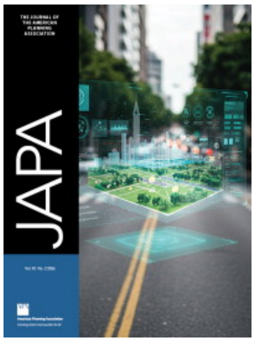

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Land Use and Road Safety: Understanding the Persistence of Vulnerable Road User Deaths and Injuries in the United States

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ABSTRACT

Problem, research strategy, and findings: Pedestrian and bicyclist deaths now account for nearly one in five traffic fatalities in the United States. They continue to rise even as peer nations have reduced deaths dramatically. We examined 222 miles of arterial highways in Florida to understand the nature of the unique risk confronted by vulnerable road users in the United States. We found that land use decisions—particularly the siting of groceries, pharmacies, gas stations, and fast-food outlets—are strongly associated with the death and injury of vulnerable road users. These *household-sustaining* uses generate exposure in locations fundamentally incompatible with vulnerable road user safety, activating latent hazards embedded into infrastructure design. We discuss in this article how land use practice differs from that of Europe, and how these differences explain the differences in safety outcomes. We conclude by developing tools for estimating the magnitude of this risk during the project development process and by outlining strategies for enhancing land use and transportation practices to better account for the land use–road safety connection.

Takeaway for practice: Meaningful progress toward Vision Zero in the United States requires acknowledging that land use decisions—not just street design—are a primary driver of the elevated risk faced by vulnerable road users. Development codes that encourage household-sustaining uses to locate along arterial corridors create predictable and preventable exposure in environments where safety is structurally unattainable without simultaneous changes to the street's design and function. Addressing this risk demands a shift in planning practice: revising zoning and site-planning standards to explicitly account for safety, redirecting high-risk uses away from arterial corridors, and applying analytic tools that identify and mitigate latent land use hazards during the planning and project development process.

KEYWORDS
Land use; zoning; pedestrian risk; road safety; urban arterials

For much of the developed world, Vision Zero programs have been enormously successful in reducing traffic-related deaths and injuries. These approaches begin from the perspective that humans are fallible, and seek to ensure that the transportation system is designed for its most vulnerable users on urban streets: pedestrians and bicyclists. Between 2000 and 2020, Sweden reported a 65% reduction in traffic fatalities, and a 64% reduction of deaths involving vulnerable road users (VRUs). The Netherlands, which pioneered the Sustainable Safety movement in 1993, saw traffic fatalities decline by half during this period (International Transport Forum, n.d.).

Vision Zero efforts in the United States have been less successful. Traffic fatalities in the United States are roughly the same today as they were in 2000, with roughly 40,000 people killed each year in motor vehicle crashes. While the absolute numbers remain relatively unchanged, the composition of these crashes has changed dramatically. Far from being safer for vulnerable road users, the number of pedestrians and bicyclists killed each year has increased by 68%. Pedestrians and bicyclists now comprise one out of every five persons killed in a traffic crash (Insurance Institute for Highway Safety, 2024); pedestrians and bicyclists are 30 times more likely to be killed on a per-mile-traveled basis than motorists (National Highway Traffic Safety Administration, 2023; League of American Bicyclists, 2024).

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It is tempting to attribute these differences to the manner in which Vision Zero is implemented in the United States. Unlike Sweden and the Netherlands, which address road safety through national programs, Vision Zero in the United States is typically adopted and implemented by local governments. Of the more than 50 jurisdictions that have adopted Vision Zero programs, only New York has reported a net reduction in deaths and injuries (Zipper, 2022). Yet the absence of national policy alone cannot explain these differences. The United Kingdom also lacks a national Vision Zero program: London first adopted Vision Zero as a policy goal in 2018, four years after its adoption in New York. Nonetheless, the United Kingdom has seen a 57% reduction in traffic fatalities during the same time period (International Transport Forum, n.d.).

Differences in design practices are another possible explanation. Research on road safety in the United States has consistently found that the deaths and injuries affecting vulnerable road users overwhelmingly occur on arterial thoroughfares, leading to the conclusion that it is the design characteristics of arterial streets, which include higher vehicle speeds and wider travel lanes, that are responsible for this phenomenon (Dumbaugh & Li, 2010; Dumbaugh & Stiles, 2025; Ewing & Dumbaugh, 2009; Marohn, 2021; Schneider, 2020; Stoker et al., 2015). While this explanation is at least partially correct, we believe it greatly oversimplifies the issue. The same street design practices used throughout Europe to address the needs of vulnerable users have also been widely adopted throughout the United States, even if they are not as consistently applied (Dumbaugh & King, 2018). As we detail in this article, it is not street design alone, but rather the unique nature of land use planning in the United States that is responsible for the heightened risk experienced by vulnerable users on its streets. We tested this assertion using a combination negative binomial regression analysis and field investigations, and proceed to discuss the implications of these findings for practice.

Land Use and Street Design

The European approach to street design begins with an express consideration of land use. While street classification schemes vary from country to country, they all entail an explicit effort to relate street design to the characteristics of the surrounding environment. In the case of the United Kingdom, roadside development is prohibited or severely restricted on motorways and primary routes, the equivalent of freeways and major arterials in the United States. For lower-order routes, streets are examined considering their movement and *place* functions, prioritizing vulnerable users in areas with adjacent roadside development (Department for Transport, 2007). In Germany, land use directs street design practice, with a streets traffic function tied directly to whether there is adjacent development on the corridor now or in the future. These are tied to target speeds, which are capped at 50 km/h (31 mph) in urban areas without roadside development, and 30 km/h (18 mph) in areas with roadside development. In urban areas, principal arterials and their operating speeds are explicitly classified as being *very problematic* or not justifiable (Road and Transport Research Association, 2006, 2008).

This approach emerged in Europe, in large part, because European design practice was focused principally on integrating the automobile into older, pre-automobile development forms. Since 1950, the population of Germany has only increased by 22%, and the population of the United Kingdom has increased by only about a third. In absolute numbers, their population growth is also comparatively low, with their total populations increasing by only 14 million and 17 million people, respectively. This means that most of their residents live in environments initially designed around pedestrian travel,[1] and that the resulting street design practices that emerged were centered on integrating automobiles safely into prewar, pedestrian-centered development forms rather than new developments centered on the automobile.

