Safe Main Street Highways Part II: Analyses of Collisions Involving Pedestrians and Bicyclists in Washington State

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SAFE MAIN STREET HIGHWAYS PART II: ANALYSES OF COLLISIONS INVOLVING PEDESTRIANS AND BICYCLISTS IN WASHINGTON STATE

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16. ABSTRACT:

This project contributes to the Washington State Strategic Highway Safety Plan, whose goals are to achieve zero road fatality and serious injury by 2030 and to reduce the number of pedestrians and bicyclists involved in motor-vehicle collisions on state highways. The study focused on "main street highways" (MSHs), which are stretches of State Routes that also act as main streets for the local populations. This report covers Part II of the study, which (1) identified hotspots of pedestrian and bicyclist collisions, and (2) developed models for estimating socio-economic and environmental predictors of collision locations.

Collision hotspots were derived from Planar and novel Network Kernel Density Estimation (KDE) methods. Case-control and negative binomial models showed that high risk pedestrian and bicyclist collision locations were significantly associated with collisions occurring (1) at street and road intersections (versus mid-blocks); (2) on wider roads; (3) on roads with bicycle lanes; (4) in low income and non-white neighborhoods.

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Introduction

The share of trips taken by non-motorized travel modes has increased in recent years, partly in response to shifts in demographics and to population growth in urbanized areas. Increases in non-motorized travel support national and state departments of transportation goals to reduce vehicle miles traveled (VMT) and associated greenhouse gas emissions and to ease highway congestion. They also reflect national and local health directives to redress physical inactivity and obesity epidemics through active transport. However, increases in non-motorized travel also raise important safety issues, as pedestrians and bicyclists constitute the most vulnerable road users. Indeed, the proportion of pedestrians killed has increased since the 2008 recession from 12 percent to 14 percent of all vehicle-related collisions (U.S. Department of Transportation, 2012). Therefore, tools to help identify locations with high risks of collisions between motor vehicles and pedestrians or bicyclists are essential to ensure that gains in mobility, air quality, and health are not accompanied by higher rates of injuries and fatalities for vulnerable road users.

Between 2007 and 2010 Washington state experienced a 36 percent growth in bicycle commuters, and the number of pedestrian commuters grew by 5.6 percent (Washington State Department of Transportation, 2012). With a 1.04 fatality rate for bicyclists and pedestrians per 100,000 population, the state is 34th in fatality rates in the nation (rates vary from 2.94 in Delaware to 0.24 in South Dakota, with a U.S. mean of 1.51) (U.S. Department of Transportation, 2012). Still, statewide, there are nearly 400 fatal and injury collisions involving pedestrian and bicycles each year. Most of these collisions occur in urban and suburban areas, where populations concentrate.

The present study investigated collisions involving pedestrians and bicyclists that occurred along state facilities. State Routes are highways that carry higher traffic volumes than local streets or roads. However, these routes also traverse towns, cities, and other areas that have been developed and urbanized. In these areas, State Routes also function as "main streets" because they are lined with a variety of central commercial and institutional services. This study focused on those stretches of State Routes that also act as main streets for the local populations, called "main street highways" (MSHs) (Cannon, Duffy, & Stevens, 2011). Strikingly, while MSHs represent less than 10 percent of the State Route network, between 2010 and 2012 60 percent of pedestrian and bicyclist collisions on State Routes and 30 percent of the fatalities resulting from those collisions occurred on MSHs. These high collision and fatality rates are likely related to the comparatively high traffic volumes and high development densities concentrated along MSHs.

The goal of this project was to identify locations along MSHs that present high risk for the occurrence of pedestrian and bicyclist collisions and to determine the characteristics of those locations that are associated with high collision risk. The study was conducted in two parts.

