.99	1.17	0.45
25-29.99	0.81	0.27
More than 30	1.48	0.65

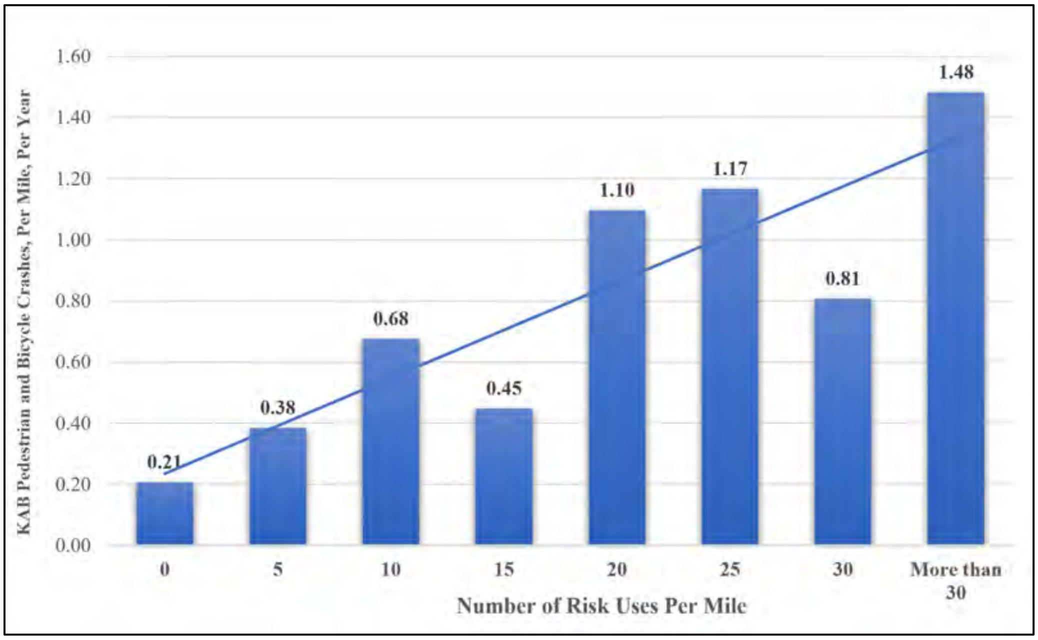
Similar to our findings for intersections, high-risk uses are strongly related to the injury and death of pedestrians and bicyclists. On average, the presence of 10 of these uses per mile would be expected to result in at least one injury or death every two years, while 20 such uses would be expected to result in at least one such death or injury every year (see Figure 4). And as with intersections, roughly half of these crashes result in a death or incapacitating injury (see Figure 5). These relationships are again strong and linear, though the relationship is not quite as strong as that observed for intersections. In case of deaths and incapacitating injuries, the number of high-risk uses per mile only explained 61% of the variation.

3.4 Site Analysis of High-Risk Locations

To better understand the role of design and development configurations on pedestrian and bicyclist crash risk, we conducted detailed evaluations of high- and low-crash locations. For intersections, a high-crash intersection is defined as one that experienced at least 2 KSI pedestrian and bicycle crashes, or at least 5 KAB pedestrian and bicycle crashes. Low-crash locations were defined as those that did not report any pedestrian deaths or injuries whatsoever during the four-year evaluation period**.** Because corridor segments were of various lengths, we defined high-crash corridors as those experiencing 5 or more KSI pedestrian or bicyclist crashes per mile. For each of these locations, we combined information from the crash data with detailed examinations of satellite imagery, the combination of which proved to be instructive.

High-Crash Intersections

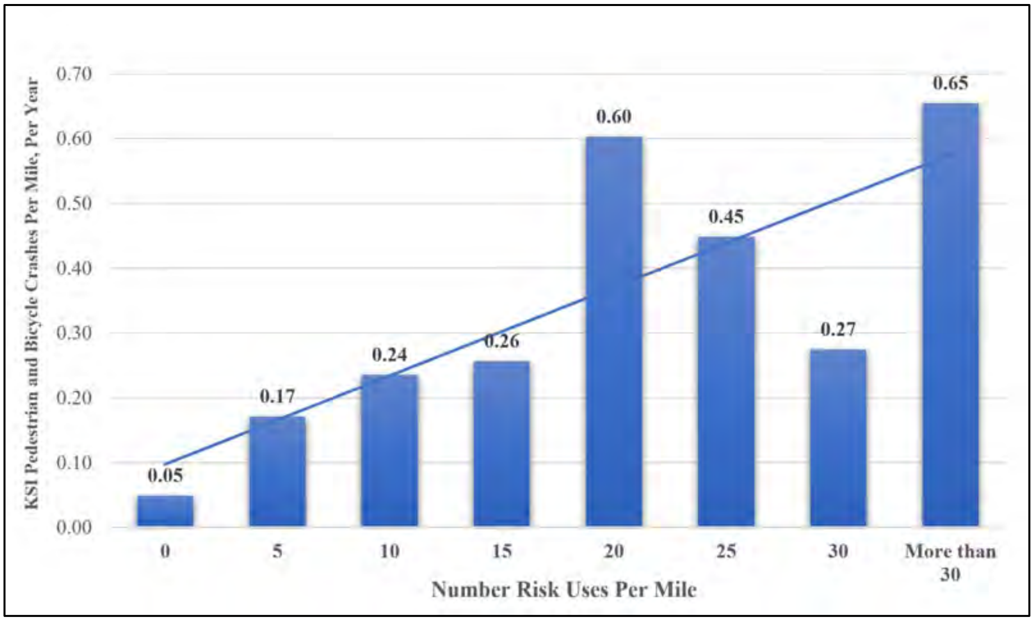
Of the 489 intersections included in this study, 50 were defined as “high crash intersections,” or intersections report 2 or more pedestrian or bicyclist KSI crashes, or 5 or more pedestrian or bicyclist KAB crashes. We examined satellite and street imagery for each of these 50 sites to identify patterns in the design and configuration of streets and land uses at these locations. What was most notable was not simply the presence of “high-risk uses” at high-crash locations, but also consistency in their configuration. Beyond having a cluster of high-risk uses, most of these intersections—38 of 50 (76%)—had a grocery or big box store located adjacent to it, often serving as an anchor for a host of associated high-risk uses, such as gas stations, restaurants, and pharmacies. (See Figure 6). These appear to serve as pedestrian trip attractors, drawing people along the surrounding corridors and through these intersections.



y = 0.237 * 0.031 (# High-Risk Uses)
R^2 = 0.764, F=19.442 (p=0.005)

Figure 4: KAB Pedestrian and Bicycle Crashes Per Mile, Per Year along Corridor Segments, By the Number of High-Risk Land Uses Per Mile, Per Year

Interestingly, two of these high-crash intersections reported zero high-risk uses, causing us to wonder whether factors other than land use might be involved. Nevertheless, an examination of satellite imagery revealed both to be confirmatory cases, with crash incidence driven by the same factors as the other intersections. The first of the two, located in Fort Lauderdale, Florida, lacked the presence of high-risk uses solely because of the manner in which the land uses are coded (see Figure 7). One side of the intersection is a development classified as “mixed use,” but which nevertheless includes a commercial strip intermixed with a gas station, both of which would have been classified as high-risk uses if considered independently. The opposite side of the intersection includes a shopping mall which contains fast food restaurants, department stores, and other uses that would similarly have been classified as high-risk uses if considered independently.



y = 0.10 * 0.014 (# High-Risk Uses)
R2 = 0.607, F=9.679 (p=0.021)

Figure 5: KSI Pedestrian and Bicycle Crashes Per Mile, Per Year along Corridor Segments, By the Number of High-Risk Land Uses Per Mile

The second case was even more instructive. This location experienced 7 bicycle crashes, all of which occurred during the day (see Figure 8, below). An examination of the intersection in relation to the surrounding area helps explain this otherwise unexpected phenomenon. This intersection is in the middle of a corridor that connects several mobile home communities to a Wal-Mart Neighborhood Market, a Target shopping center, and a Walgreens pharmacy—all of which contain groceries—as well numerous fast-food restaurants. The distance between these locations, a little more than ½ mile, would encourage bicycle use.

If it is indeed the case that bicycle and pedestrian access between the mobile home communities and this shopping complex is the issue, then one would expect that the other intersections along the corridor would be high-crash locations as well. And indeed they are, with all three intersections along the corridor included among the 50 most hazardous. This demonstrates the important role than land use plays not only as a destination for pedestrian and bicyclist trips, but also in establishing their lines of movement. As will be discussed further, land use placement can be used to draw pedestrian and bicyclist towards—or away from—hazardous locations.

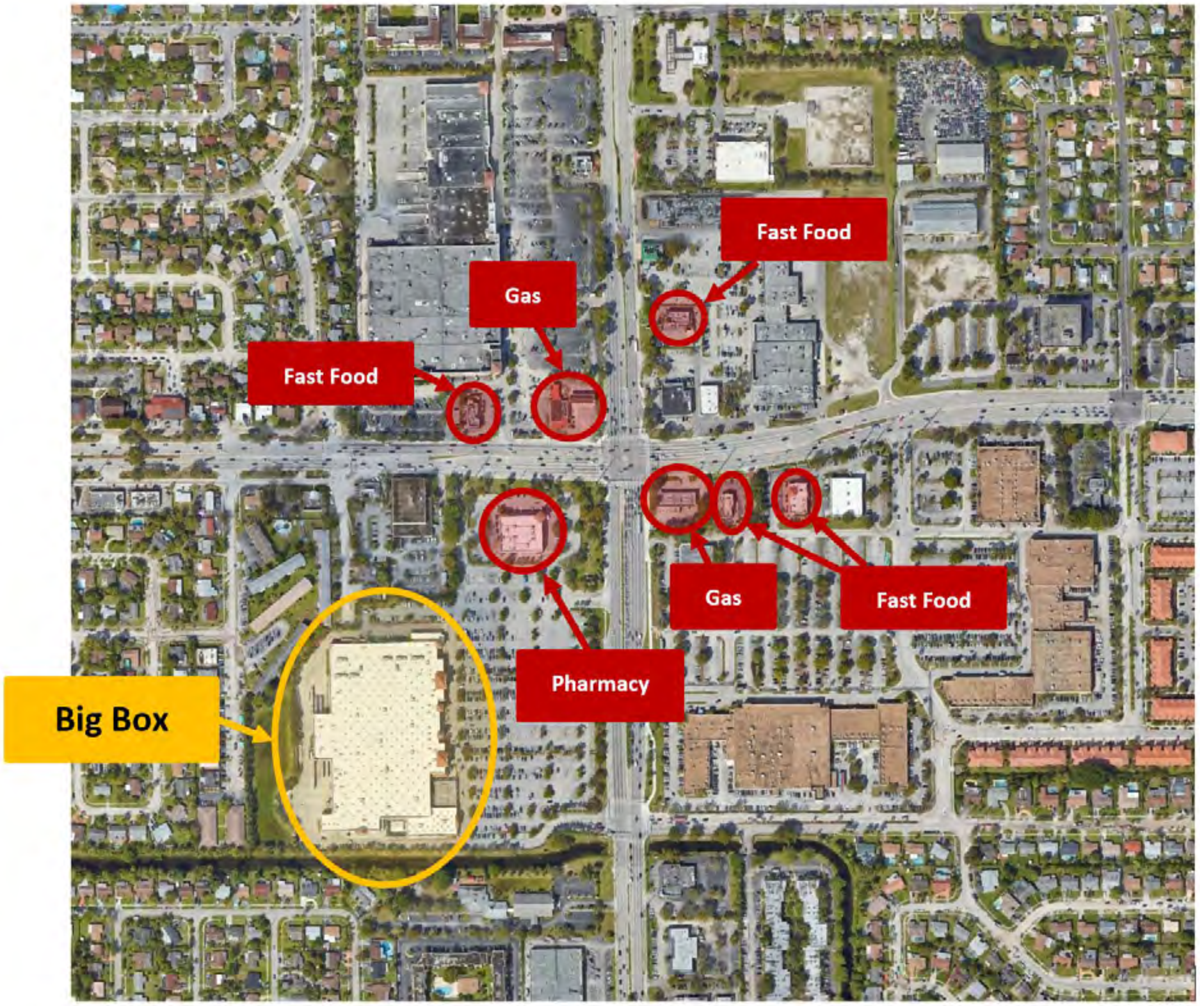


Figure 6: Big Box Stores (top) and Groceries (bottom) Anchoring High-Crash Intersections