This is markedly different than the developmental conditions that occurred in the United States. Unlike Europe, which has experienced only moderate population growth, the United States has added 180 million new people since 1950, a population increase of 120%. This has allowed planners and urban designers to fundamentally reshape urban form in response to the automobile. Influential early planners in the United States, such as Charles Mumford Robinson (1916) and Frederick Law Olmsted, Jr. (1916) called for redesigning urban streets according to their specific traffic functions, with higher-order streets designed specifically to accommodate automobile use. This resulted in the U.S. practice of defining streets according to their *functional classification*, creating the arterial-collector-local designations that continue to be used

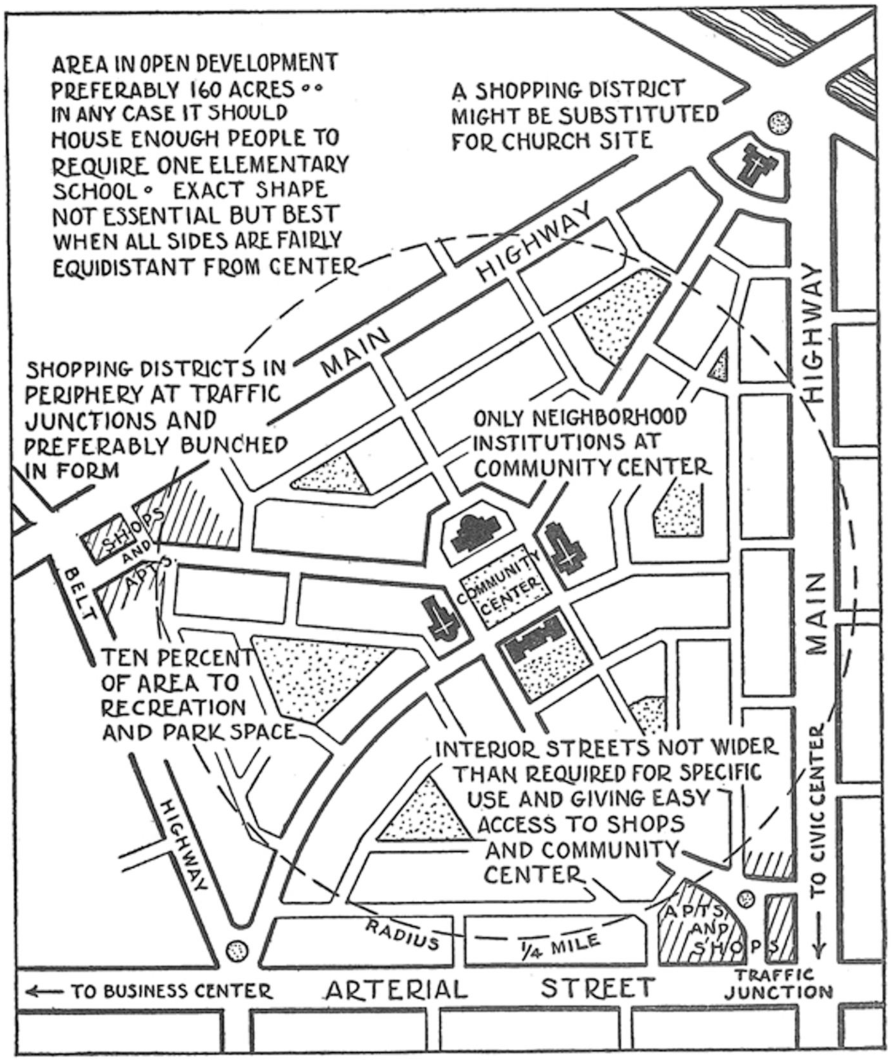

Figure 1. The design basis for arterial-oriented commercial uses. Source: Clarence Perry (1929). Public domain.

today (American Association of State Highway and Transportation Officials, 2018). These ideas were disseminated throughout the planning profession through seminal works such as John Nolen's *City Planning* (Nolen, 1916) and the 1929 Regional Plan for New York.

Beyond simply developing new classes of streets, planners and urban designers in the United States further sought to reconfigure land uses as well. Clarence Perry imported the English garden suburb concept to the United States and reconfigured it for the automobile, resulting in the neighborhood unit concept (Perry, 1929). The neighborhood unit not only embedded the functional classification system into community design practice in the United States, but it also promoted the relocation of household-supporting retail and commercial uses outside of communities, and onto the automobile-oriented arterial highways that surround them (see Figure 1).[2] The neighborhood unit concept, along with prescription for arterial-oriented commercial uses, was adopted by the Federal Housing Administration (1936) and used in the development of the mortgage underwriting programs and land development codes that have shaped nearly all of the postwar development that occurred in the United States.

Collectively, this formed the basis for "suburbia" (Levine, 2006),[3] with the Urban Land Institute (2016) estimating that nearly 80% of the persons residing in metropolitan areas in the United States live in suburban environments, nearly all of which follow some variant of the neighborhood-unit model. This development pattern and the corresponding land use configurations are so embedded into U.S. land development practice that most grocery, restaurant, and pharmacy chains have made locating on an arterial with traffic volumes of 20,000 vehicles per day or greater a core feature of their site selection process (International Council of Shopping Centers,

Table 1. State highways examined in this study.

Metro area	Route no.	Alternate names/designations	Intersections		Corridor segments	
			Count	Length (miles)	Count	Length (miles)
Tampa–St. Pete	SR-55	US 19, 34th St.	56	5.3	38	30.2
	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.	57	5.4	38	26.8
	SR-580	Dale Mabry Hwy., West Busch Blvd.	48	4.5	37	20.4
Orlando	SR-50	Colonial Drive	58	3.3	38	19.3
	SR-600	Orange Blossom Trail, Mills Ave. Orlando Ave., US 17, US 441	53	5	26	10.3
Miami–Fort Lauderdale–West Palm Beach	SR-816	Oakland Park Blvd.	33	3.1	22	8.1
	SR-817	University Dr.	52	4.9	40	16.2
	SR-838	Sunrise Blvd.	36	3.4	22	8.8
	SR-809	Military Trail	77	7.3	61	32.6
	SR-802	Lake Worth Rd.	19	1.8	12	5.4
Total			489	44	334	178.1

2023). As we argue below, land use is playing a critical and unrecognized role in the negative safety outcomes experienced by pedestrians and bicyclists in the United States.