One determined methods to identify collision hotspots on MSHs. Hotspot analyses point to locations with high frequencies of collisions. These hotspots can be used to identify problematic locations that are potential candidates for safety improvements. For example, identifying and ranking high traffic collision zones is essential for developing and enforcing efficient countermeasures for pedestrian and bike safety. Knowing the locations of collision hotspots will also guide law enforcement and safety policies and priorities. Departments of transportation can focus on these zones to enhance traffic safety within their limited financial resources.

The second part of the study employed models to examine the effects on the risk of collision occurrence of MSH infrastructure and traffic characteristics, as well as the land use and built environment characteristics, along the MSHs. Supporting material can be found in the Appendices.

I. Collisions on Main Street Highways

The Washington State Department of Transportation (WSDOT) has identified 405 "main street highways" (MSHs) within the state. Washington's MSHs run along 1,007 km of the 118 State Routes, whose total length is more than 11, 000 km (7,000 miles) (see Table A - 1). Over 3.2 million residents, about half of Washington's population, have a main street highway running through their city. MSHs run through 183 cities and small towns (out of 281 incorporated cities and towns, see Table A - 2) in 38 of Washington's 39 counties (San Juan County doesn't have any MSHs; see Table A - 3). Five MSHs are located in two counties; King County has 23.8 percent of the total length of MSHs in Washington state (see Figure A - 1).

Three buffer distances were used to capture the characteristics of the areas along MSHs: 100, 200, and 300 meters. MSH "zones" were defined as areas within these buffer distances, which together covered 53,264.55, 113,067.77, and 179,100.09 acres (83.2, 176.7, and 280 mi^2), respectively.

Between 2001 and 2012, a total of 5,865, pedestrian and bicyclist collisions occurred in the 100-m buffer zone, with 7,460 in the 200-m zone, and 8,830 in the 300-m zone.[1] These collisions represented more than 14 percent, 18 percent, and 21 percent of the state's total number of pedestrian and bicyclist collisions, respectively, a share that did not change over the decade (Table 1). At least 50 percent of the collisions in MSH zones were along the state route

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[1] Collisions were geocoded using four different methods related to street and road types (state routes, county roads, and city streets) and times at which the geocoding was performed. The methods have been summarized in a parallel report (Moudon and Kang, 2017). The four methods included the following:

- a point system for each collision location using the ArcGIS online street network routing
- an intersection location system using the ArcGIS online street network routing
- a linear referencing system
- a combination of methods used when WSDOT, TRAC, and the UFL have geocoded collisions for past projects.

traversing the MSH, with the other 50 percent along city cross-streets (Table 2). Sixty percent of the collisions involved pedestrians and 40 percent were bicyclists (Table 3). Almost 15 percent of the collisions caused a serious injury or a fatality, while about 44 percent involved possible or no injury (Table 4).

The distribution of collisions in MSHs by county and city is provided in Table A - 4 and Table A - 5. Figure 1 shows the locations of MSHs in the state, as well as the collisions in the three buffer- delineated MSH zones.

Table 1. Summary of Collisions in Washington State and MSH Zones by Year

Year	Ped-Bicycle Collision in Washington State				Ped-Bicycle Collision in MSH Zones					
	Total		Geocoded		100m		200m		300m	
2001	3,200	100.0%	2,802	87.6%	546	17.1%	670	20.9%	763	23.8%
2002	3,336	100.0%	2,947	88.3%	483	14.5%	616	18.5%	722	21.6%
2003	3,359	100.0%	2,979	88.7%	537	16.0%	657	19.6%	747	22.2%
2004	3,396	100.0%	3,023	89.0%	485	14.3%	617	18.2%	731	21.5%
2005	3,529	100.0%	3,109	88.1%	444	12.6%	562	15.9%	680	19.3%
2006	3,666	100.0%	3,280	89.5%	446	12.2%	605	16.5%	732	20.0%
2007	3,485	100.0%	3,067	88.0%	431	12.4%	577	16.6%	700	20.1%
2008	3,513	100.0%	3,101	88.3%	462	13.2%	598	17.0%	714	20.3%
2009	3,383	100.0%	3,292	97.3%	434	12.8%	562	16.6%	672	19.9%
2010	3,569	100.0%	3,529	98.9%	517	14.5%	659	18.5%	777	21.8%
2011	3,427	100.0%	3,352	97.8%	520	15.2%	643	18.8%	763	22.3%
2012	3,572	100.0%	3,511	98.3%	560	15.7%	694	19.4%	829	23.2%
Total	41,435	100.0%	37,992	91.7%	5,865	14.2%	7,460	18.0%	8,830	21.3%