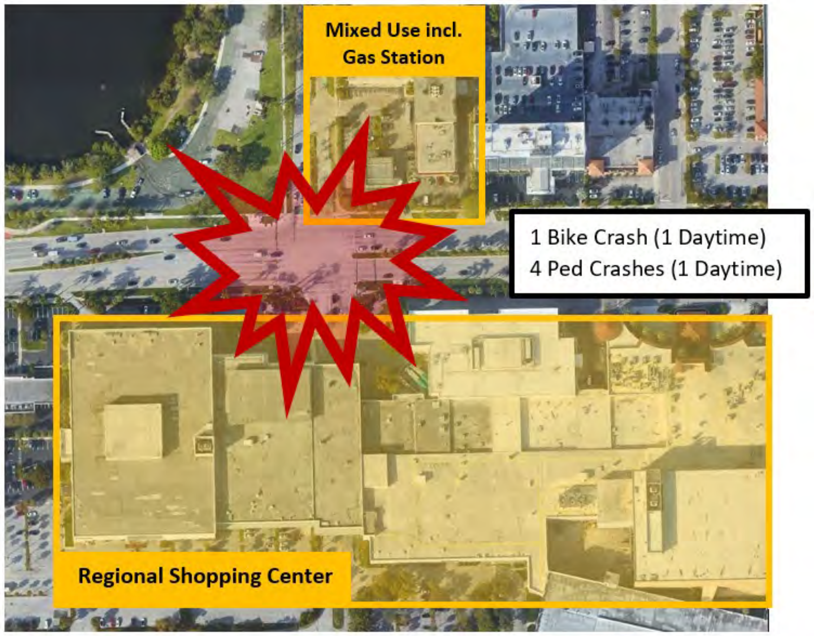


Figure 7: Pedestrian and Bicycle Crashes at Galleria Mall, Fort Lauderdale

Figure 8: How Land Uses Create Corridor-Level Risk (US-19 in St. Petersburg, FL)

Considering Lower-Risk Intersections

While high-risk uses explain the clustering of pedestrian and bicycle crashes, we were also interested in understanding how these uses might be safely accommodated. Specifically—are there locations that contain concentrations of these uses that do NOT result in pedestrian and bicyclist death and injury? And if so, how do their characteristics differ from the high-crash intersections described above?

This approach helps identify the specific triggers that can transform a safe location into a hazardous one, providing concrete guidance on strategies to adopt, or to avoid. For this analysis, the intersections of interest were defined as having 5 or more of high-risk uses, but which did not report a single pedestrian and bicyclist injury during the four-year study period. Of the 498 intersections considered in this study, 19 fell into this category. Table 36, below compares these intersections against their high-crash counterparts. While these intersections are similar in terms of median household income, daily traffic volumes, and posted speed limits, they are notably different in that they are smaller, less complex intersections which have fewer travel lanes and lower traffic volumes on the intersecting street. Stated in more concrete terms, they are minor intersections with shorter crossing distances.

Table 36: How Safe Intersections with Five or More High-Risk Uses Differ from High-Crash Intersections

	High-Crash Intersections	**No Crash, 5+ Risk Use Intersections**		
	Mean	**Mean**	**Difference**	**% Difference**
Median Household Income	$47,952.37	$53,968.97	$6,016.60	12.55%
% White Residents	59.93%	76.12%	16.19%	27.01%
% Black Residents	30.52%	14.23%	-16.29%	-53.38%
% Hispanic	23.02%	24.51%	1.49%	6.49%
% Renter	51.05%	41.88%	-9.16%	-17.95%
% Walk Commute	1.43%	1.58%	0.15%	10.53%
% Bike Commute	1.01%	0.60%	-0.41%	-40.55%
AADT	45,203	41,540	-3,664	-8.10%
Cross St AADT	23,616	11,323	12,293	-52.05%
Avg # Lanes	5.80	5.00	-0.80	-13.76%
Posted Speed Limit	41.75	40.79	-0.96	-2.30%
Median Width	22.88	20.78	-2.11	-9.20%

A review of satellite imagery reveals differences in the composition and configuration of land uses as well. Groceries and big box stores—which serve as destination anchors for pedestrian and bicyclist trips—are almost entirely absent from these intersections. In the cases where they are present, they are generally set back from the primary thoroughfare and accessed using lower-volume side streets, rather than through a direct driveway connection (see Figure 9). Signal control provides access to secondary streets, which result in traffic accessing the site at lower speeds and, presumably, with greater attention to pedestrians and bicyclists.

Figure 9: Grocery and Retail Uses Removed from Arterials and Major Intersections

High-Crash Corridor Segments

27 of the 334 corridor segments examined in this study were high-crash sections, defined as segments experiencing 5 or more pedestrian or bicyclist KSI crashes per mile during the study period. While all of the 27 high pedestrian crash corridors had at least one high-risk use present, there were comparatively few instances where a grocery or big box were present. Instead, the problem streets clustered into 3 general categories. The first and most prevalent, comprising 10 of the 27 sections, were 6-lane arterials traversing gridded street networks (see Figure 10). These are areas that appear to have been initially developed in the 1960s, and which attempt to prioritize the corridor's mobility function by restricting traffic signals to major intersections. The result is the presence of unprotected crossings across high-volume streets, which, as shown in the figures below, proved to be problematic for pedestrians, bicyclists, and motorists alike. These are streets that, regardless of their context classification or intended traffic function, are functioning as urban streets.

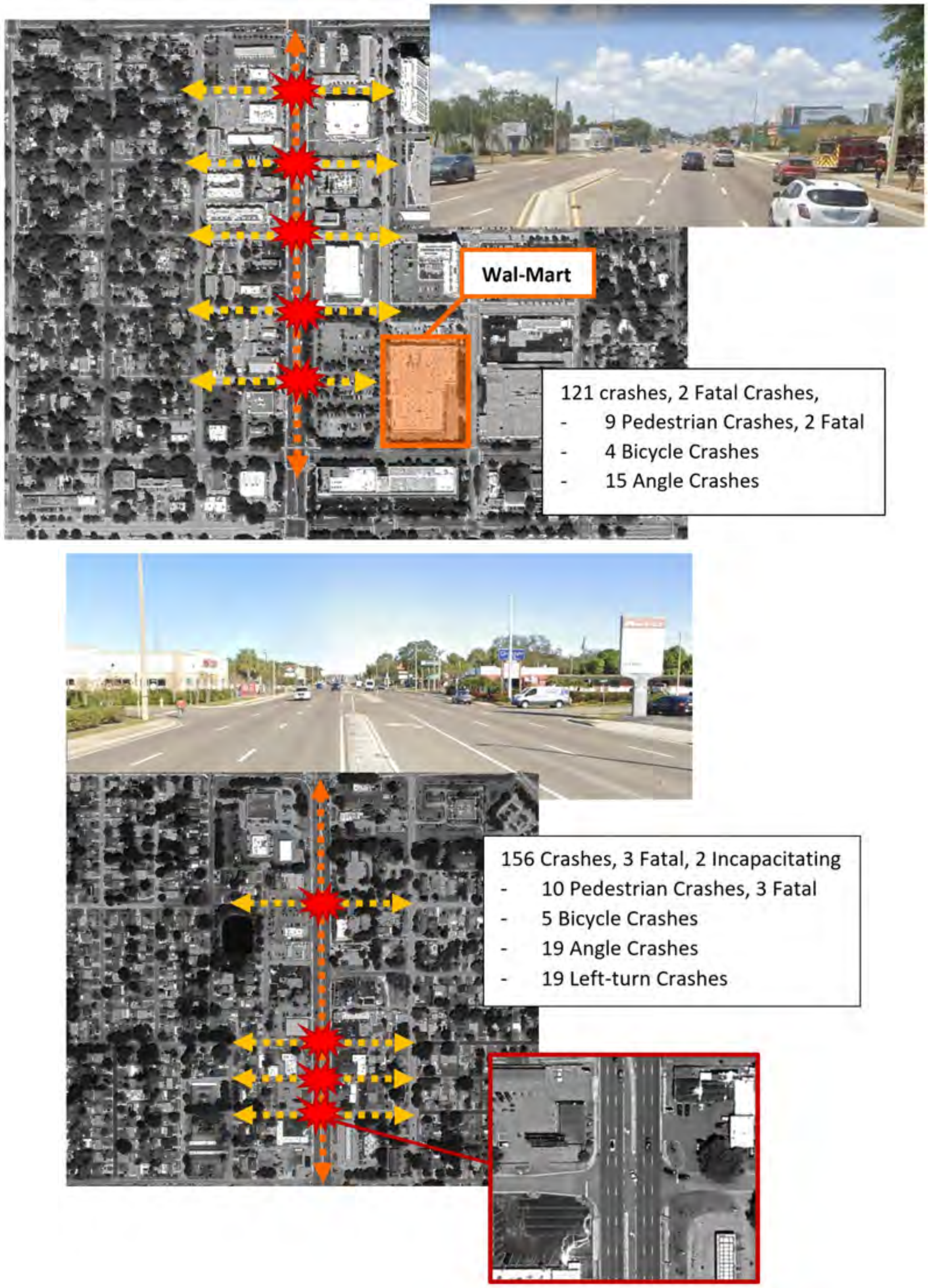


Figure 10: High-Crash Corridors with Big Box Stores (top) and without (bottom)

As was done with intersections, we also examined locations with concentrations of high-risk uses, but which did not report any pedestrian or bicyclist injuries during the study period. As shown in Table 37, below, these segments are similar in most respects, with only moderate differences in income, traffic volumes, or the geometric features of the corridors themselves. Instead, the primary differences are that the low-crash locations have fewer intersections and lower population densities than their high-crash counterparts. Stated in simple terms, risk increases as these corridors become more urban.

Table 37: High-Crash Segments Compared Against Low-Crash Segments with Concentrations of High-Risk Uses

	5+KSI	20+ Risk Uses, 0 KAB	Difference	% Diff.	t	p
Median HH Income	53,107	55,189	2,081	3.92%	-0.365	0.358
% White Residents	64.63	72.95	8.32	12.88%	-1.512	0.068
% Black Residents	25.12	15.60	-9.52	-37.89%	1.75	0.043
% Hispanic	24.01	31.52	7.50	31.26%	-1.621	0.055
% Renter	47.61	39.32	-8.29	-17.42%	1.755	0.042
% Walk Commute	1.53	1.58	0.05	3.56%	-0.133	0.447
% Bike Commute	1.04	0.60	-0.44	-42.01%	2.083	0.021
AADT	43,465	48,211	4,746	10.92%	-1.227	0.112
Avg # Lanes	5.70	5.60	-0.10	-1.73%	0.321	0.375
Posted Speed Limit	43.40	43.11	-0.28	-0.65%	0.195	0.423
Median Width	22.59	20.69	-1.90	-8.42%	0.945	0.174
# Intersections	7.89	5.75	-2.14	-27.12%	1.792	0.039
Pop Sq. Mile	5,380	4,259	-1,121	-20.84%	2.098	0.020

The second problematic configuration can perhaps best be described as "transitioning corridors," which occur when high-risk uses begin to locate on rural highways as a result of the urbanization of the corridor. These take two primary forms. The first are corridors with nearby mobile home communities, which were initially located in more rural areas at the edge of a metropolitan area. While these may not initially have been a safety problem when the area was principally rural, they became a safety problem as the corridor was subsumed into the larger metropolitan area, shifting the overall context from rural to urban (see Figure 11). As high-risk uses locate along the corridor, these mobile home communities serve as a point of origin for pedestrian and bicyclist trips in an urbanizing—and unsafe—environment. A second and related configuration is embodied by West Colonial Drive in Orlando (on which 4 of the 27 high-crash segments were located), but which is emblematic of problematic facilities throughout North and Central Florida, characterized by rural highways transitioning to suburban conditions (see Figure 12).

Figure 11: Rural-Suburban Transition—Mobile Home Communities

Exacerbating the problem is that many of these roads have recently been widened to accommodate future growth projected along the corridor. In both cases, the formerly rural character of these roads is identifiable by their ongoing use of ditch and culverts to accommodate drainage and stormwater runoff. The hazards are created, in this case, by the transformation of a rural corridor into a suburban one. This suggests a need for not only considering traffic forecasts when moving forward with new capacity projects, but also the current and future characteristics of surrounding land uses. Local development codes indicate permitted uses along the corridor, which allows for the identification—and thus prevention—of the future safety hazards that may emerge in the future. Where arterial-oriented retail is permitted in local development codes, the arterial needs to either be designed to safely accommodate these uses and the associated users, or else land use codes need to be modified to restrict future development from locating on these facilities.