Examining the Role of Land Use on the Safety of Vulnerable Road Users

To understand the role of land use on the injury and death of vulnerable road users, we examined urban arterial thoroughfares in the state of Florida. Our dependent variable is KAB crashes involving pedestrian and bicyclists, which includes fatalities (K), incapacitating injuries (A), and non-incapacitating injuries (B).

Using satellite imagery and data supplied by the Florida Department of Transportation (FDOT), we selected 10 urban arterial highways from the Miami, Orlando, and Tampa regions, all of which have adopted Vision Zero targets at the regional, county, and local levels.[4] To account for environmental differences in crash risk at corridors and major intersections, we divided these data into major intersections and corridor segments. Major intersections are defined by the presence of a traffic signal and includes the area within 250 ft on either side of the intersection, which is the typical distance at which a traffic signal influences traffic operation, a distance referred to in engineering analyses as the *intersection area of influence*. Corridor segments are simply length of roadway between these intersection locations. Because of their unique characteristics, we eliminated corridor segments that contained highway ramps and overpasses. We also eliminated segments that were less than 0.2 mile in length to prevent the characteristics of nearby intersections from influencing corridor-level performance.

To carry out this ruleset, we visually examined each route through a specially prepared interface that 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 that 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 data set containing information for 334 corridor segments and 489 intersections, shown in Table 1 below.

Database, Variable, and Model Development

With these definitions of corridor segments and intersections, we proceeded to develop a data set containing information on street design characteristics, census information, land use, and crash data. Street design information was obtained from the FDOT Roadway Characteristics Inventory, which 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. In cases where a segment crossed multiple sections with different values for a given variable, weighted averages were used based on the proportion of the segment within each value.

This method of weighting was used for numeric variables including AADT, lanes, speed limit, and various widths. For the categorical variable of

Table 2. Crashes involving vulnerable users, 2017–2020.

	Corridor	Intersection	Total
Total	811	1,056	1,867
Fatal	78	40	118
KSI	213	192	405
KAB	486	581	1,067

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 U.S. Census 2018 American Community Survey 5-year estimates at the block group unit of geography. Because we were interested in characteristics of the immediate surrounding area, our scripting first added a buffer of 250 ft to each segment and then calculated 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.

Land use data for this analysis use 2018 parcel data from the Florida Department of Revenue (DOR). This data set 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 added a buffer of 250 ft for each segment and then tallied 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 these 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*. Pharmacies and convenience stores, which sell food goods, were often likewise clustered into these variables. To overcome these differences, we generated a combined variable of *Groceries and Convenience Stores* that includes groceries, pharmacies, gas stations, and convenience stores.

Finally, we collected geolocated information on pedestrian and bicycle crashes from Signal 4 Analytics for the 2017 to 2020 period and spatially assigned to the corridor segments and intersections, shown in Table 2. Because our dependent variable was overdispersed (i.e., had a variance that was greater than the mean), we used negative binomial models to examine the effects of site characteristics on KAB crashes involving vulnerable users. While we obtained information on total, injurious, and fatal crashes, this study focuses on KAB crashes involving pedestrians and bicyclists, with KAB crashes defined as crashes involving a fatality (K), incapacitating injury (A), or non-incapacitating injury (B). We also examined KSI crashes, which entail a fatality (K) or incapacitating severe injury (SI). For brevity, we include only KAB crashes in the following analysis.

Table 3. Descriptives for intersection-level variables.

	Min.	Max.	Mean	*SD*
AADT (000s)	5.60	85.60	41.42	13.31
No. lanes	1.86	8	5.58	1.04
Median width (ft)	0	60	22.51	8.06
Speed limit (mph)	25	55	43.09	5.11
% sidewalk coverage	0	100	93.46	19.34
Population per sq. mi. (000s)	0.32	16.40	4.50	2.34
Median household income (000s)	18.82	173.73	59.20	24.24
# Groceries and convenience stores	0	16	2.23	2.08
# Commercial shopping centers	0	33	0.40	1.62
# Fast food restaurants	0	3	0.31	0.65
# Restaurants	0	4	0.27	0.58
# Bars	0	1	0.02	0.14
# Offices	0	121	1.76	7.03
# Department stores	0	2	0.05	0.24
# Banks and insurance companies	0	3	0.27	0.58
# Mixed use buildings	0	56	0.40	2.77
# Parks and recreational facilities	0	4	0.10	0.41
# Schools	0	2	0.11	0.35

A route-level fixed effects variable was included to control for unobserved heterogeneity across corridors and metropolitan areas, incorporating population-level and contextual differences such as enforcement practices, reporting standards, or other unmeasured influences on crash frequency. Robust standard errors were clustered by route to account for potential within-corridor correlation among observations. Model coefficients for significant variables are exponentiated and reported as incident rate ratios (IRRs), representing the proportional change in expected crash frequency associated with a one-unit change in each explanatory variable.

Major Intersections

Descriptive statistics for variables examined in the model are shown, detailed in Table 3, below. We tested a variety of land use variables as part of these analyses, though most proved to have little statistically meaningful relationship with road safety outcomes and were dropped from the final models.

Table 4 presents the model results. Areas with higher population densities, which correspond to higher levels of trip generation, reported higher numbers of KAB VRU crashes. Of the land use variables tested, two entered the model: groceries and convenience stores, which are the neighborhood-supporting uses detailed by Clarence Perry, and fast-food restaurants, which are a natural byproduct

Table 4. Model of KAB crashes involving vulnerable users at intersections.