MSH Zones (100m, 200m, 300m) were created by using the ArcGIS buffer tools with 'round end type'.
To avoid overlaps, the number of collisions on MSH Zones was counted by using 'dissolved MSH Zones'

Table 2. MSH Collisions by Road Type and Buffer Size

Category		MSH Zones					
		100m Buffer		200m Buffer		300m Buffer	
Road Type	State Route	4,252	72.5%	4,346	58.3%	4,402	49.9%
	County Road	6	0.1%	9	0.1%	20	0.2%
	City Street	1,606	27.4%	3,103	41.6%	4,406	49.9%
	Miscellaneous Traffic way	1	0.0%	2	0.0%	2	0.0%
	Total	5,865	100.0%	7,460	100.0%	8,830	100.0%

There were four categories in road type. In our database; the 'collision report type' variable was used to identify this information.

Table 3. MSH Collisions by Collision Type and Buffer Size

Category		MSH Zones					
		100m Buffer		200m Buffer		300m Buffer	
Collision Type	With Pedestrian	3,541	60.4%	4,485	60.1%	5,295	60.0%
	With Cyclist	2,317	39.5%	2,962	39.7%	3,515	39.8%
	With Ped & Cyclist	7	0.1%	13	0.2%	20	0.2%
	Total	5,865	100.0%	7,460	100.0%	8,830	100.0%

In total, 111 pedestrian and cyclist collisions occurred from 2001 to 2012, making up only 0.007 percent of all collisions.

Table 4. MSH Collisions by Injury Severity and Buffer Size

Category		MSH Zones					
		100m		200m		300m	
Collision Severity	Fatal	104	2.3%	123	2.1%	135	1.9%
	Serious Injury	565	12.4%	732	12.4%	851	12.1%
	Evident Injury	1,874	41.2%	2,447	41.5%	2,936	41.6%
	Possible Injury	1,528	33.6%	2,022	34.3%	2,468	35.0%
	No Injury	477	10.5%	566	9.6%	669	9.5%
	Total	4,548	100.0%	5,890	100.0%	7,059	100.0%

Observations with ‘Non-Traffic Fatality’, ’Non-Traffic Injury’ and ‘Unknown’ were removed from the table.