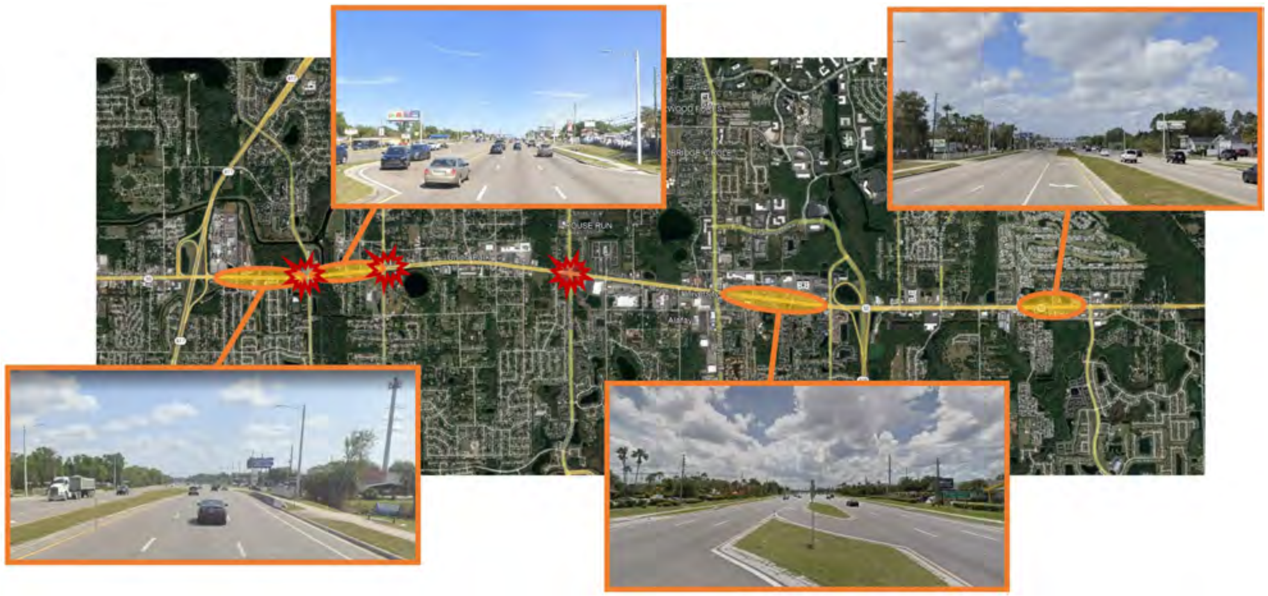


Figure 12: High-Crash Segments and Intersections on Transitional Corridor: East Colonial Drive

Considering Segments with 20 or More High-Risk Uses Per Mile and 0 Pedestrian or Bicyclist KAB Collisions

36 corridors had 20 or more high-risk uses per mile, but did not report any pedestrian or bicycle KAB crashes. While many of these appeared to be the result of local factors, a shared characteristic is that they have generally lower-population densities than the high-crash segments, often with few nearby residential uses. The result is that the land uses do not have the origins that generate pedestrian and bicycle trips along the corridor. Where residential uses are present, typically have little or no direct connection with the arterial segment, making it difficult for pedestrians to access the corridor, and thereby encouraging automobile travel instead of walking or bicycling (see Figure 13). The absence of pedestrian deaths and injuries along these corridors would thus appear to be less a result of anything inherently safe about these corridors themselves but, instead the result of a development configuration that discourages walking and bicycling.

Figure 13: Corridors with Limited (Left) and No (Right) Residential Connections to the Arterial

Considered as a whole, C3 arterial configurations, characterized as 6-lane divided highways with limited intersection control, should be avoided in areas with connected street networks or higher residential densities. When located near residential areas, access to the arterial should be severely limited. This has the secondary effect of encouraging road uses to shift from walking to bicycling to automobile travel, though it should be observed that C3 arterial corridors are, by definition, principally intended for automobile use.

Urban Comparisons

While an examination of urban streets was not part of this project's scope of work, the role that high-risk uses and urbanization played in creating risk along C3 corridors suggested the need for considering whether alternate design and development configurations might better accommodate them. The findings below should be regarded as preliminary; a more focused study is needed to develop meaningful recommendations. Nonetheless, we believe these preliminary findings are instructive as a starting point for developing guidance on the adaptation of C3 corridors.

For this examination, we sought to identify more urban, "main-street" type configurations. We identified 9 such streets in our study area. While these are not high-volume streets, they have concentrations of high risks uses while nevertheless being among the most "pedestrian-friendly" in the state (see Figure 14). These streets are:

- Atlantic Avenue, Delray Beach
- Central Avenue (Main Street Section), St. Petersburg

- Central Avenue (General Urban Section), St Petersburg
- Cleveland Street (Main Street Section), Clearwater
- Cleveland Street (General Urban Section), Clearwater
- Lake Avenue, Downtown Lake Worth
- Las Olas Boulevard (Main Street Section), Fort Lauderdale
- Las Olas Boulevard (Las Olas Village Section), Fort Lauderdale
- East Tarpon Avenue, Tarpon Springs

Figure 14: High-Risk Uses Along Lower-Volume, Urban Streets
(Clockwise from top left: Cleveland St, Tarpon Ave, Atlantic Ave, Central Ave)

Table 38 presents summary statistics for these streets. These streets all include heavy concentrations of high-risk uses, though they are characterized by urban, rather than suburban, configurations, with smaller rights-of-way, minimal building setbacks, and parking located on the street or in shared lots or garages located behind the buildings. These are streets that would be classified C4 or C5 under FDOT's Context Classification Framework.

Despite accommodating high levels of pedestrian activity, there were no pedestrian or bicyclist fatalities on any of these streets during the 4-year study period, and only 2 serious injuries. The remaining injuries all appeared minor according to the police reports, with the pedestrian or bicyclist able to leave the crash scene without medical treatment.

Crashes involving bicyclists were more common, with 5 of the 9 sections reporting at least one bicycle crash resulting in a minor injury, though none resulted in an incapacitating injury or death. The two problematic sections were the urban section of Central Avenue in St. Petersburg and Atlantic Avenue in Delray. In the case of Central Avenue, 1 pedestrian was seriously injured while crossing in the crosswalk, while the two pedestrians were injured when attempting to dart between moving cars at 2:45 in the morning, with both pedestrians suspected of being under the influence of alcohol, while the bicycle collisions were all the result of cars attempting to enter or exit angled parking. In the case of Atlantic Avenue, both bicycle crashes were the result of "dooring" by a stopped car—i.e., a crash occurring because an occupant of a parked vehicle opened the car door in front of an approaching bicyclist, resulting in the bicyclist colliding with the opened door. The remaining 4 cases all involved vehicles turning left onto a driveway or side street, resulting in a collision with the bicyclist (see Figure 15).

Table 38: Pedestrian and Bicycle Crashes on Urban Comparison Streets (Four-Year Totals)

Name	**Length (miles)**	**Risk Uses**	**Ped KSI**	**Ped KAB**	**Bike KSI**	**Bike KAB**
Atlantic Ave, Delray Beach	0.28	32	1	3	0	2
Central Ave (Main), St Pete	0.42	19	0	1	0	3
Central Ave (Urban), St Pete	0.34	28	1	3	0	3
Cleveland Street (Main), Clearwater	0.28	42	0	0	0	0
Cleveland Street (Urban), Clearwater	0.41	5	0	0	0	1
Lake Avenue, Lake Worth	0.21	47	0	0	0	0
Las Olas Blvd (Main)	0.31	16	0	0	0	0
Las Olas Blvd (Village)	0.18	19	0	0	0	1
E. Tarpon Ave, Tarpon Springs	0.24	21	0	0	0	0
Total	2.67	229	2	7	0	10

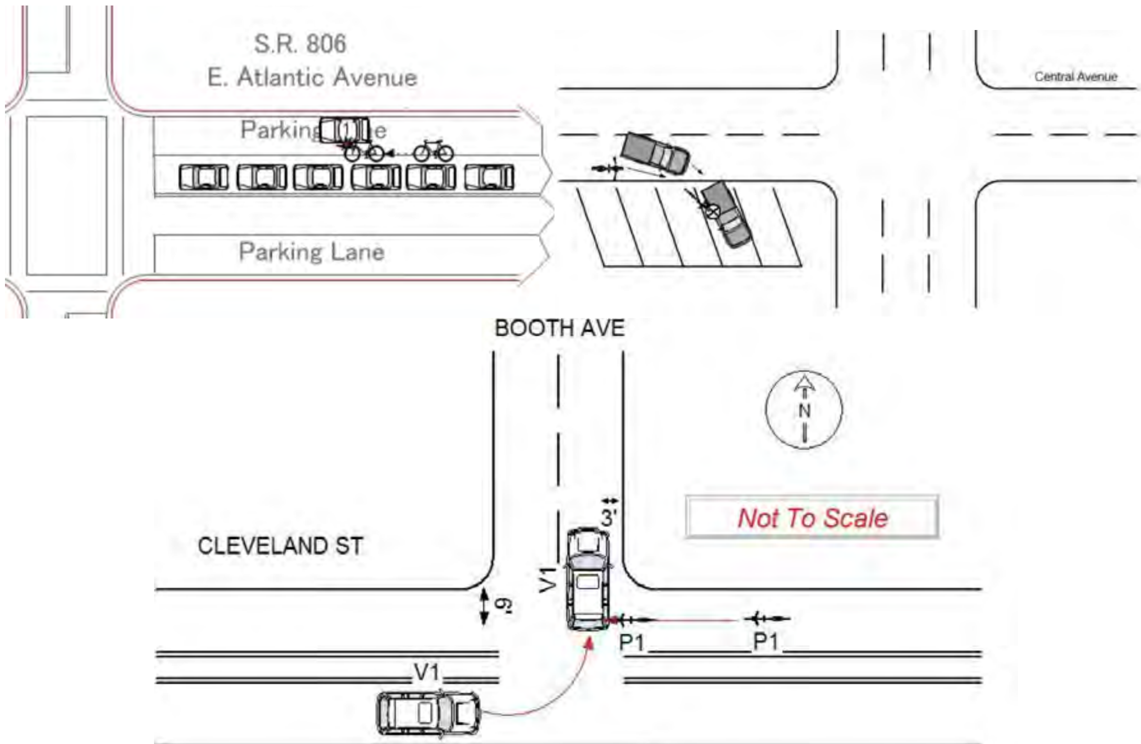


Figure 15: Urban Bicycle Collisions: Dooring (top left) Angle Parking, (top right), and Left-Turn (bottom)

While several of these streets do not have a perfect safety record, the complete absence of traffic fatalities and serious injuries, despite intense concentrations of high-risk uses and high levels of pedestrian and bicyclist activity, suggests that high-risk are better located on lower-speed, lower-volume streets than along C3 corridors, and far preferable to the hybrid suburban/urban configurations depicted in Figure 10, above. It further supports this study's major finding, which is that the pedestrian and bicyclist safety problem occurring along C3 corridors is as much a problem of land use as it is of street design.

Nonetheless, this is simply a preliminary analysis. There is a need for future research that can elaborate on the basis for the variations in safety performance observed in Table 6, and use this to inform street design guidance. It must further be observed that levels of walking and bicycling are almost certainly much higher on these corridors than on the C3 corridors that served as the basis of this study; basic descriptive statistics, such as those presented in Table 39, does not account for difference in volume and exposure. Future research is necessary to do so.

4. FINDINGS AND RECOMMENDATIONS

FDOT's context classification system provides guidance for designing streets in harmony with their developmental context. While this prescriptive approach to street design can greatly aid in addressing the safety needs of pedestrians and bicyclists, it presents challenges in "transitional" areas, such as along arterial corridors classified as "C3 Suburban." This study had three specific objectives:

1. The identification of contextual factors that may place pedestrians and bicyclists at increased risk along C3 corridors
2. Estimation of the relative effects that specific features of C3 corridors have on crash incidence, thereby allowing for the prioritization of safety-related countermeasures
3. The identification of threshold values that may serve to trigger a reconsideration of design treatments along C3 corridors.

To achieve these objectives, we examined 4 years of pedestrian and bicycle crashes occurring along 222 miles of arterial thoroughfares in major metropolitan areas in the state (see Table 2). Because intersections and the segments between them were suspected of having different crash characteristics, these corridors were broken into 489 intersection locations and 334 corridor segments. Risk factors were examined through a two-layered approach. The first used negative binomial regression models to understand design and developmental factors that influence the incidence of pedestrian and bicycle crashes, injuries, and deaths. The second consisted of detailed examinations of high- and low-crash locations in order to identify the design and developmental configurations that may be responsible for these crashes. The sections below summarize the major findings from this study and conclude by detailing a framework that can be applied to not only mitigate existing safety problems, but to prevent future safety issues from emerging.