	Coef.	Clustered SE	z	*P* > z	IRR
AADT (000s)	0.000	0.008	−0.040	0.966	
No. lanes	0.043	0.105	0.410	0.680	
Median width (ft)	0.031	0.011	2.730	0.006	1.032
Speed limit (mph)	−0.066	0.020	−3.200	0.001	0.937
% sidewalk coverage	0.001	0.002	0.460	0.646	
Pop sq. mi. (000s)	0.098	0.023	4.340	0.000	1.103
Median household income (000s)	−0.008	0.003	−2.410	0.016	0.992
# Groceries and convenience	0.102	0.030	3.380	0.001	1.107
# Fast food	0.221	0.058	3.840	0.000	1.248
Route fixed effects					
SR 595 (Reference)					
SR 50	0.211	0.196	1.070	0.283	
SR 802	−0.019	0.112	−0.170	0.868	
SR-809	−0.006	0.075	−0.090	0.932	
SR-816	−0.143	0.144	−1.000	0.319	
SR 55	0.361	0.160	2.260	0.024	1.435
SR 580	0.291	0.187	1.550	0.120	
SR 600	−0.679	0.074	−9.190	0.000	0.507
SR 838	0.285	0.112	2.530	0.011	1.329
SR 817	−0.061	0.220	−0.280	0.781	
Constant	1.558	0.637	2.440	0.015	

of the neighborhood scheme. The effects of these variables are notable. Each grocery or pharmacy was associated with a 10.7% increase in KAB crashes involving VRUs, each fast-food restaurant was associated with a 25% increase.

Of the street design variables, only two proved to be significantly associated with the incidence of fatal and injurious crashes involving vulnerable users. Higher vehicle speeds were associated with significantly *fewer* of these crash types, while wider medians were associated more. This should not be interpreted as meaning that places with higher speed limits are safer. Higher speed limits are applied in areas that are access controlled, or which lack adjacent roadside development. While wider medians are generally thought of as a pedestrian safety feature on arterials, this did not prove to be the case at intersections, where they are associated with the presence of left turn lanes, which introduce traffic conflicts for crossing pedestrians and introduce additional VRU crossing conflicts.

Corridor Segments

The model for corridor segments used the same variables as that for major intersections, though we added two control variables. First, because segments were divided at major signalized intersections, they had some variation in length. Correspondingly, segment length was included as a control variable. Next, some corridor segments had minor, unsignalized intersections along their length. As the presence of unsignalized intersections may affect the segment's crash characteristics, we included the number of unsignalized intersections into the models as well. Descriptive statistics for these variables are shown in Table 5.

Table 5. Corridor-level descriptive statistics.

	Min.	Max.	Mean	*SD*
Segment length (miles)	0.2	2.60	0.53	0.32
AADT (000s)	7.06	85.50	41.79	13.86
No. lanes	2.00	8	5.63	1.06
Median width (ft)	0	60	22.47	7.88
Speed limit (mph)	28	55	44.28	5.08
No. intersections	0	32	7.40	5.94
% sidewalk coverage	0	100	92.45	20.14
Population per sq. mi. (000s)	0.33	13.93	4.36	2.36
Median household income (000s)	18.04	169.50	61.48	25.79
# Groceries and convenience stores	0	43	5.62	5.68
# Commercial shopping centers	0	17	0.76	1.67
# Fast food restaurants	0	8	0.84	1.35
# Restaurants	0	10	0.98	1.53
# Bars	0	4	0.14	0.50
# Offices	0	127	6.64	13.20
# Department stores	0	2	0.14	0.41
# Banks and insurance companies	0	6	0.52	0.90
# Mixed use buildings	0	90	1.19	5.52
# Parks and recreational facilities	0	14	0.27	1.16
# Schools	0	5	0.30	0.65
Segment length (miles)	0.20	2.60	0.53	0.324
# Intersections	0	32	7.40	5.94

The model for corridor segments is presented in Table 6. Longer segments and segments with higher populations densities report more VRU KAB crashes. Segments with more intersections, which create traffic conflicts with pedestrians, were associated with more KAB crashes. Of the street design variables, only the percentage of sidewalk coverage proved to have a statistically meaningful relationship with KAB crashes involving vulnerable users, though the variable entered the model positively, indicating that higher proportions of sidewalk coverage are associated with more KAB crashes involving vulnerable users. This is to be expected. Sidewalks are present in more urbanized locations, which have higher pedestrian volumes (Merlin et al., 2020). Wider medians, which were identified as a risk factor for intersections, are generally associated with fewer VRU crashes here, consistent with their function as pedestrian buffers. Each grocery and convenience store was associated with a 4.7% increase in KAB crashes, and each fast-food restaurant associated with a 5.9% increase.

Understanding the Relationship Between Land Use and Road Safety

While high vehicle speeds and heavy traffic volumes can certainly be problematic for pedestrians, these

Table 6. Model of KAB crashes.

	Coef.	Clustered SE	z	P > z	IRR
Segment length	0.272	0.114	2.390	0.017	1.313
AADT (000s)	−0.009	0.008	−1.210	0.226	
No. lanes	−0.003	0.076	−0.040	0.969	
Median width (ft)	−0.016	0.009	−1.840	0.066	0.984
Speed limit (mph)	−0.016	0.035	−0.460	0.644	
No. intersections	0.044	0.010	4.490	0.000	1.045
% sidewalk coverage	0.011	0.003	3.910	0.000	1.011
Population per sq. mi. (000s)	0.154	0.026	5.970	0.000	1.166
Median household income (000s)	0.001	0.002	0.220	0.828	
# Groceries and convenience	0.046	0.009	5.290	0.000	1.047
# Fast food	0.058	0.029	2.010	0.045	1.059
Route fixed effects					
SR 595 (Reference)					
SR 50	1.286	0.214	6.010	0.000	3.618
SR 802	−0.256	0.091	−2.820	0.005	0.774
SR 809	−0.576	0.139	−4.150	0.000	0.562
SR 816	−0.947	0.117	−8.060	0.000	0.388
SR 55	0.483	0.246	1.960	0.050	1.621
SR 580	0.370	0.152	2.440	0.015	1.448
SR 600	−0.513	0.159	−3.230	0.001	0.598
SR 838	0.362	0.130	2.780	0.005	1.436
SR 817	−0.625	0.165	−3.790	0.000	0.535
Constant	−0.979	1.666	−0.590	0.557	

models show that it is not these features alone that are responsible for the crash risk experienced by vulnerable road users. While these features may be hazardous to pedestrians and bicyclists, in the absence of destination attractions drawing vulnerable road users to these locations, these hazards remain *latent* and *unexpressed*.