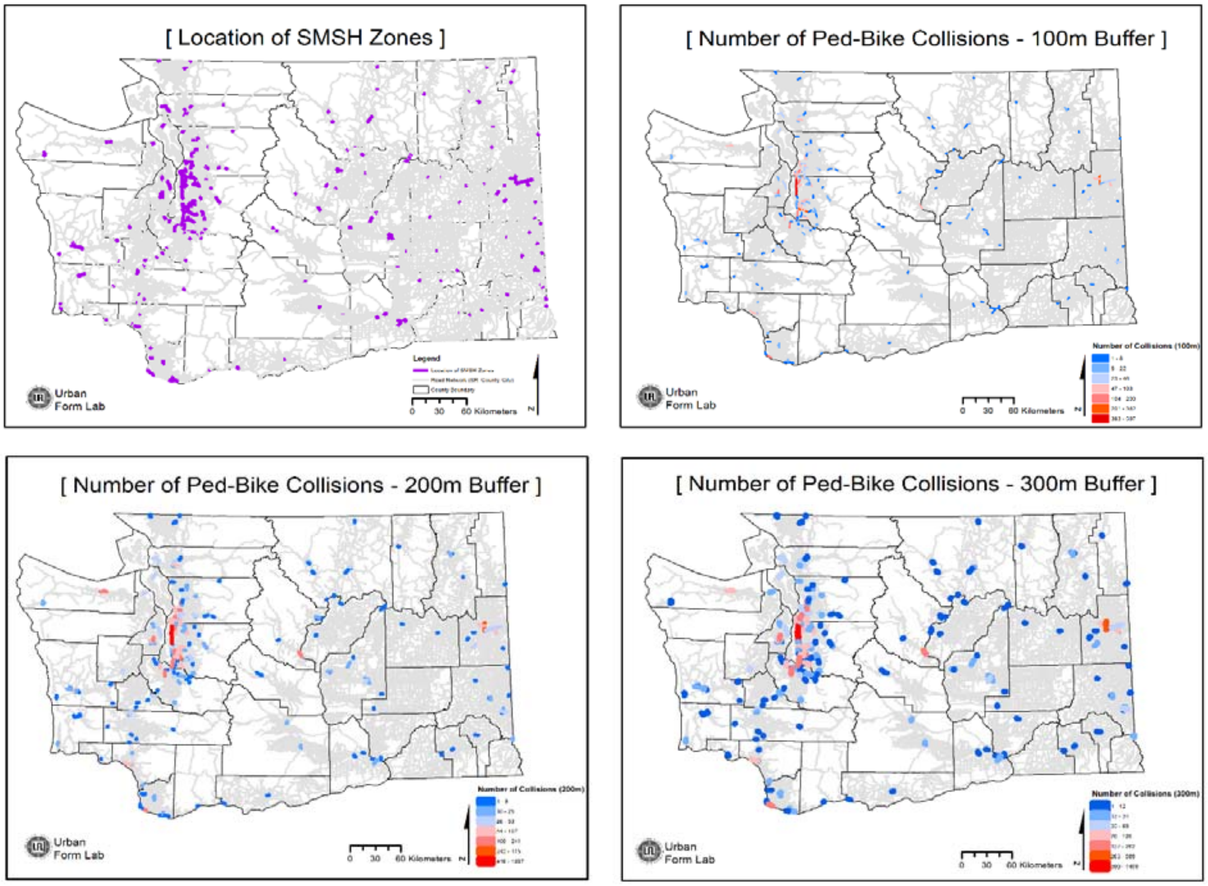

Figure 1. Locations of MSH Zones and Numbers of Pedestrian and Bicyclist Collisions in MSH Zones by Buffer Size

II. Collision Hotspot Analyses

Hotspots can be used to identify locations that are potential candidates for safety improvements. For example, identifying and ranking high traffic collision zones is essential for developing and enforcing efficient countermeasures for pedestrian and bicycle safety. Knowing the locations of collision hotspots will also guide law enforcement and safety policies and priorities. Departments of transportation can focus on these zones to enhance traffic safety within their limited financial resources.

Two kernel density analysis methods were used to identify hotspots of pedestrian and bicyclist collisions: a planar method and a network-based method. In both methods, only the collisions occurring along State Routes were considered. Figure A - 2 and Figure A - 3 summarize the frequency of collision occurrence normalized by kilometer of State Route.

1. Planar Kernel Density Estimation

The Planar Kernel Density Estimation (PKDE) tool in ArcGIS calculates the density of point features (in our case, collision locations) around each output raster cell on the basis of a circular buffer. The PKDE has been used to identify collision hot spots in previous studies (Pulugurtha et al., 2007; Quistberg et al., 2015). With the PKDE, a smoothly curved surface is fitted over each point as a distance decay function. The surface value is highest at the location of the point and decreases with increasing distance from the point, reaching zero at the search radius distance from the point. The general form of the PKDE is defined as follows:

$$PKDE_k = \sum_{i=1}^{n} \frac{1}{\pi r^2} k(\frac{d_{is}}{r})$$

where $PKDE_k$ is the density at location (s), (r) is the search radius of this function, (k) is the weight of a point (i) at distance d_{is} to location (s), and (k) is modeled as a function of the ratio between d_{is} and (r). So the function calculates the distance decay effect from the centroid of the raster cell to all incident points. A 100-meter circular buffer was used as a search radius from the centroid of the raster cell. Grid cells used in the analysis and in the maps were 30 x 30 meters. Figure 2 shows hotspots in MSHs for the entire state. More detailed maps of selected counties and cities are provided in the Appendix (see Figure A - 4).