4.1 Multivariate Analysis

As expected, the number of pedestrian and bicycle crashes occurring on a corridor are strongly associated with income. Compared to affluent areas, lower income areas report 200% more KSI pedestrian crashes per mile and 300% more KSI bicycle crashes, indicating the need to prioritize lower-income areas for safety investments. Nonetheless, the negative binomial models used in this analysis help reveal the underlying factors that lead to differences in crash incidence. The demographic variables entered the models as expected, with higher population densities being generally associated with an increased incidence in pedestrian and bicycle crashes, though not always at statistically significant levels, and increases in income being associated with a reduction in these crashes. Average annual daily traffic did not prove to be meaningfully associated with pedestrian and bicyclist crashes.

Street Characteristics Influencing Pedestrian and Bicycle Crashes

For intersections, the number of lanes along a corridor was associated with increases in pedestrian KSI crashes, as was median width. Collectively, these variables suggest a risk associated with both longer intersection crossing distances, as well as multi-directional threats associated with turning vehicles. Higher speed limits were associated with fewer pedestrian and bicyclist crashes, a factor most likely explained by the fact that streets with higher posted speeds are generally located in less densely developed areas that have a great deal of access control. For corridor segments, the only street design variable statistically related to pedestrian and bicycle crashes was the presence of a raised, planted median, which was associated with reductions in pedestrian and bicyclist crashes. We expect this finding is principally attributable to the fact that landscaped medians occur primarily in affluent suburban areas with a great deal of access control and low pedestrian and bicycle traffic volumes.

Development Characteristics

The factors that proved to have the strongest effect on the incidence of pedestrian and bicycle crashes were land use characteristics. Grocery stores, gas stations, fast food restaurants and shopping centers were associated with significant increases in these crashes, with each additional one increasing crashes between 6% and 20%, depending on the type of crash being considered. As these uses tend to cluster together in anchor-outparcel configurations, a single intersection of corridor is likely to have many of these uses clustered together, exacerbating crash risk at these locations.

4.2 Threshold Analysis and Examination of High- and Low-Crash Locations

This phase of the effort sought to identify threshold values that should trigger the use of enhanced design criteria. To the extent that there is a single trigger, it is the presence and concentration of “high-risk” uses along C3 arterials, with high-risk uses defined as groceries, pharmacies, commercial shopping centers, gas stations, convenience stores and fast-food restaurants. As shown in Figures 2-5, above, the magnitude of the safety problem increases as a direct function of the number of these uses that are present, with the number of these uses explaining <u>*nearly all*</u> of the observed variation in crash incidence.

We further examined satellite imagery to better understand the specific nature of the hazards occurring at intersections and along corridor segments. For intersections, the most hazardous locations for pedestrians and bicyclists were those where land uses adopt “anchor and outparcel” configurations. These are characterized by the presence of a grocery or a big box store serving as an anchor for a host of secondary uses, such as pharmacies, gas stations, and fast-food restaurants (see Figure 6, above).These locations attract pedestrian and bicycle trips from nearby residential areas, drawing these users along the surrounding driveways and intersections. Addressing the risk associated with these uses entails identifying the development’s trip generation characteristics and associated lines of movement, and ensuring safe access to the site for vulnerable users (see Figure 8 for an example).

For corridor segments, the problem is less about the specific nature of these uses themselves, and more about the creation of lines of movement that conflict with vehicle paths. While risk uses and their attendant driveways are certainly a risk factor, the highest risk corridors are those with higher residential densities (which originate pedestrian and bicycle trips) and uncontrolled intersections. These corridors result in lines of movement that result in clusters of crashes at unprotected intersections (See Figure 10, above, for an example). The risk of these locations is further compounded by race, with crashes being less likely to occur in areas with concentrations of white residents, and more likely to occur in locations with concentrations of black residents.

Threshold Values for Enhanced Design Criteria

While an objective of this task was initially to identify threshold values which might trigger the use of enhanced design criteria on C3 corridors, the issue is more complicated than a determination of whether or not a street is or is not sufficiently safe. The introduction of a single high-risk use along a C3 corridor constitutes a safety hazard, and the magnitude of the hazard increases as a direct function of the number of such uses that are present. When determining threshold values for enhanced design criteria, the functional question—and one that is a policy decision beyond the scope of this study—is the number of pedestrian deaths and injuries that will be tolerated before an alternate design treatment is warranted.

While we disagree with efforts to financialize human health and well-being, the National Highway and Traffic Safety Administration (2023) has nonetheless assigned dollar values to crashes based on injury severity (see Table 40), numbers which can be used to estimate the costs and benefits of a safety intervention similar to how we currently quantify the economic costs of congestion. Using the expected crash values shown in Figures 2-5, one can multiple the expected number of crashes by the corresponding cost in Table 39 to estimate their annual costs. As crashes are cumulative, this value can, in turn, be multiplied by the number of years to estimate the longer-term risk of failing to intervene.

Table 39: NHTSA (2023) Estimates of the Cost of Crashes, by Severity

	PDO Vehicle	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatal
Medical	$0	$0	$2,210	$13,269	$69,345	$188,626	$363,229	$17,289
EMS	$31	$24	$106	$228	$486	$976	$999	$1,060
Market Prod.	$0	$0	$2,315	$23,096	$92,716	$229,903	$306,236	$1,010,970
Household Prod.	$71	$55	$848	$8,990	$39,001	$116,482	$127,886	$367,148
Insurance Admin.	$523	$225	$2,212	$8,220	$28,698	$36,485	$38,081	$36,245
Workplace Costs	$99	$76	$56	$418	$3,240	$7,077	$7,794	$13,589
Legal Costs	$0	$0	$740	$6,243	$27,714	$73,799	$110,012	$138,025
Subtotal	$724	$380	$8,487	$60,464	$261,200	$653,348	$954,237	$1,584,326
Congestion	$1,327	$1,008	$1,207	$1,339	$1,691	$1,814	$1,857	$7,133
Prop. Damage	$3,200	$1,864	$9,650	$9,616	$17,835	$20,565	$23,234	$15,185
Subtotal	$4,527	$2,872	$10,857	$10,955	$19,526	$22,379	$25,091	$22,318
Total Econ.	$5,251	$3,252	$19,344	$71,419	$280,726	$675,727	$979,328	$1,606,644
QALYs	$0	$0	$41,112	$402,341	$1,763,881	$2,938,008	$5,068,923	$9,651,851
Comp.Total	$5,251	$3,252	$60,456	$473,760	$2,044,607	$3,613,735	$6,048,251	$11,258,495

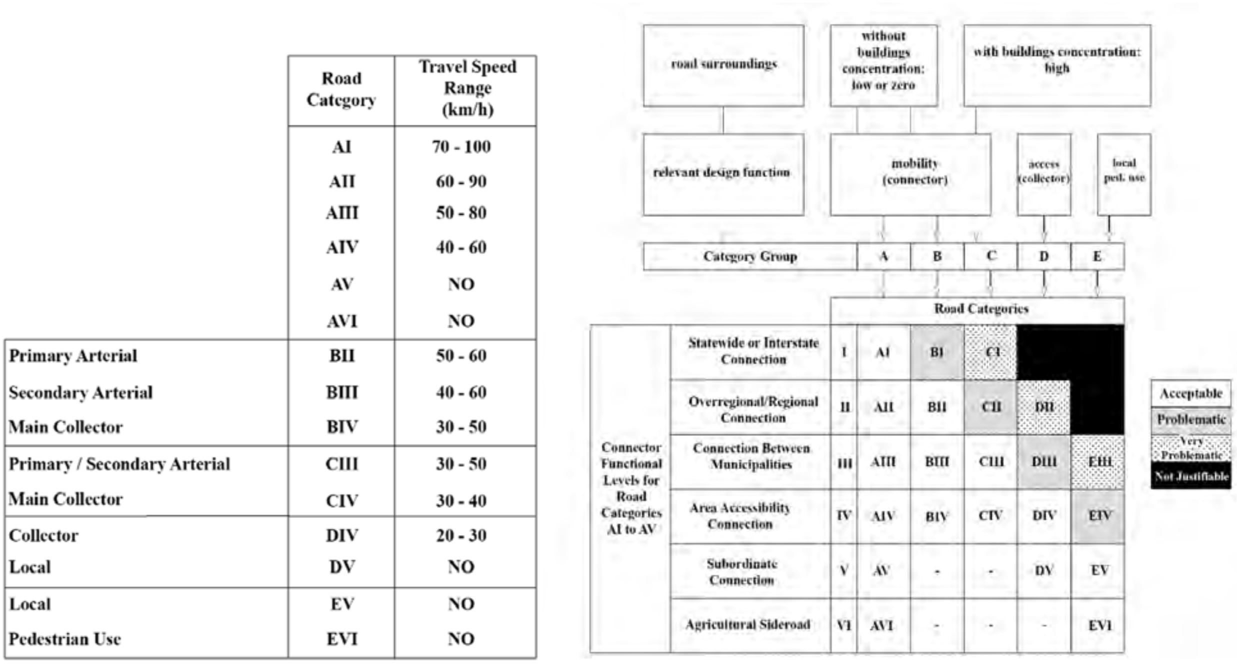
*Note: Unit costs are expressed on a per-person basis for all injury levels. PDO costs are expressed on a per-damaged-vehicle basis.

4.3 Mitigating Current Crash Risk and Preventing Future Deaths and Injuries

The first—and perhaps most important—recommendation of this study is that the pedestrian and bicyclist safety problem identified in this study is not a problem with suburban (C3) corridors generally, but largely a problem associated with C3 corridors surrounded by commercial uses.

FDOT's *Context Classification Guide* (2020) designates these as C3C corridors and provides specifications for their design. ***Any street meeting the criteria of a C3C corridor should be reclassified as being "problematic" and prioritized for safety interventions.***

The street classification commonly used in Europe provides a useful frame of reference. Under this framework, shown in Figure 16, C3C corridors would be immediately categorized as "problematic." For the access-related functions prevalent on the high-risk corridors examined in this study, European guidance would establish target speeds between 20-50 km/h (15-30 MPH). This is markedly less than that proposed in FDOT's context classification criteria, which establishes target speeds of 35-45 MPH (with 55 MPH permissible under certain circumstances). Under the European framework, such streets would be flagged as being either very problematic (DII), or else expressly prohibited (EII). FDOT should likely identify C3C corridors as problematic.



	Road Category	Travel Speed Range (km/h)
	AI	70 - 100
	AII	60 - 90
	AIII	50 - 80
	AIV	40 - 60
	AV	NO
	AVI	NO
Primary Arterial	BII	50 - 60
Secondary Arterial	BIII	40 - 60
Main Collector	BIV	30 - 50
Primary / Secondary Arterial	CIII	30 - 50
Main Collector	CIV	30 - 40
Collector	DIV	20 - 30
Local	DV	NO
Local	EV	NO
Pedestrian Use	EVI	NO

			Category Group: A	B	C	D	E
			Road Categories				
Connector Functional Levels for Road Categories AI to AV	Statewide or Interstate Connection	I	AI	BI	CI		
	Overregional/Regional Connection	II	AII	BII	CII	DII	
	Connection Between Municipalities	III	AIII	BIII	CIII	DIII	EIII
	Area Accessibility Connection	IV	AIV	BIV	CIV	DIV	EIV
	Subordinate Connection	V	AV	-	-	DV	EV
	Agricultural Sideroad	VI	AVI	-	-	-	EVI

Figure 16: European Street Classification Framework

Eliminating Problematic C3C Corridors through Planning and Design

While this project's scope of work was focused on identifying the safety hazards of C3 corridors, we would like to conclude by outlining an approach for addressing these hazards, which could be elaborated upon in a subsequent project, should such elaborations be desired. As detailed above, the safety problem emerging on C3 corridors is a mismatch between a street's intended function and its actual use. These problems are created when local governments permit commercial and retailed development along C3 corridors, which introduces access-related traffic on streets designed to serve limited-access mobility functions. Once such conditions have been created, three options are available:

1. Change the street's design (and thus its function)
2. Change adjacent land uses
3. Change both

In all three cases, the objective is to align a street's transportation function to the characteristics of adjacent development. Doing so requires that transportation professionals recognize that urban transformation is not simply a matter of street design. The successful transformation of a corridor requires that there be a ***clear vision* for the corridor not only in the present, but in *the future***, and that both street design and land development are integrated into a comprehensive whole. This is consistent with the overall framework detailed in FDOT's *Context Classification Guide*, but requires the integration of two tools not expressly included in that manual: ***land use controls*** and ***time***. In the sections below, we detail how these tools can be used to address the safety of C3C corridors, and identify potential policy levers than may be applied to realize these objectives.