It is land use that draws pedestrians and bicyclists to these locations and makes these hazards manifest. The land uses of specific concern are those that provide access to everyday household needs—groceries, convenience stores, pharmacies, fast-food restaurants—which we refer to as *household-sustaining uses* for the remainder of this article. The role that these uses play in activating the latent hazards can be readily evidenced through a real-world illustration. In the top left image of Figure 2, we have a perfectly unremarkable rural highway located on the edge of the Orlando Metropolitan region, one that would be largely indistinguishable from its European counterparts. Yet fast-forward 5 years, and the development planned and approved by the local planning department has changed the entire context, use, and operation of this road, even though the street's geometry has remained entirely unchanged. The addition of household-sustaining uses, rather than changes to street design, have transformed it from a rural highway into a destination for vulnerable road users, one that presently kills or maims three pedestrians and bicyclists every year. Thus, while arterials may be inherently dangerous for pedestrians and bicyclists, it is land use decisions that are translating these latent hazards into deaths and injuries.

To confirm this interpretation of the model results, we further conducted field investigations and safety audits of the 50 most hazardous intersections and 25 most hazardous corridor segments. Two major findings emerged from this effort. The first was that, for high-crash intersections, defined as those experiencing two more KSI (killed or severely injured) crashes or five or more KAB crashes, one or more of these *high-risk uses* were always present, with 38 of the 50 specifically having a grocery or big box store, such as Walmart or Target, serving as an anchor. When considered at the corridor level, the distribution of crashes involving vulnerable road users, as illustrated in Figure 3, tended to follow the shortest network path between lower-income communities and household-supporting retail attractions or, in other words, between the origin and destination ends of utilitarian trips.

Advancing Road Safety in the United States

Logically, there are two approaches for addressing this safety problem. The first is to redesign arterials to be more accommodating to vulnerable road users by reducing speeds, eliminating vehicle lanes, and relocating traffic. The problem with this approach, however, is that there are 178,000 miles of urban arterial streets in the United States (Federal Highway Administration, 2024), an extent that is more than three times the length of the nation's Interstate Highway System. While it may not be necessary to redesign the entirety of this system, the redesign of even a small fraction of it is a major enterprise, one that would require a dramatic reallocation of capital resources and fundamental realignment of political will.

The second approach is to reconsider land use.

Nearly all conventional transportation planning practice is centered on the idea that travel is a derived demand. Land use establishes trip origins and destinations. This understanding underpins regional transportation planning (Hayse, 2009) travel demand modeling (Niemeier & Bai, 2009), and traffic impact analysis (Institute of Transportation Engineers, 2010). Yet this understanding is curiously absent in discussions of road safety. Nonetheless, land use determines trip origins and attractions for

Figure 2. U.S. 441 in St. Cloud (FL). 1999 (top left), 2005 (top right), and present (bottom). Source: Google Earth, author.

pedestrians (Turner et al., 1998), resulting in trips being assigned to the transportation network. These trips are not in themselves hazardous. They become hazardous when these land uses are in locations that draw road users to unsafe locations which, for the purposes of this article, are arterial thoroughfares. Thus, while street design certainly matters, the thoughtful location of households and household-supporting land uses can prevent pedestrians and bicyclists traveling along unsafe facilities in the first place (see Figure 4).

Land use creates exposure. Indeed, land use is used to predict rates of trip generation, with the Institute of Transportation Engineers' (2017) *Trip Generation Manual* presenting bivariate regression equations for estimating such travel demand measures such as daily and peak-period trip generation. Understanding VRU crashes as a function of land use allows similar predictive tools to be developed from the results of this study, predictive tools than can be similarly used to estimate crash exposure and can, in turn, inform the development of land use plans, regional transportation plans, development proposals, and traffic impact analyses.

Figure 5 shows the relationship between KAB crashes at major intersections and the number of household-sustaining uses. The relationship is perfectly linear, significant to the 0.005 level, and explains 83% of the observed variation along the arterial highways examined in this study. To conduct a similar prediction tool for KAB pedestrian and bicycle crashes at the corridor level, we regressed the number of KAB crashes per mile against the number of household-sustaining uses per mile. The results are significant at the 0.000 level, explaining 88% of the observed variation (see Figure 6).

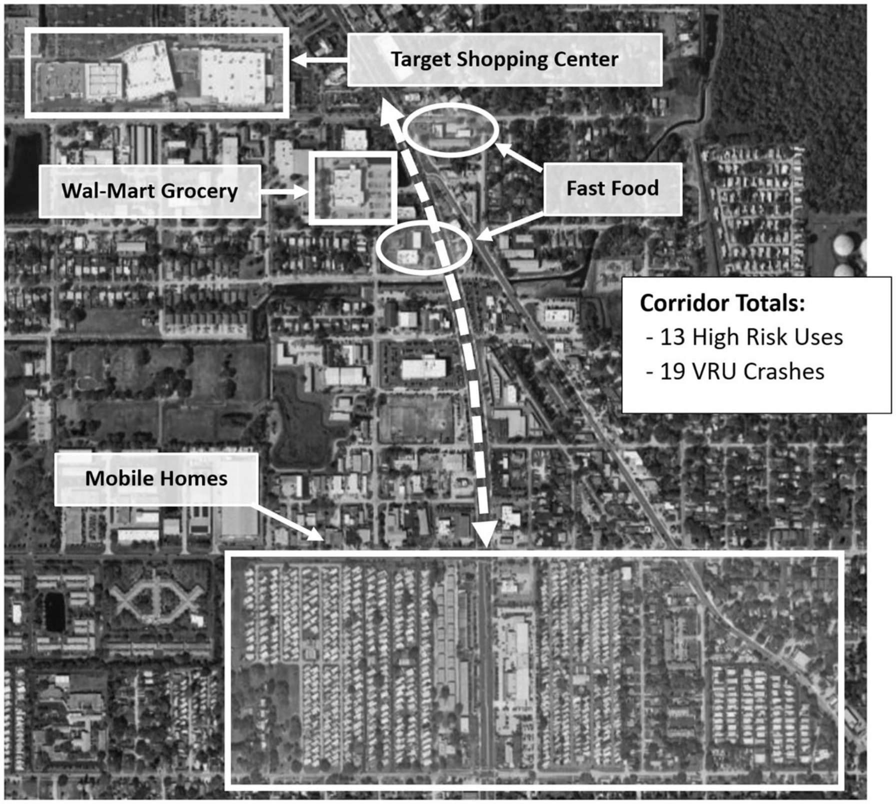

Figure 3. How land use patterns result in exposure and crash risk. Image source: Google Earth.