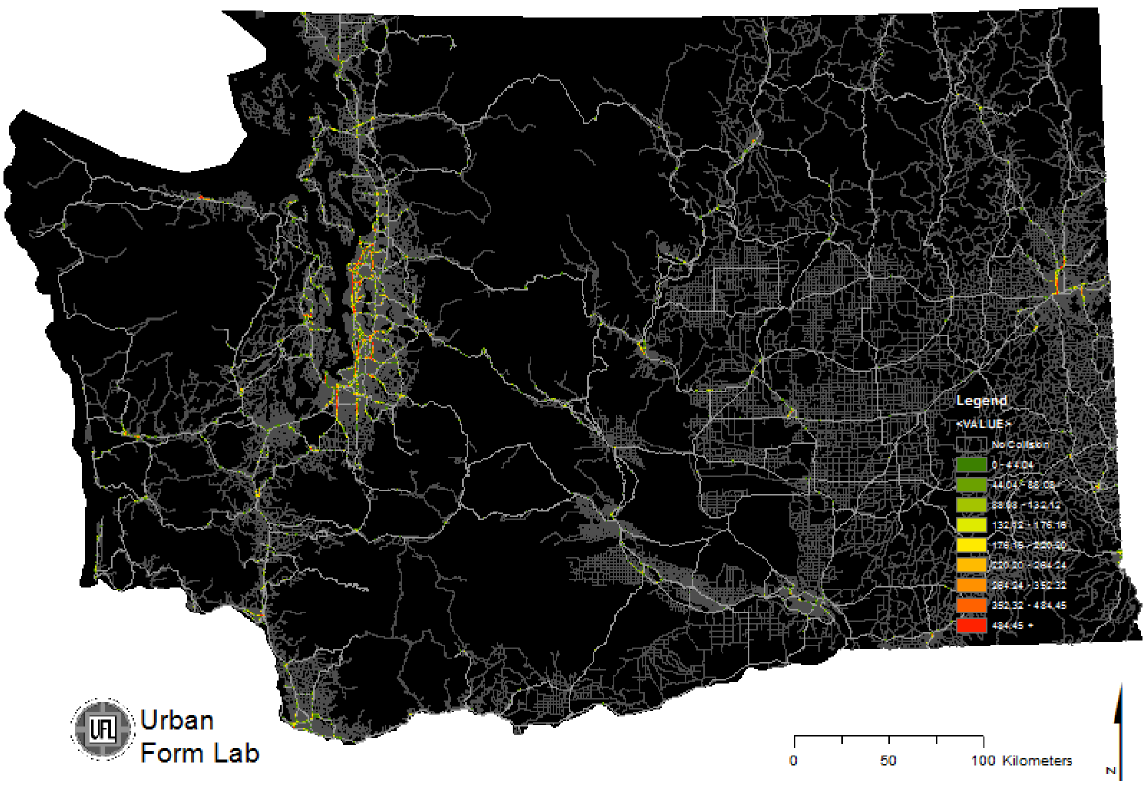

Figure 2. Planar KDE Analysis of Washington

2. Network Kernel Density Estimation

This analysis was based on the work of Xie and Yan (2008). It constrained hotspots to the transportation network by using a Network Kernel Density Estimation (NKDE) procedure. This constraint was useful because the geocoding process used also located the collisions along the same network. As a result, the NKDE procedure determined collision hotspots in a manner that was closely tied to the network data that were used to represent the collision locations. The goal was to create a closer connection that could produce a more precise depiction of collision hotspots than the Planar KDE approach.