1. **Immediate-Term: Changing a Street's Design (and Function).** Because state and local governments have direct control over the design and operation of the transportation system, **street redesign** is the most immediate tool at their disposal. Once commercial and retail uses are located along these corridors, the only viable near-term remedy is to prioritize the street's embedded access functions over its mobility functions. This means accepting adjacent development as a permanent characteristic of the corridor and redesigning the street to be more accommodating for vulnerable road users. This may entail actions such as lowering operating speeds, eliminating travel lanes, re-allocating right-of-way to pedestrians and bicyclists, increasing the frequency of intersection control devices, and modifying intersection operations by reducing cycle lengths and restricting vehicle turning movements, such as permitted left-turns. These are all actions which will likely reduce vehicle speeds and increase delay.

2. **Medium Term: Encourage the Transformation of Land Uses Along a Corridor.** In large part, the buildings that house high-risk uses are neither designed nor intended to be a permanent feature of the landscape; big box stores, gas stations, and strip developments typically have a functional life of only about 15 years, after which they are abandoned by their initial owners because of rising maintenance costs. This creates opportunities for redevelopment, particularly in rapidly growing metropolitan areas, where land assembly often presents challenges for infill development projects. Enhancing safety through redevelopment will require a clear plan for the future vision of the corridor, which can take one of two forms, depending on the nature of the corridor.

    - *Preserve the Corridor's Mobility Function by Phasing Out Unsafe Uses.* For corridors that only have small pockets of these uses (such as that shown in Figure 9, above and Figure 17, below), it may be desirable to discourage the future redevelopment of these properties, either through **land use regulation** or through **property acquisition**. This preserves the corridor's mobility function while eliminating the hazardous uses responsible for the creation of safety problems. This will discourage pedestrian and bicycle trips along the corridor by removing the destination ends of these trips.

Figure 17: 0 Pedestrian and Bicycle Crashes on a C3 Arterial

- *Redevelop High-Risk Uses into Safer Development Configurations.* In developed areas that are experiencing population growth, which includes all of the areas examined in this study, it may not be possible to eliminate these uses. In such conditions, land uses can be encouraged to reconfigure into less hazardous forms. Along C3 corridors, this will entail **limiting the number of direct connections to the arterial network** and **reorienting these uses inward**. Figure 18, below, shows how this might be done. In this case, the grocery and associated shops and restaurants are oriented inward onto a secondary, collector street network. Residential access is provided through the rear of the site, allowing pedestrians and bicyclists to access these destinations without traveling along the arterial network.

- **Longer-Term: Prevent the Creation of New C3C Corridors.** The strategies outlined above are attempts to retrofit hazards that have already been created. Over the longer-term, it is important that land use plans are developed that **prevent the creation of future hazards**. This entails ensuring the **local zoning ordinances** do not permit high-risk uses to locate along arterial corridors, and that **local subdivision regulations** applied to the corridor provide limited—and safe—connections. The success of this approach is contingent on compliance from local governments, though the state has multiple mechanisms to encourage compliance. Compliance can be incentivized through the creation of grant programs that make local governments eligible for infrastructure funding provided they demonstrate compliance. Similarly, project funding can be withheld from local governments that fail to demonstrate consistency with state guidance. If such services are not already available, it may be useful for the state to provide technical assistance to local governments to ensure plan consistency.

Figure 18: The Internal Reorientation of High-Risk Uses

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APPENDIX A: MULTIDISCIPLINARY REVIEW OF ROAD SAFETY ISSUES AFFECTING LOWER-INCOME AND MINORITY POPULATIONS

Research by Discipline, Dependent Variable, and Geography

Among our selected seventy-eight studies concerning road crash disparities among low-income and minority communities, the largest share is from public health lead authors, comprising thirty-four studies. Of the remainder, eighteen are from planning lead authors, sixteen are from civil engineering lead authors, and ten are from varied other discipline lead authors including geography, psychology, and sociology. There are differences in the type of safety issues considered by researchers in relation to income or minority status for our selected articles, as indicated by their primary dependent variables (Table 40). Of the seventy-eight selected studies, thirty-one focus on pedestrian crashes or injuries, with six of those looking only at pediatric crashes or injuries and twenty-five at all-ages of pedestrian crashes or injuries. Seven additional studies combined the research of both pedestrian and bicycle crashes or injuries, while four studies analyzed just bicycle crashes. While only three studies directly studied alcohol-involved crashes, and only four studies directly examined the usage of vehicle restraints, both of these topics were present in some of the nineteen studies that focused on general road crashes or injuries, as well as in a few of the pedestrian studies. There are also differences in the source of data used for analysis by discipline. For the twenty-seven studies in our selection that used injury or mortality data such as from hospital records, eighteen were from public health lead-authored studies. In contrast, for the twenty-seven studies in our selection that used collision data such as from departments of transportation, only one was from public health while twenty-one were either planning or civil engineering lead authors.

Table 40: Counts of Selected Studies by Dependent Variable Type

Type	Subtype	Count
Crashes or Injuries	General Road	15
	General Road, Pediatric	4
	Pedestrian	25
	Pedestrian, Pediatric	6
	Bicycle	4
	Pedestrian and Bicycle	7
	Alcohol-involved	3
	Freight	1
Other Variables	Arrests/Traffic Stops	2
	Vehicle Yielding to Pedestrians	2
	Seat Belt / Child Seat Usage	4
	Review	2
	Helmet Use	1
	Perceptions of Safety	1
	Bikeway Access	1

Finally, there were variations in the geographies or units of analysis used by different disciplines for identifying disparities among our selection of research articles, especially between planning and public health lead-authored research (Figure 18). Census areas were the geography of choice of planning studies to aggregate collisions for comparisons, while only two studies in the selection aggregated crashes to road segments. Of the eighteen planning studies included in our selection, thirteen analyzed crash incidences at the level of Census tracts or Census block groups. Alternately public health studies favored calculating crash rates for population groups such as race or ethnic categories, with eighteen of the thirty-six public health studies using such groupings. Following the same trend over time as for disciplines, the use of geographies in studies greatly increased from 2011 in line with the contributions from planning scholars, while using population groups as a unit of comparison remained steady through all time periods (Figure 18).

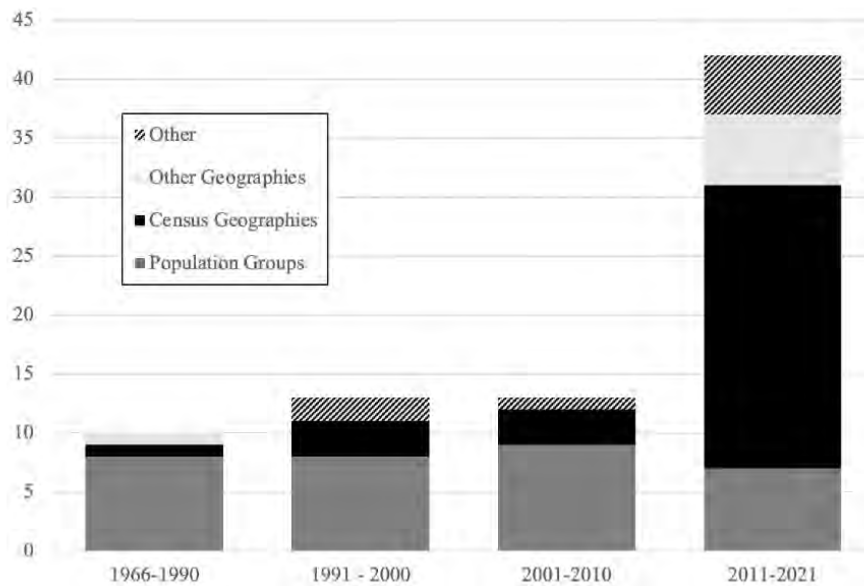

Figure 19: Counts of Selected Studies by Geography/Unit of Analysis and Year

Research Identifying Disparities of Risk

Research into socioeconomic disparities has repeatedly found that Black, Hispanic, and Indigenous population subgroups have higher rates of pedestrian injuries and deaths compared to White subgroups as summarized in Table 41, as well as finding clear disparities by income level. This research agenda began with a focus on childhood traffic injuries in the 1980s and extended into the 1990s with several influential articles by public health researchers noting an elevated risk for certain subgroups of children. Rivara and Barbara (1985) found numerous socioeconomic factors influencing childhood pedestrian injury in Memphis Census tracts, including a higher proportion of non-White population, more families below the poverty level, and lower household incomes. They also found a majority of injured children were crossing at non-intersection locations, while less than 5% were playing in the roadway. In Montreal, childhood pedestrian and bicycle injuries were found to be at least four times higher in lower-income areas and disparities were greater for pedestrians than cycling injuries (Pless et al., 1987, Dougherty et al. 1990).

Table 41: Literature Estimates of Pedestrian Risk for Minority Groups Compared to White Group

Black		**Hispanic**		**Indigenous**			
IRR		**IRR**		**IRR**		**Location**	**Citation**
1.7	*Child fat.*	N.A		N.A.		US National	Waller et. al, (1989)
1.2	*Child fat.*	N.A		N.A.		Birmingham AL	King & Palmisano (1992)
N.A		1.7/1.2	*M/F fat.*	3.7/2.8	*M/F fat.*	New Mexico	Schiff & Becker (1996)
N.A		2.1	*Inj.*	N.A.		Orange Cty. CA	Agran et al. (1998)
1.7/1.0	*M/F fat.*	1.5/1.1	*M/F fat.*	N.A.		Los Angeles CA	Demetriades et al. (1998)
1.8/3.9	*U/R fat.*	1.3/0.6	*U/R fat.*	6.1/6.8	*U/R fat.*	Arizona	Campos-Outcalt et al. (2002)
1.3	*AM. fat*	1.1	*AM. fat*	4.1	*AM. fat*	Wisconsin	McAndrews et al. (2013)
2.1/1.7	*M/F fat.*	2.2/1.6	*M/F fat.*	4.3/2.8	*M/F fat.*	US National	Naumann & Beck (2013)
1.7/1.2	*Fat./inj.*	1.2/0.9	*Fat./inj.*	1.5/1.9	*Fat./inj.*	US National	Hamann et al. (2020) *
2.8	*Inj.*	N.A.		N.A.		North Carolina	Harmon et al. (2021)

N.A. = Not Available; Fat. = Fatality; Inj. = Injury; M/F = Male/Female; U/R = Urban/Rural; AM fat.= All mode fatality; * *Indigenous was included as part of "Multiracial" category*

At the national level, Waller et al., (1989) looked at accidental childhood deaths, and noted that Black children had 1.6 times the rate of pedestrian traffic fatalities compared to all children, while Indigenous children had 3.9 times the rate of non-traffic crashes, which occur in driveways or otherwise on private property. And in an Alabama case-controlled study of racial differences, King and Palmisano (1992) found pedestrian injury rates 1.2 times higher among Black children compared to White children. Hispanic children in Orange County California cities were also found to have 3.6 times higher pedestrian crash injury rates than non-Hispanic Whites before adjusting for Census block groups, and 2.1 times higher rates after adjustment (Agran et al. 1996). A follow-up study correlated pedestrian injuries among Hispanic families in the same area to household poverty, number of persons per household, recent family moves, and parental English literacy but did not include non-Hispanic Whites for comparison (Agran et al. 1998). Finally, Marcin et al. (2003) found that children from the lowest income households had rates of pedestrian injuries and mortality three times higher than the highest income group.

Starting in the 1990s public health researchers expanded beyond just childhood injuries to include consideration of adult traffic injuries with a particular focus on comparing race and ethnic disparities. Race and ethnicity variables were first added to the Fatality Analysis Reporting System (FARS) in 1999 (Briggs et al. 2005). To understand the high rate of traffic fatalities in New Mexico compared to other states, Schiff and Becker (1996) explored ethnic disparities, finding higher rates of 1988-1990 traffic fatalities among Hispanics compared to White non-Hispanics (1.7 times higher for males, 1.2 times for females) and especially high rates for Indigenous (3.7 times higher for males, 2.8 times for females). A study in adjacent Arizona found even higher rates of injury for Indigenous peoples, with urban pedestrian fatality rates 6.1 times higher than White non-Hispanics and rural pedestrian fatality rates 6.8 times higher (Campos-Outcalt et al., 2002). The same study also found that in urban settings Black pedestrians had fatality rates 1.8 times higher than White non-Hispanic pedestrians (Campos-

Outcalt et al., 2002). In a study of trauma deaths in the city of Los Angeles, Demetriades et al. (1998) showed that Black men had a 1.7 times higher rate of pedestrian deaths compared to White men, while no difference in rates was found among women. And in Seattle, a 1998 study examined the circumstances of traffic fatalities, finding that non-Whites were over-represented (Harruff et al. 1998).