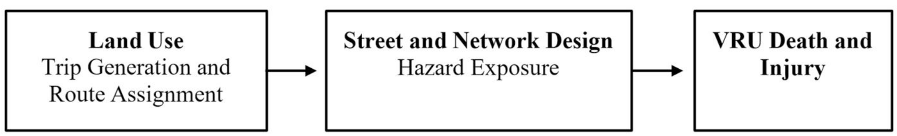

Figure 4. Land use, exposure, and safety outcomes.

Relocating Household-Sustaining Uses

It is not sufficient to simply advocate for the elimination of household-sustaining uses from multilane arterials, however. These uses must be located somewhere, raising a second relevant question: Does the removal of these uses from arterials actually enhance safety, or does it simply transfer the safety problem from one location to another?

To understand the effects of reconfiguring and relocating these uses, we identified seven walkable commercial street segments in the four metropolitan areas examined in this study. While designated as arterials, these are all two-lane streets with traditional site configurations, similar to English high streets and their European counterparts. These include street-oriented buildings, parallel on-street parking, and supplemental parking using rear lots, garages, and public parking lots (see Figure 7). As shown in Table 7, these 1.9 miles of urban commercial streets[5] reported seven injurious crashes involving vulnerable users during the 4-year study period, and one serious injury. Converted into statistics that can be compared against those presented in Figure 8, these street segments averaged 95 household-supporting uses per mile, more than any of the arterial segments considered in this analysis. They nonetheless reported only 0.9 injurious crashes per mile per year, a 38% reduction over the 30+ risk use category.

The potential benefit of relocating these uses becomes even more evident when one considers severe crashes. There were no fatalities involving a vulnerable user on these streets, and only a single incapacitating crash, translating to only 0.13 incapacitating crashes per mile, per year. Table 8, below, shows the difference in KSI crashes for conventional arterial segments against the average for walkable streets. To facilitate interpretation, we present both the percentage of the difference between the walkable and conventional locations, as well as the

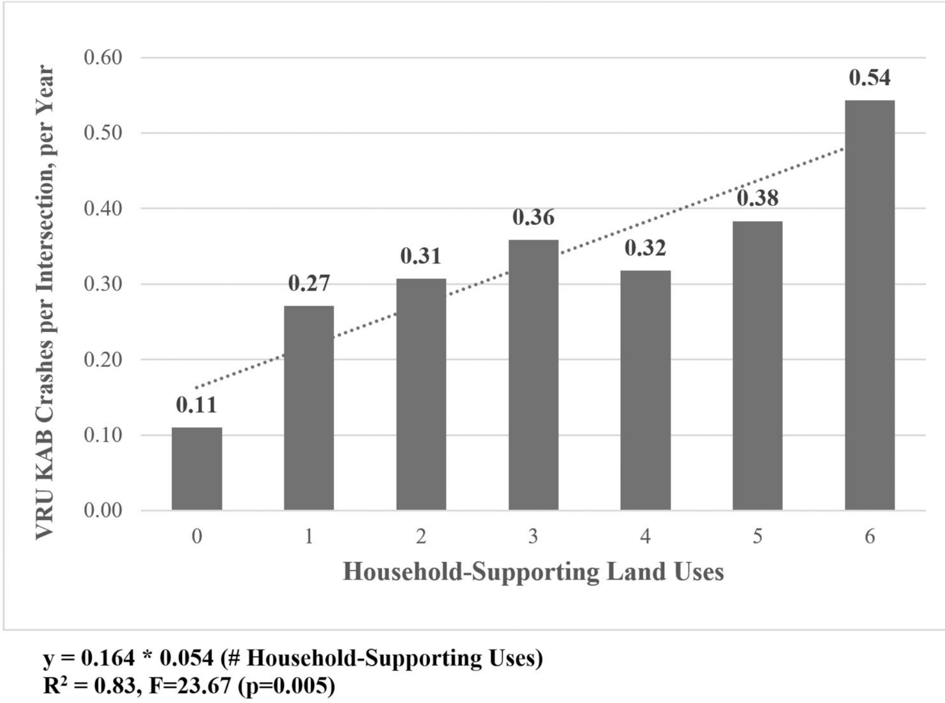

Figure 5. Average KAB pedestrian and bicycle crashes per intersection, per year, by the number of household-supporting land uses.