An ArcGIS Python script tool was created to conduct a network-based hotspot analysis using the NKDE approach. While based on the methods outlined by Xie and Yan (2008), the tool used street intersections as the unit of analysis rather than the roadway segments, or lixels, defined by Xie and Yan (2008). The use of intersections might facilitate future comparisons with the Planar KDE results. PKDE values from raster cells could be extracted and assigned to an intersection point. Comparative analyses could then be done of the PKDE and NKDE values for all intersections. For the purposes of this analysis, the following equation served to estimate the distance-weighted sum total of all the collisions that occurred within a 100-m distance (or search radius) of a given street intersection:

$$NKDE_k = \sum_{i=1}^{n} \frac{\frac{1}{d_i}\left(\frac{1}{\sqrt{2\pi}}\right) e^{\frac{-B^2}{{d_i}^2}}}{\frac{1}{B}\left(\frac{1}{\sqrt{2\pi}}\right) e^{-1}}$$

where d_i is the distance between the intersection (k) and the collision (i) and B represents the search distance of 100 m. The resulting values of this equation range from 0 to 1, where a weight of 0 indicates that the collision occurred right at 100 m, and 1 shows that the collision occurred right at the given intersection. The weights for collisions occurring between these locations were produced by using a Gaussian Kernel. This analysis was applied only to intersections with MSHs along Washington state routes. Figure 3 shows the collision hotspots on MSHs for Washington state. More detailed maps of selected counties and cities are shown in the Appendix (see Figure A - 5).