A 2013 national study across adult ages also found that Indigenous people had the highest rates of pedestrian crashes—over 4 times the rate of Whites for males—followed by Blacks and Hispanics who had just over 2 times the rate of Whites for males; in the under 15 age group, Black children were at the highest risk (Naumann and Beck 2013). Even after hospital admission, Blacks and Hispanics have 1.2 times and 1.3 times higher likelihood of mortality respectively in comparison with Whites (Maybury et al. 2010). This is an important finding, indicating that not only are Black pedestrian more likely to be involved in a collision, but they are also more likely to die after being hospitalized, suggested disparities in both exposure and treatment.

In a more recent national study, a category of “multiracial” included Indigenous peoples, who showed the highest risk for pedestrian injuries (1.9 times the White group), while Black people were found to have the highest risk for pedestrian fatalities (Hamann et al., 2020). McAndrews et al. (2017) calculate per trip injury rates, showing that Black travelers were 1.6 times more likely to have an inpatient injury as a pedestrian compared to a motor vehicle trip, while White men were only 1.2 times more likely; the disparity was wider for Black women who were 1.7 times more likely to have an inpatient injury, compared to White women who had no additional risk from a walking trip. Indigenous men faced the highest increased risk for walking trips, being 3.5 times more likely to have an inpatient injury and 5.5 times more likely to be in a fatal crash (McAndrews et al. 2017). Most recently, a North Carolina study based on hospital visits found Black residents had more than or nearly double the pedestrian injury rates per 100,000 person years than Whites for all but the 80+ age category (Harmon et al. 2021).

Studies have sometime included income alongside or instead of race and ethnicity. In a study of Census tracts in Orange County California, Chakravarthy et. al. (2010) found that the strongest predictor of pedestrian injuries was the percentage of the population below the poverty level, followed by the percentage of the population with less than a high school education and the percentage of the population where English was not the primary language spoken at home. Race variables were not included in the study. Pediatric pedestrian injuries in Chicago were found by Statter et al. (2011) to be spatially concentrated in lower-income, higher density Black neighborhoods, in contrast to higher income, lower density non-Black neighborhoods. In addition to public health studies, there were also contributions from a few planning and civil engineering lead authors starting in the 1990s, whose disciplines had previously not focused on income or race disparities. Epperson (1995) found that area poverty explained higher rates of Black cycling crashes in Dade County, Florida. Pedestrian crashes of individuals walking the roadway were found to be related to area signifiers of poverty such as unemployment and single parent households in North Carolina (McMahon et al. 1999). Finally, Stamatiadis and Puccini (1999) set out to determine if socioeconomic differences could help explain why Southeastern US states had higher fatal crash rates. They found that lower education and lower-income levels were associated with increased risk of being involved in fatal single vehicle crashes, and that older vehicles were associated with increased risk of both single and multi-vehicle crashes.

Research on Pedestrian Behavior and Alcohol Involvement

The notion that pedestrians bear responsibility for their involvement in crashes has long historical roots embodied by the concept of "jaywalking," which promoted and enforced a view that streets rightfully belong to cars and not pedestrians. (Norton 2007). This idea has continued to shape not just enforcement practices but also coding of crash reports and a small share of research. In a Washington DC study, Preusser et al. (2002) make the assumption that all midblock crashes involve a pedestrian "suddenly" appearing in the path of a vehicle, terming these "dart-dash" type crashes; they observed such crashes were more common in lower-income areas and among children, and that they decreased between 1976 to 1998, while "vehicle turning" type crashes had increased. A more recent Florida study also uses the category of "dart or dash" as well as "improperly in roadway," which are likely named or imputed based on the crash reporting framework (Guo et al. 2017). However most academic studies do not use such value-laden terms in relation to pedestrian crashes. Some studies in our selection have also specifically sought to create knowledge about the relationship of racial bias with pedestrian crossing. Goddard et al. (2015) found that motorists were twice as likely to yield for a white pedestrian than a black one. Coughenour et al. (2017) added income area comparisons, finding cars in high income areas passed Black pedestrians in the midst of crosswalks over five times more frequently than in a low-income area, however they were slightly more likely to yield Black pedestrians if they were waiting at the intersection.

A NHTSA report based on 1990 to 1994 national data described that where alcohol was involved in a fatal crash, pedestrians were more than twice as likely as drivers to be recorded as using alcohol. Black and Hispanic pedestrians had slightly higher rates of alcohol-involved pedestrian fatal crashes than White people, while the rate of indicated-alcohol use by Native American people was twice that of White people (Voas 2000). Long and Ferenchak (2021) examine "intoxicated walking" in Albuquerque, New Mexico, finding that nighttime pedestrian crash rates are higher in areas containing bars and restaurants that serve alcohol. While they make the observation that crash rates are elevated in non-White areas, they do not construct a model that controls for other conditions.

Nesoff et al. (2019) also suggests further study of the role of intoxication in pedestrian crashes, based on a Baltimore City Census block group model that correlates the number of to-go alcohol outlets with pedestrian injuries, while controlling for traffic volume, household income and other neighborhood characteristics, but without controlling for race or ethnicity. Recently one study also raised the potential connection of homeless rates with pedestrian crashes. Bernhardt and Kockelman (2021) find that homelessness is correlated with county pedestrian crashes in Texas, as well as near encampments in Austin, and suggest the relationship of homelessness, mental health and pedestrian crashes for further study.

Research Highlighting Differences in Exposure

Several papers have concluded that exposure is a likely contributor to disparities in pedestrian crash risk between race, ethnicity, or income groups. Yet exposure has been challenging to adequately measure and model. Both Loukaitou-Sideris et al. (2007) and Noland et al. (2013)

point to low automobile ownership rates in low-income areas as indicators of more pedestrian travel which increase exposure to crash risk for such communities. Other planning studies have also shown the relationship of road crashes with increased transit use (Cottrill and Thakuriah 2010, Lin et al. 2019). For pediatric injuries, Laflamme and Diderichsen (2000) considered in a review how differential exposure was the best supported explanation for higher mortality about among lower social classes. However while it is commonly presumed that lower-income households walk more the more affluent ones, a study using National Household Travel Survey data found that it is the most affluent households that do the greatest amount of walking, though their walking is largely recreational in nature, whereas walk trips undertaken by lower-income households are intended to accomplish utilitarian ends, such as work or shopping (Yang and Diez Roux, 2012). This suggests that it is not simply overall levels of walking that matters, but rather walking that occurs in poorly-designed environments. Affluent households walk by choice, rather than necessity. If their residential location isn't accommodating for walking, they can travel elsewhere to engage in this recreational activity. Indeed the author of an early study of Dade County Florida which found each additional percent of Census tract population below the poverty level was associated with 3.3 additional bicycle crashes per 1000 residents surmised that "rather than being the mode of choice, the bicycle is often the mode of last resort" (Epperson 1995).

With most studies in our selection lacking detailed pedestrian trip data, population density has been used to control for pedestrian exposure, along with employment density (Loukaitou-Sideris et al. 2007) or commercial Walk Scores (Nesoff et al. 2019). The inference is that areas with higher employment and residential densities report higher rates of walking, and therefore have higher overall rates of exposure. In a study where total population was used to control for exposure, two other indicators of exposure, walk commuting and low automobile ownership, were found to be associated with more pedestrian crashes (Chimba et al. 2018). Based on Census reported commuting trips in Austin, Yu (2014) found that higher Census tract poverty rates are associated with both more pedestrian and bike trips and crashes, while a higher share of White residents are associated with less walking and fewer pedestrian crashes.

Recently the topic of exposure, and especially its measurement, has been a growing focus of studies concerning pedestrian and bicycle crash disparities. Indeed, Merlin et al. (2020) in a conceptual review of crash studies, regard increased exposure as an explanation for the existence of higher crash rates in lower-income communities. Quality exposure data for pedestrians and cyclists is not often available, yet several studies have shown its value in modeling. Tao et al. (2021) demonstrate how the inclusion of direct pedestrian and cyclist exposure variables leads to identification of more low-income Census tracts as higher risk areas. Lee et al. (2019) propose a predictive crash risk model for use in long term planning based on the inclusion of walking hours data; racial disparities are included in models both walking exposure and pedestrian crash risk. McAndrews et al. (2013, 2017) sought to introduce improved exposure data that better accounted for active travel trips into calculations of population risk, with findings that strengthen existing understandings of elevated pedestrian risk for Black and Indigenous travelers compared to White travelers.

Research Examining the Built Environment

There has been extensive literature in civil engineering and planning about the effect of the built environment on road crashes, encompassing topics such as road widths, road design, intersection controls, and pedestrian countermeasures (Ewing and Dumbaugh 2009). Yet most of this research has not focused on, or meaningfully included, consideration of low-income and minority communities. Among studies that do incorporate considerations of income, race, or ethnic disparity, this review identified ten broadly defined environmental factors associated with increased pedestrian crashes. These are factors that showed commonality across studies despite different study locations, model distributions and approaches to controlling for exposure. The factors are summarized in Table 42 and include commercial land uses, arterial / wider roads, higher speed limits, higher traffic volumes, transit stops, lacking sidewalks, residential land uses, lacking shoulders, interrupting driveways, and lacking lighting.

Table 42: Common Environmental Factors Associated with Pedestrian Crashes in Selected Studies That Consider Socioeconomic Disparities

Environmental Factor	**Citations**
Commercial land uses	Schneider et al. (2021), Lin et al. (2019), Yu et al. (2018), Hwang et al. (2017)*, Kravetz and Noland (2012), Loukaitou-Sideris et al. (2007)
Arterial / wider roads	Schneider et al. (2021), Yu et al. (2018), Hwang et al. (2017) *, Kravetz and Noland (2012)
Higher speed limits	Schneider et al. (2021), Lin et al. (2019), Al-Mahameed et al. (2019) McMahon et al. (1999)
Higher traffic volumes	Schneider et al. (2021), Yu et al. (2018), Loukaitou-Sideris et al. (2007), McMahon et al. (1999) **
Transit stops	Schneider et al. (2021), Lin et al. (2019), Cottrill and Thakuriah (2010)
Lacking sidewalks	Al-Mahameed et al. (2019), Hwang et al. (2017) *, McMahon et al. (1999) **
Lacking lighting	Guo et al. (2017), Loukaitou-Sideris et al. (2007)
Lacking shoulders	Al-Mahameed et al. (2019), McMahon et al. (1999) **
Interrupting driveways	Schneider et al. (2021), Loukaitou-Sideris et al. (2007)

**Pediatric pedestrian crashes;* ***Roadway pedestrian crashes*

Among studies, Loukaitou-Sideris et al. (2007) conducted a spatial analysis of the distribution of crashes in Los Angeles finding that commercial retail land use had the strongest effect of any variable on pedestrian crashes; the authors then observed conditions in mostly poor and non-White case study neighborhoods, finding populations more prone to walking, yet doing so in poor walking environments due to interrupting driveways, visibility obstructions, and lighting conditions. Cottrill and Thakuriah (2010) also point to the interaction of exposure and environment, finding positive effects on crash rates from transit use and walkability as measured by dense land uses and blocks. These two studies have been especially influential, judged by their being among the four most highly cited articles in our selection. Additionally, Kravetz and Noland (2012) studied the distribution of road safety designs in New Jersey finding commercial land uses and wider roads associated with increased crashes; in terms of road design they found that crosswalks and sidewalk buffers were less prevalent in low-income areas, although that difference was not correlated to differences in crash rates. In terms of their methods, these three planning studies used either Poisson or Negative Binomial modelling of crashes aggregated to either Census tracts or Census block groups. An earlier study examining just in-roadway pedestrian crashes showed that missing sidewalks and shoulders, as well as unemployment helped explain the prevalence of walking on roadway pedestrian collisions in North Carolina (McMahon et al. 1999).