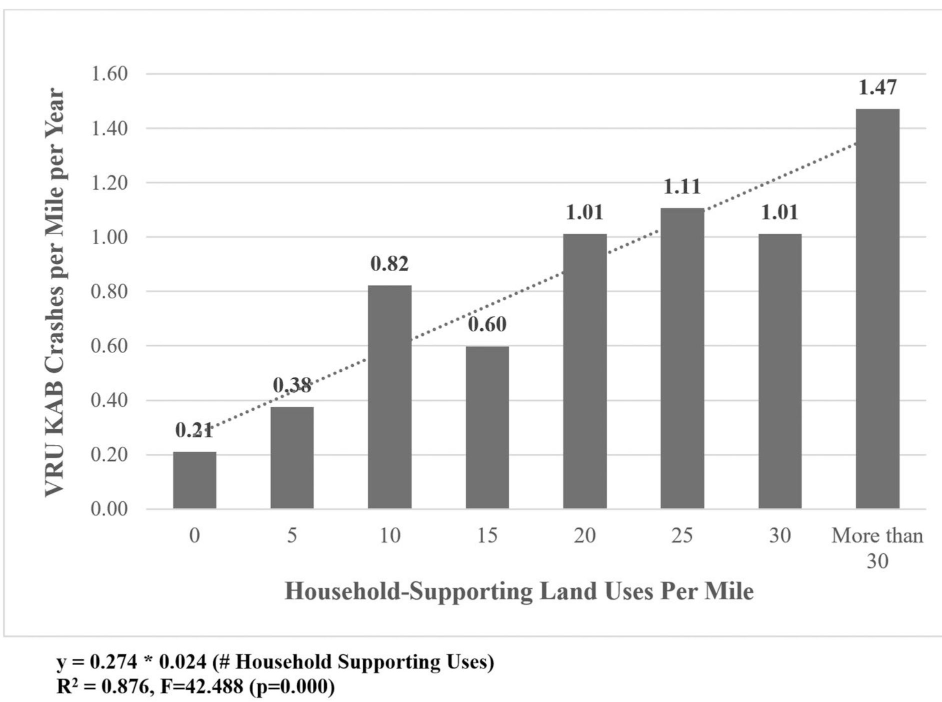

Figure 6. Average KAB pedestrian and bicycle crashes per mile, per year along corridor segments, by the number of household-sustaining land uses per mile, per year.

magnitude of the crash reduction expected if the uses were relocated to a walkable environment. The differences are staggering. The walkable locations outperformed every conventional arterial segment other than those where household-supporting uses are entirely absent. They greatly outperformed those with large concentrations of such uses, with an 80% fewer KSI crashes occurring on the walkable segments. Given that most fatal crashes involving vulnerable users occur on urban arterials

Figure 7. Household-supporting uses along lower-volume, urban streets. Clockwise from top left: Cleveland Street, Tarpon Avenue, Atlantic Avenue, Las Olas Boulevard. Image source: author.

Table 7. Crashes involving vulnerable users on urban street sections, 2017–2020.

	Length (miles)	Risk uses	Vulnerable user crashes	
Name			KSI	KAB
Atlantic Avenue, Delray Beach	0.28	32	1	3
Cleveland Street (Main), Clearwater	0.28	42	0	0
Cleveland Street (Urban), Clearwater	0.41	5	0	0
Lake Avenue, Lake Worth	0.21	47	0	0
Las Olas Boulevard (Main)	0.31	16	0	0
Las Olas Boulevard (Village)	0.18	19	0	0
E. Tarpon Avenue, Tarpon Springs	0.24	21	0	0
Total	**1.91**	**182**	**1**	**3**

(Governor's Highway Safety Association, 2024), and that nearly every pedestrian crash hot spot in the United States occurs on multilane arterials lined with commercial uses (Schneider et al., 2021), changes to local land use policies that result in the relocation of these uses to walkable environments promise to have a more profound effect on reducing the death and injury of vulnerable road users than any other countermeasure available.

Finally, we should observe that the comparatively low frequency of crashes occurring on these streets should not be used to imply that such urban configurations are the only way VRU safety can be achieved. Dumbaugh and Rae (2009), for example, found that the reconfiguration of a conventional suburban strip center anchored by groceries and department stores can have a profound effect on reducing crash incidence (see Figure 8). Instead, it is our hope that these findings encourage planners to adopt more safety-centered approaches to land development codes and site planning processes.

Conclusion: Using Land Use Planning to Address the Safety of Vulnerable Road Users

Vision Zero begins with a simple but powerful premise: No loss of life on the transportation system is acceptable. Despite the ambitious nature of this goal, the United States has made little meaningful progress toward its realization. In this article, we have sought to demonstrate that land use decisions play a profound and largely unacknowledged role in the death and injury of vulnerable road users. Through the adoption of zoning ordinances that locate household-supporting land uses such as groceries, fast food, pharmacies, and convenience stores along arterials, U.S. planning practice continues to place essential household destinations in environments that are