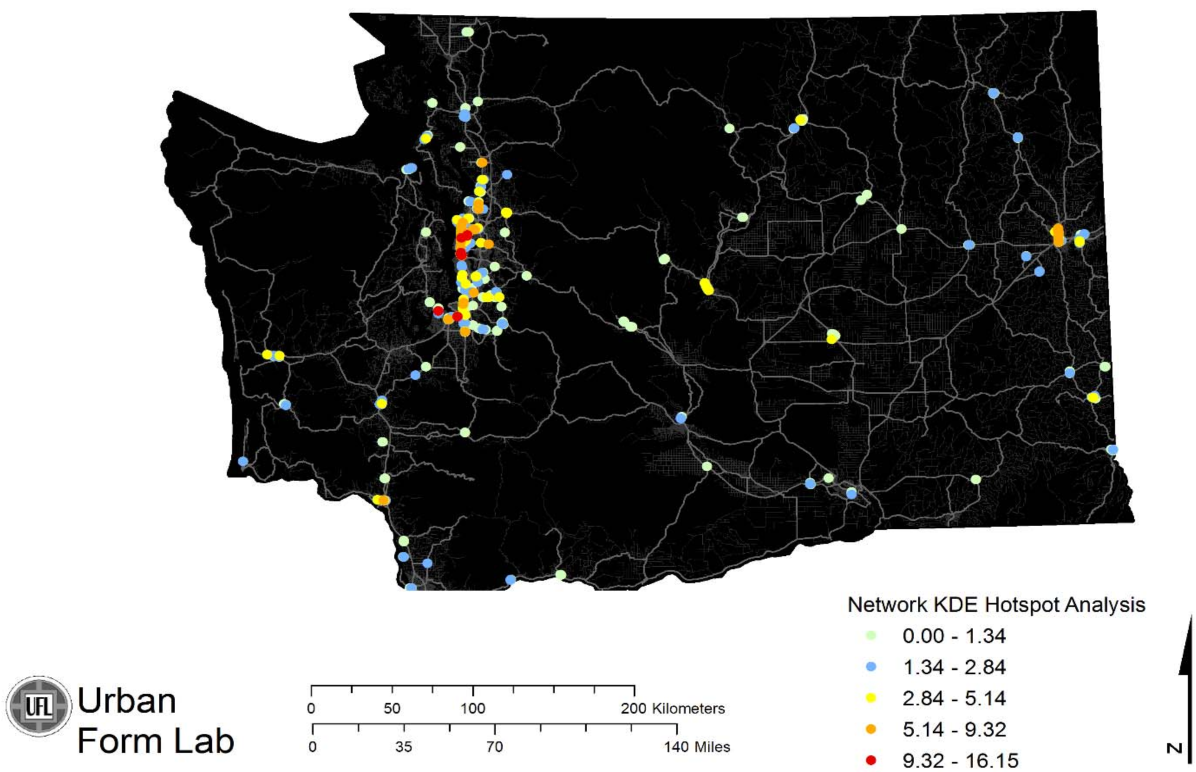

Figure 3. Network KDE Analysis of Washington

3. Discussion

Hotspot analyses help in visually displaying locations with different degrees of spatial concentration of collisions. We used red, yellow, blue, and green areas to depict concentrations of collision ranging from high to low. These hotspots can be used to identify problematic locations that are potential candidates for safety improvements. For example, identifying and ranking high traffic collision zones is essential for developing and enforcing efficient countermeasures for pedestrian and bicyclist safety. Knowing the locations of collision hotspots will also guide law enforcement and safety policies and priorities. Departments of transportation can focus on these zones to enhance traffic safety within their limited financial resources.

Figure 2 and 3 show ten classes of hotspots with the Planar KDE and five classes with the Network KDE. The numbers of hotspot classes were selected for illustrative purposes, ranking hotspots in ten and five categories, respectively, for ease of visualization. Different numbers of classes of collision concentrations can and should be tested to rank locations and develop intervention strategies aimed at reducing the number of collisions. The number of hotspot classes and related ranking could be based on resources available for remediation by year, biennium, or decade. Furthermore, classes of hotspots could be established by simply calculating the total number of collisions included in each class, which would provide a first-hand assessment of the magnitude of the safety problem in each class. Hence many classes would yield fewer high hotspot areas with a smaller total number of collisions, and conversely, fewer classes would yield more areas with a higher total number of collisions.

The size of the radius used to calculate distance between collision locations should also be tested. We selected 100 m, which, as shown in Figure 4, corresponds to a relatively small area around intersections. The size of the radius should relate to areas of future intervention; that is, the small 100-m radius works if the intent is to focus on safe or unsafe intersections, and radii of 200 m or more is appropriate if the intent is to address the safety of areas resembling neighborhoods.

Concerning the two hotspot detection methods presented in this study, the Planar KDE used Euclidian distance to calculate collision density within the selected buffer radius, and the unit of analysis was a 30-m raster cell. The Network KDE used network distance to calculate collision density, and the unit of analysis was the intersection. While PKDE analyses are relatively easy and fast to conduct, NKDE analyses, which are more difficult to perform and require access to roadway network data sets, may be better at identifying collision hotspots since pedestrian and bicyclist collisions occur mostly on roads (Figure 4).

Future work is necessary to compare the results of the Planar and Network KDE approaches. Several publications reported on the results of studies using the Network KDE (Xie and Yan, 2008; Okabe et al., 2009; Dai et al., 2010). However, these studies were focused more on the technical development of Network KDE tools than on their results. Also, there has been little more than visual comparisons of the two methods. So, to the best of our knowledge, no study has systematically analyzed and compared these two approaches. One possible way to compare these methods would be to apply the prediction accuracy index (PAI), which can be found in Chainey et al. (2008). The PAI is calculated by dividing the so-called "hit rate percentage" (the number of collisions in hotspot areas divided by the total number of collisions) by the hotspot area percentage (the area of hotspots divided by the total area). So, the PAI attempts to capture the predictive accuracy of hotspots. Nevertheless, because the definition of hotspots can be controversial, sensitivity analyses of PAI should be included in future studies by varying the cut-off value (e.g., top 10 percent of total area) of hot spots.