Siddiqui et al. (2014) compared modeling approaches of the effects of built environmental variables in low-income and majority non-White traffic analysis zones, finding through a Bayesian Poisson-lognormal model that residential units, intersections, mid-speed limit roads (35mph) and population density were associated with increased pedestrian crashes in two Florida counties. Also using Florida data, Guo et al. (2017) found that higher-income areas are more likely to have less severe crashes—which may be related to unequal reporting of crashes—and that lower-income areas have more pedestrian crashes occurring at night without lighting. Bayesian inference was used to model Austin Texas crashes in a planning study, finding that arterial roads and commercial units were associated with increased crashes in all areas, but that the presence of schools were associated with crashes only for non-White or lower-income areas (Yu et al. 2018).

Research on childhood pedestrian injuries also evolved to include measurement of the effect of the built environment on crash risks, as disciplines beyond public health took some interest. Yiannakoulias et al. (2011) found in an Alberta study that new residential developments in communities with higher proportions of families below the poverty line was associated with increased childhood pedestrian injuries, in contrast to the opposite effect observed for new developments in higher income areas. Hwang et al. (2017) studied the effects of the environments near schools on child pedestrian injuries finding commercial land uses and arterial roads associated with greater crash risk along with longer blocks, fewer crosswalks, and poor sidewalk coverage. Additionally, Ferenchak and Marshall (2019) compare the spatial distribution and area demographics of reported pedestrian pediatric crashes, with survey results based on asking parents to rate the perceived safety of areas; finding that both approaches—which they term “reactive” and “proactive” —are in agreement that minority and low-income communities experience worse road safety.

Most crash studies with an interest in built environmental effects related to income or race and ethnicity have analyzed Census geographies such as tracts or block groups, however a handful have conducted analysis at the segment level. Al-Mahameed et al. (2019) used structural equation modeling to disaggregate sources of crash risk while accounting for exposure, finding that paved shoulders, sidewalks, and bike lanes form pedestrian-friendly areas that decrease crash rates, while low education levels, poverty, low wage workers, and carless population form low social status areas that increase crash rates. Schneider et al. (2021) identify 60 pedestrian crash corridor hot spots in the United States, finding that most are wide, high speed roads with adjacent retail and often bordering lower-income and minority communities. Furthermore, most studies of crash disparities have focused on metropolitan settings. However, Marshall and Ferenchak (2017) find that rural zip codes are at a higher risk for pedestrian fatality, and that racial disparities remain; both urban and rural Black zip codes had higher pedestrian crash risk than White communities.

Recent interdisciplinary research on the built environment and low-income or minority communities have explored freight crashes, air quality, and Vision Zero policy outcomes. Yuan and Wang (2021) observe that low-income and minority communities both have higher levels of freight traffic and more freight crashes. Braun et al. (2021) measure both crash risk and exposure to pollution for cyclists in Los Angeles, finding that communities marginalized through race, ethnicity, or income bear both burdens disproportionately. And in a third interdisciplinary study, Rebentisch et al. (2019) analyzes the distribution of both safety investment and crash injuries between 2009 and 2018 in light of the New York City's 2014 enactment of a Vision Zero policy, finding that the data-driven Vision Zero approach to focus investment on high crash locations did not reduce income-based disparities in injuries or fatalities, despite reducing disparities in safety infrastructure between lower and higher income areas.

The effect of the built environment on cycling crashes is of growing interest to the research community, with some research also considering income, race, or ethnicity. Cycling trips increased in the US after 2000, with most of that growth being among male cyclists (Pucher et al. 2011). Lusk et al. (2019) used mixed method to study the perceptions of bicycle facility crash and crime safety in low-income communities in Boston, finding that residents prefer wide, but less isolated, two-way paths. Using crash data and Census tracts in the San Francisco Bay Area, Barajas (2018) shows that safety infrastructure and reduced traffic volume do not protect Black or Hispanic cyclists to the extent that they protect White cyclists. He finds local roads only reduce crashes for White cyclists, while major arterial roads have over twice the positive effects on crash frequency for Black of Hispanic cyclists compared to White cyclists; additionally no type of bikeway offered protection to Hispanic cyclists, unlike for other groups (Barajas 2018). Similarly investigating the influence of both environmental and social factors on bicycle crashes, Delmelle et al. (2012) model location quotients of Buffalo neighborhood pedestrian crash frequency as compared to bicycle crash frequency. They find that street network characteristics were less influential than education, ethnicity, and land use in influencing relative risk of pedestrian versus bicycle crashes; neighborhoods with more retail and a larger share of Black population tended to have more pedestrian crashes, while neighborhoods with a larger Hispanic population and a larger share of population with no high school degree were associated with bicycle crashes. Finally, Lubitow and Miller (2013) have shown through a Portland bikeway project case study that narratives of safety in regard to policy initiatives can help conceal issues of race and equity, and reinforce existing disparities.

APPENDIX B: FULL LOCATION DESCRIPTIVE STATISTICS

Road Network Descriptive Statistics, Corridor Segment (n=334)

	Mean	Std. Dev.	Min	Max
Segment Length (Mi)	0.5	0.3	0.2	2.6
AADT	41786.1	13857.1	7064.7	85500.0
Intersections/Driveways	7.4	5.9	0.0	32.0
Lanes	5.6	1.1	2.0	8.0
Speed Limit (Mph)	44.3	5.1	28.5	55.0
Median Width (Ft)	22.5	7.9	0.0	60.0
Has Raised Paved Median	0.7	0.5	0.0	1.0
Has Raised Vegetative Median	0.8	0.4	0.0	1.0
Sidewalk Combined Width (Ft)	11.1	2.6	0.0	19.0
Sidewalk Combined Buffer (Ft)	15.5	21.0	0.0	150.8
Sidewalk Coverage (%)	92.6	20.2	0.0	122.3
Bike lane Coverage (%)	44.7	47.7	0.0	100.0
Shoulder Combined Outer Width (Ft)	12.2	8.4	0.0	36.0
Shoulder Combined Inner Width (Ft)	2.3	1.7	0.0	8.6

Road Network Descriptive Statistics, Intersection (n=489)

	Mean	Std. Dev.	Min	Max
Segment Length (Mi)	0.095	0	0.095	0.095
AADT	41418.1	13307.2	5600.0	85597.3
Intersections/Driveways	2.0	1.2	0.0	8.0
Lanes	5.6	1.0	1.9	8.0
Speed Limit (Mph)	43.1	5.1	25.0	55.0
Median Width (Ft)	22.5	8.1	0.0	60.0
Has Raised Paved Median	0.6	0.5	0.0	1.0
Has Raised Vegetative Median	0.4	0.5	0.0	1.0
Sidewalk Combined Width (Ft)	11.1	2.8	0.0	19.5
Sidewalk Combined Buffer (Ft)	13.3	19.9	0.0	157.1
Sidewalk Coverage (%)	93.7	19.6	0.0	150.0
Bike lane Coverage (%)	40.0	46.7	0.0	100.0
Shoulder Combined Outer Width (Ft)	11.1	8.0	0.0	37.5
Shoulder Combined Inner Width (Ft)	1.5	1.9	0.0	12.0

Socio-Demographic Descriptive Statistics, Corridor Segment (n=334)

	Mean	Std. Dev.	Min	Max
Population Per Sq. Mi.	4368.5	2358.3	332.3	13933.1
Median HH Income ($)	61498.8	25816.4	18040.2	169503.2
Poverty Individual (%)	14.1	8.7	1.1	48.8
Race White (%)	69.8	22.2	3.1	99.1
Race Black (%)	19.6	21.2	0.0	92.8
Race Indigenous (%)	0.3	0.6	0.0	5.3
Ethnicity Hispanic (%)	24.7	17.1	1.0	76.6
Foreign Born (%)	23.3	12.1	4.6	51.4
Rented Units (%)	40.7	19.7	1.7	94.3
Vacant Units (%)	13.2	8.2	0.0	46.1
Multifamily Units (%)	33.9	21.0	0.0	89.1
Drive Commute (%)	87.4	5.6	64.7	97.5
Transit Commute (%)	2.1	2.5	0.0	16.1
Bike Commute (%)	0.7	0.9	0.0	4.6
Walk Commute (%)	1.6	1.9	0.0	13.4
WFH (%)	6.7	4.4	0.2	25.7
No Vehicle HHs (%)	3.4	3.4	0.0	22.6

Socio-Demographic Descriptive Statistics, Intersection (n=489)

	Mean	Std. Dev.	Min	Max
Population Per Sq. Mi.	4,497.6	23,40.7	321.2	16,398.1
Median HH Income ($)	59,204.8	24,235.3	188,15.5	173,732.6
Poverty Individual (%)	15.1	9.3	1.1	57.2
Race White (%)	68.3	23.4	0.4	98.6
Race Black (%)	21.6	23.0	0.0	97.9
Race Indigenous (%)	0.3	0.6	0.0	4.7
Ethnicity Hispanic (%)	23.1	16.6	0.0	73.9
Foreign Born (%)	22.9	12.1	4.1	60.7
Rented Units (%)	43.1	19.2	2.4	99.6
Vacant Units (%)	13.9	8.5	0.0	50.5
Multifamily Units (%)	36.0	20.8	0.0	95.0
Drive Commute (%)	86.8	5.8	61.6	97.3
Transit Commute (%)	2.7	3.3	0.0	23.1
Bike Commute (%)	0.7	0.9	0.0	6.0
Walk Commute (%)	1.6	1.8	0.0	13.4
WFH (%)	6.6	4.5	0.0	26.2
No Vehicle HHs (%)	3.8	3.7	0.0	28.1

Adjacent Land Use Descriptive Statistics, Corridor Segment (n=334)

	Mean	Std. Dev.	Min	Max
Groceries and Gas Stations	5.6	5.7	0.0	43.0
Community Shopping Centers	0.8	1.7	0.0	17.0
Regional Shopping Centers	0.0	0.1	0.0	2.0
Fast Food Restaurants	0.9	1.4	0.0	8.0
Restaurants	1.0	1.6	0.0	10.0
Hotels or Bars	2.3	20.7	0.0	267.0
Offices	6.7	13.2	0.0	127.0
Department Stores	0.1	0.4	0.0	2.0
Banks or Insurance	0.5	0.9	0.0	6.0
Auto Sales or Related	2.1	3.2	0.0	22.0
Repair Stores	0.2	0.9	0.0	10.0
Parks or Recreation	0.3	1.2	0.0	14.0
Schools	0.3	0.7	0.0	5.0
Hospitals	0.0	0.2	0.0	3.0
Industrial	1.4	3.0	0.0	24.0
Bus Stops	4.2	3.3	0.0	21.0

Adjacent Land Use Descriptive Statistics, Intersection (n=489)

	Mean	Std. Dev.	Min	Max
Groceries and Gas Stations	2.2	2.1	0.0	16.0
Community Shopping Centers	0.4	1.6	0.0	33.0
Regional Shopping Centers	0.0	0.1	0.0	1.0
Fast Food Restaurants	0.3	0.6	0.0	3.0
Restaurants	0.3	0.6	0.0	4.0
Hotels or Bars	0.1	0.4	0.0	3.0
Offices	1.8	7.0	0.0	121.0
Department Stores	0.1	0.2	0.0	2.0
Banks or Insurance	0.3	0.6	0.0	3.0
Auto Sales or Related	0.5	1.0	0.0	6.0
Repair Stores	0.0	0.1	0.0	1.0
Parks or Recreation	0.1	0.4	0.0	4.0
Schools	0.1	0.3	0.0	2.0
Hospitals	0.0	0.1	0.0	1.0
Industrial	0.3	0.7	0.0	5.0
Bus Stops	1.3	1.1	0.0	7.0

APPENDIX C: PEDESTRIAN-ONLY MODELS

Pedestrian Crashes, Intersection (n=489)

	Coef.	Std. Err.	z	p	Odds Ratio
AADT (000)	0.008	0.006	1.28	0.200	1.008
Lanes	0.083	0.085	0.98	0.329	1.087
Median Width (Ft)	0.036	0.010	3.47	0.001	1.037
Speed Limit (Mph)	-0.053	0.018	-2.99	0.003	0.948
Raised, Planted Median	-0.335	0.132	-2.55	0.011	0.715
Population Per Sq. Mi. (000)	0.060	0.027	2.21	0.027	1.062
Median HH income ($000)	-0.007	0.003	-2.15	0.031	0.993
Race Black (%)	0.007	0.003	2.58	0.010	1.007
Fast Food Restaurants	0.277	0.087	3.18	0.001	1.319
Community Shopping Centers	0.092	0.053	1.73	0.083	1.096
Groceries and Gas Stations	0.135	0.030	4.48	0.000	1.145
Bus Stops	0.081	0.055	1.48	0.139	1.084
Constant	0.264	0.698	0.38	0.706	1.302