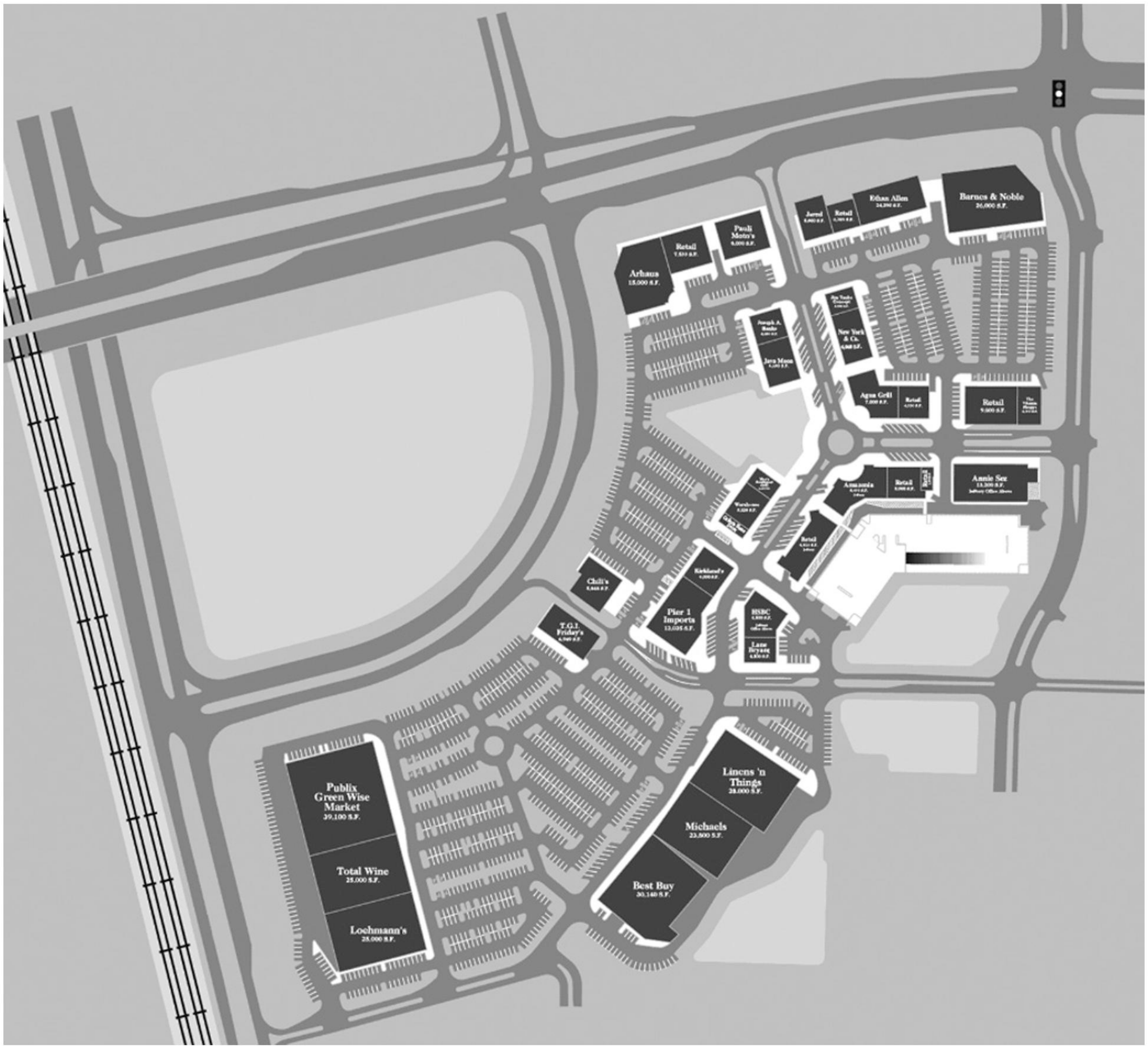

Figure 8. Commercial plaza reconfigured away from arterial highways. Source: Dumbaugh & Rae (2009).

Table 8. Change in KSI crashes involving vulnerable users per mile, per year: Conventional arterial versus walkable street.

High-risk uses per mile	KSI per mile, per year: conventional arterial	% Difference from walkable baseline (0.13 mile/year)	Estimated % KSI reduction if shifted to a walkable configuration
0	0.05	−62%	—
0.01–4.99	0.17	31%	−24%
5–9.99	0.24	85%	−46%
10–14.99	0.26	100%	−50%
15–19.99	0.6	362%	−78%
20–24.99	0.45	246%	−71%
25–29.99	0.27	108%	−52%
>30	0.65	400%	−80%

structurally incompatible with pedestrian and bicycle safety. In doing so, it systematically activates the latent risks inherent to arterial design, leading to the persistently high fatality rates that distinguish U.S. safety outcomes from those in Sweden, Germany, and the United Kingdom, countries that actively prohibit such practices.

Conventional Vision Zero countermeasures have proven insufficient, in part because they address problems occurring at the edges of the system, such as speed and street design. Programs that leave hazardous development patterns intact—or which encourage their continued reproduction—are unlikely to yield meaningful safety improvements.

Road safety for vulnerable users must therefore be understood not merely as a function of street geometry or user behavior, but as a spatial outcome of transportation and land development configurations.

Understanding road safety as a land use problem opens exciting new paths for reducing the death and injury of vulnerable users. Unlike arterial reconstruction projects, which are capital intensive and reactive in nature, land use–oriented strategies have the potential to leverage existing market dynamics and policy levers. At present, retail zones are greatly oversupplied in the United States and the market for these uses is softening (Brooks & Meltzer, 2024). Moreover, much of the construction that comprises arterial-oriented retail has a functional life of only about 20 years (Dunham-Jones & Williamson, 2011). These create unique opportunities for repurposing or eliminating older, arterial-oriented commercial uses and the latent hazards they create. Doing so will require the creative use of zoning ordinances, overlay districts, and traffic impact analyses to prevent the reestablishment of these uses at hazardous locations, as well as the modification of land use plans to ensure that local area residents are able to safely access household-supporting destinations in the future.

If the United States is to make genuine progress toward zero deaths, land use planning must be recognized not simply as a peripheral concern, but as the foundation of creating a truly safe system. This demands active collaboration: Land use planners must develop codes that anticipate travel patterns and their associated safety outcomes, elected officials must align land development policies with Vision Zero goals, and land developers[6] need to be treated as partners in the creation of safe environments. We thus conclude with the hope that a broader understanding of crash risk will allow the United States to begin to meaningfully move toward zero deaths and injuries.

Notes

1. While large sections of these countries were rebuilt following World War II, most of the reconstruction followed prewar development patterns, mirroring the initial street dimensions and building densities that existed prior to the war. In the limited areas where new development forms were adopted, they tended to entail higher-density modernist developments, typically over the existing street network, resulting in a more urban development framework than that found in the United States (Diefendorf, 1993; Hasegawa, 1992).
2. Clarence Perry was not especially concerned about the safety effects of this practice on pedestrians, stating that "shoppers on foot will not be so much bothered, since they will stream across the street anyway, often with the protection of a traffic light" (Perry, 1939, p. 71).
3. Clarence Stein provided the safety basis for this approach through his design for Radburn, asserting that relocating retail and commercial uses to the adjacent arterials would remove this traffic from residential areas, thereby enhancing pedestrian safety (Larsen, 2016).
4. These include both Vision Zero plans and targets for Broward County, Hillsborough County, Miami-Dade County, Orange County, Palm Beach County, and Pinellas County, as well as the cities of Fort Lauderdale, Orlando, St. Peterburg, Tampa, and West Palm Beach, as well as the metropolitan planning organizations (MPOs) for Orlando and Tampa–St. Pete. In the Miami region, MPOs are administered by the individual counties, all of which have Vision Zero plans, as noted above.
5. We also examined Central Avenue in St. Petersburg, which differed from the remaining sites in that it used angled on-street parking. The two sections of this street totaled 0.76 mile and experienced 10 KAB collisions involving vulnerable users, which is more than all of the other walkable locations combined. A review of police accident reports at this location revealed that the problem was attributable to conflicts associated with vehicles attempting to enter and exit the angled on-street parking, resulting in collision with bicyclists. Given the complete absence of information on the safety impacts of angled on-street parking, we felt it important to include these findings here, but to separate them from the larger analysis.
6. A recent focus group with land developers found that they have a largely favorable view of addressing road safety through site planning and design, provided it is addressed in pre-development meetings. Where issues arise are when there are differing or inconsistent requests between different departments or layers of governance, or when the requests arise during the latter stages of the project development process (Combs et al., 2025).

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