KAB Pedestrian Crashes, Intersection (n=489)

	Coef.	Std. Err.	z	p	Odds Ratio
AADT (000)	0.008	0.007	1.07	0.287	1.008
Lanes	0.092	0.099	0.92	0.355	1.096
Median Width (Ft)	0.041	0.012	3.51	0.000	1.042
Speed Limit (Mph)	-0.064	0.021	-3.14	0.002	0.938
Raised, Planted Median	-0.231	0.146	-1.58	0.114	0.794
Population Per Sq. Mi. (000)	0.083	0.030	2.80	0.005	1.087
Median HH income ($000)	-0.010	0.004	-2.44	0.015	0.990
Race Black (%)	0.008	0.003	2.47	0.014	1.008
Fast Food Restaurants	0.244	0.095	2.58	0.010	1.276
Community Shopping Centers	0.078	0.036	2.19	0.028	1.081
Groceries and Gas Stations	0.139	0.031	4.48	0.000	1.149
Bus Stops	0.092	0.065	1.42	0.154	1.096
Constant	0.049	0.791	0.06	0.951	1.050

KSI Pedestrian Crashes, Intersection (n=489)

	Coef.	Std. Err.	z	p	Odds Ratio
AADT (000)	0.010	0.011	0.88	0.376	1.010
Lanes	0.341	0.164	2.08	0.037	1.406
Median Width (Ft)	0.035	0.018	1.94	0.052	1.036
Speed Limit (Mph)	-0.082	0.032	-2.55	0.011	0.921
Raised, Planted Median	-0.560	0.225	-2.49	0.013	0.571
Population Per Sq. Mi. (000)	0.032	0.044	0.73	0.464	1.033
Median HH income ($000)	-0.011	0.006	-1.67	0.094	0.989
Race Black (%)	0.011	0.004	2.59	0.010	1.011
Fast Food Restaurants	0.257	0.135	1.91	0.057	1.293
Community Shopping Centers	0.064	0.039	1.65	0.099	1.066
Groceries and Gas Stations	0.141	0.046	3.09	0.002	1.151
Bus Stops	0.067	0.099	0.68	0.499	1.069
Constant	-1.226	1.243	-0.99	0.324	0.293

Pedestrian Crashes, Corridor Segment (n=334)

	Coef.	Std. Err.	z	p	Odds Ratio
Segment Length (Mi)	-0.001	0.351	0.00	0.997	0.999
AADT (000)	-0.008	0.008	-1.04	0.299	0.992
Lanes	0.038	0.105	0.36	0.716	1.039
Median Width (Ft)	0.012	0.014	0.81	0.418	1.012
Speed Limit (Mph)	-0.033	0.023	-1.44	0.149	0.968
Raised, Planted Median	-0.370	0.203	-1.82	0.068	0.691
Population Per Sq. Mi. (000)	0.080	0.038	2.12	0.034	1.083
Median HH income ($000)	-0.012	0.004	-2.98	0.003	0.988
Race Black (%)	0.002	0.004	0.43	0.668	1.002
Fast Food Restaurants	0.080	0.052	1.55	0.122	1.083
Community Shopping Centers	0.116	0.041	2.82	0.005	1.123
Groceries and Gas Stations	0.063	0.016	3.92	0.000	1.065
Bus Stops	0.058	0.030	1.93	0.053	1.060
Constant	1.097	0.902	1.22	0.224	2.995

KAB Pedestrian Crashes, Corridor Segment (n=334)

	Coef.	Std. Err.	z	p	Odds Ratio
Segment Length (Mi)	0.070	0.393	0.18	0.859	1.073
AADT (000)	-0.008	0.009	-0.85	0.396	0.992
Lanes	0.003	0.117	0.03	0.976	1.003
Median Width (Ft)	0.012	0.016	0.74	0.458	1.012
Speed Limit (Mph)	-0.021	0.026	-0.83	0.409	0.979
Raised, Planted Median	-0.406	0.229	-1.78	0.076	0.666
Population Per Sq. Mi. (000)	0.078	0.044	1.80	0.072	1.081
Median HH income ($000)	-0.007	0.004	-1.55	0.121	0.993
Race Black (%)	0.004	0.005	0.93	0.352	1.004
Fast Food Restaurants	0.101	0.058	1.72	0.085	1.106
Community Shopping Centers	0.061	0.047	1.28	0.200	1.063
Groceries and Gas Stations	0.061	0.019	3.26	0.001	1.063
Bus Stops	0.066	0.033	1.98	0.048	1.068
Constant	0.073	1.031	0.07	0.943	1.076

KSI Pedestrian Crashes, Corridor Segment (n=334)

	Coef.	Std. Err.	z	p	Odds Ratio
Segment Length (Mi)	0.302	0.465	0.65	0.516	1.353
AADT (000)	-0.016	0.011	-1.43	0.152	0.984
Lanes	0.185	0.147	1.26	0.208	1.203
Median Width (Ft)	0.018	0.021	0.88	0.380	1.018
Speed Limit (Mph)	-0.018	0.032	-0.57	0.566	0.982
Raised, Planted Median	-0.367	0.286	-1.28	0.200	0.693
Population Per Sq. Mi. (000)	0.089	0.053	1.67	0.096	1.093
Median HH income ($000)	-0.012	0.006	-2.11	0.035	0.988
Race Black (%)	0.003	0.006	0.54	0.586	1.003
Fast Food Restaurants	0.085	0.072	1.18	0.237	1.089
Community Shopping Centers	0.077	0.059	1.32	0.185	1.080
Groceries and Gas Stations	0.055	0.021	2.64	0.008	1.057
Bus Stops	0.052	0.040	1.28	0.200	1.053
Constant	-1.334	1.266	-1.05	0.292	0.263

APPENDIX D: BICYCLE-ONLY MODELS

Bicycle Crashes, Intersection (n=489)

	Coef.	Std. Err.	z	p	Odds Ratio
AADT (000)	-0.003	0.006	-0.47	0.638	0.997
Lanes	0.106	0.084	1.26	0.207	1.112
Median Width (Ft)	0.034	0.011	3.20	0.001	1.035
Speed Limit (Mph)	-0.037	0.018	-2.10	0.035	0.964
Raised, Planted Median	-0.539	0.138	-3.90	0.000	0.583
Population Per Sq. Mi. (000)	0.052	0.030	1.78	0.076	1.053
Median HH income ($000)	-0.007	0.003	-2.07	0.039	0.993
Race Black (%)	0.000	0.003	0.04	0.969	1.000
Fast Food Restaurants	0.222	0.088	2.52	0.012	1.249
Community Shopping Centers	0.033	0.029	1.13	0.260	1.034
Groceries and Gas Stations	0.049	0.031	1.61	0.108	1.050
Bus Stops	0.087	0.060	1.45	0.147	1.091
Constant	0.268	0.708	0.38	0.704	1.307

KAB Bicycle Crashes, Intersection (n=489)

	Coef.	Std. Err.	z	p	Odds Ratio
AADT (000)	-0.004	0.008	-0.45	0.652	0.996
Lanes	0.112	0.104	1.07	0.284	1.119
Median Width (Ft)	0.032	0.013	2.36	0.018	1.033
Speed Limit (Mph)	-0.040	0.023	-1.77	0.076	0.961
Raised, Planted Median	-0.570	0.180	-3.17	0.002	0.566
Population Per Sq. Mi. (000)	0.008	0.038	0.21	0.835	1.008
Median HH income ($000)	-0.009	0.004	-2.03	0.043	0.991
Race Black (%)	-0.003	0.004	-0.79	0.428	0.997
Fast Food Restaurants	0.082	0.113	0.73	0.468	1.085
Community Shopping Centers	0.028	0.038	0.73	0.466	1.028
Groceries and Gas Stations	0.030	0.038	0.80	0.424	1.030
Bus Stops	0.076	0.076	0.99	0.320	1.079
Constant	0.247	0.879	0.28	0.779	1.280

KSI Bicycle Crashes, Intersection (n=489)

	Coef.	Std. Err.	z	p	Odds Ratio
AADT (000)	-0.022	0.016	-1.44	0.151	0.978
Lanes	0.397	0.230	1.73	0.084	1.487
Median Width (Ft)	0.050	0.026	1.94	0.053	1.051
Speed Limit (Mph)	-0.047	0.041	-1.16	0.245	0.954
Raised, Planted Median	0.000	0.322	0.00	1.000	1.000
Population Per Sq. Mi. (000)	-0.031	0.076	-0.41	0.682	0.969
Median HH income ($000)	-0.016	0.008	-1.94	0.053	0.984
Race Black (%)	-0.013	0.008	-1.57	0.116	0.987
Fast Food Restaurants	0.484	0.179	2.70	0.007	1.623
Community Shopping Centers	-0.002	0.112	-0.02	0.988	0.998
Groceries and Gas Stations	-0.012	0.080	-0.15	0.880	0.988
Bus Stops	0.146	0.144	1.01	0.312	1.157
Constant	-1.723	1.776	-0.97	0.332	0.179

Bicycle Crashes, Corridor Segment (n=334)

	Coef.	Std. Err.	z	p	Odds Ratio
Segment Length (Mi)	0.067	0.323	0.21	0.835	1.069
AADT (000)	-0.006	0.007	-0.79	0.432	0.994
Lanes	-0.073	0.095	-0.77	0.441	0.930
Median Width (Ft)	0.036	0.013	2.78	0.006	1.037
Speed Limit (Mph)	-0.027	0.021	-1.33	0.184	0.973
Raised, Planted Median	-0.284	0.193	-1.47	0.140	0.753
Population Per Sq. Mi. (000)	0.112	0.037	3.07	0.002	1.119
Median HH income ($000)	-0.010	0.004	-2.70	0.007	0.990
Race Black (%)	-0.006	0.004	-1.50	0.134	0.994
Fast Food Restaurants	0.111	0.050	2.22	0.026	1.117
Community Shopping Centers	0.068	0.041	1.67	0.096	1.070
Groceries and Gas Stations	0.043	0.015	2.80	0.005	1.044
Bus Stops	0.064	0.028	2.27	0.023	1.066
Constant	0.709	0.850	0.83	0.404	2.032

KAB Bicycle Crashes, Corridor Segment (n=334)

	Coef.	Std. Err.	z	p	Odds Ratio
Segment Length (Mi)	-0.112	0.395	-0.28	0.777	0.894
AADT (000)	0.000	0.009	-0.02	0.982	1.000
Lanes	-0.121	0.114	-1.06	0.290	0.886
Median Width (Ft)	0.033	0.016	2.07	0.038	1.034
Speed Limit (Mph)	0.023	0.026	0.90	0.366	1.023
Raised, Planted Median	-0.321	0.235	-1.37	0.171	0.725
Population Per Sq. Mi. (000)	0.097	0.043	2.24	0.025	1.102
Median HH income ($000)	-0.006	0.004	-1.46	0.144	0.994
Race Black (%)	0.001	0.005	0.14	0.889	1.001
Fast Food Restaurants	0.079	0.062	1.29	0.197	1.082
Community Shopping Centers	0.094	0.044	2.12	0.034	1.099
Groceries and Gas Stations	0.049	0.017	2.79	0.005	1.050
Bus Stops	0.080	0.034	2.35	0.019	1.083
Constant	-2.314	1.066	-2.17	0.030	0.099

KSI Bicycle Crashes, Corridor Segment (n=334)

	Coef.	Std. Err.	z	p	Odds Ratio
Segment Length (Mi)	-0.033	0.572	-0.06	0.954	0.968
AADT (000)	-0.004	0.014	-0.30	0.764	0.996
Lanes	-0.092	0.171	-0.54	0.589	0.912
Median Width (Ft)	0.052	0.023	2.28	0.023	1.053
Speed Limit (Mph)	0.005	0.041	0.12	0.901	1.005
Raised, Planted Median	-0.631	0.336	-1.87	0.061	0.532
Population Per Sq. Mi. (000)	0.087	0.065	1.32	0.186	1.091
Median HH income ($000)	-0.015	0.007	-2.18	0.029	0.985
Race Black (%)	0.001	0.007	0.12	0.904	1.001
Fast Food Restaurants	-0.103	0.112	-0.92	0.358	0.902
Community Shopping Centers	0.151	0.066	2.29	0.022	1.163
Groceries and Gas Stations	0.042	0.024	1.73	0.084	1.043
Bus Stops	0.068	0.051	1.35	0.178	1.070
Constant	-2.096	1.630	-1.29	0.198	0.123