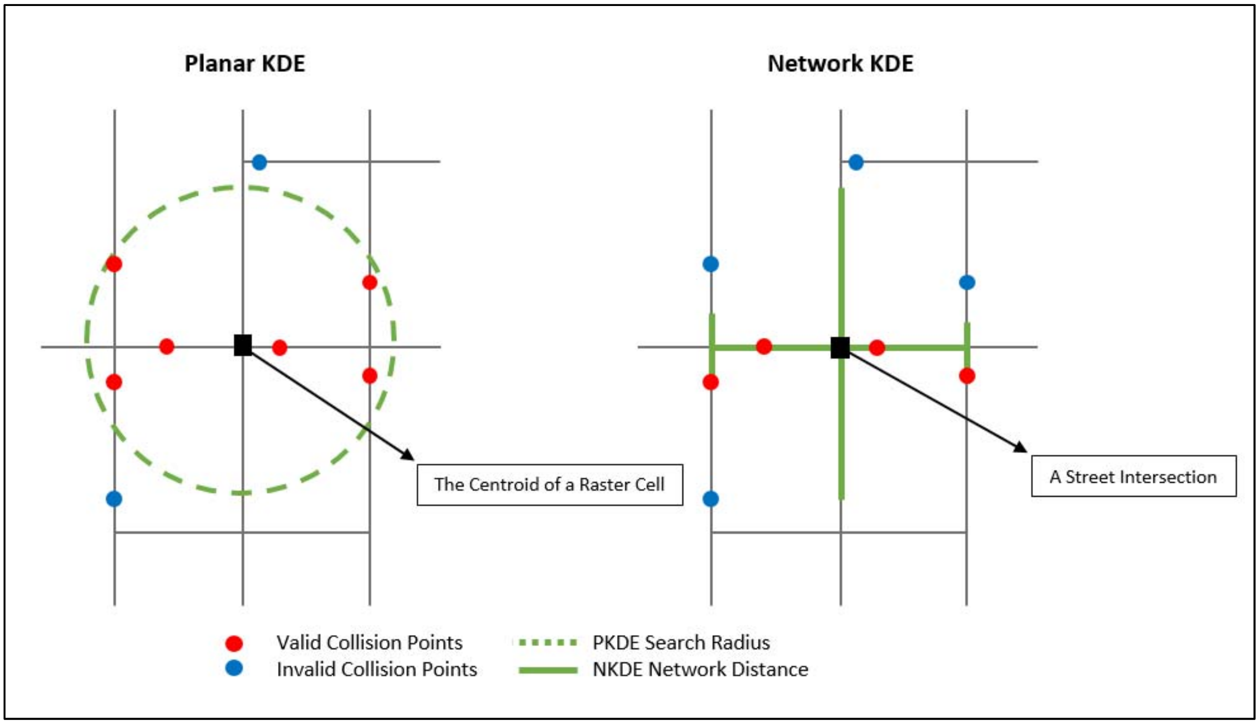

Figure 4. Measuring the Distance of a Collision to the Centroid of a Raster within the Planar KDE and to a Street Intersection within the Network KDE

III. Collision Predictors

The objective of this analysis was to identify environmental and socio-economic factors that are associated with pedestrian and bicyclist collisions at intersections and mid-blocks on main street highways. The study investigated the risk and protective factors related to pedestrian and bicyclist collisions by using locational characteristics and surrounding neighborhood information. The study hypothesized that pedestrian and bicyclist collisions would be more likely to occur on more trafficked State Routes with complex road configurations and features. Also, collisions would be more likely to occur along stretches of road with surrounding built environmental factors that supported pedestrian and bicycle travel. Finally, neighborhood socio-economic factors would also be related to the occurrence of pedestrian and bicyclist collisions.

1. Built Environment

Collision frequency has been associated with the characteristics of the built environment at the locations where the collisions occur. Both micro and macro environmental factors have been related to collision occurrence (Jiao, Moudon, and Li, 2013).

Micro environmental factors associated with collisions have been identified in previous studies (Zajac and Ivan, 2003; Ewing, 2006; Wier et al., 2009; Moudon, Lin et al., 2011; Zahabi et al., 2011; Quistberg et al., 2015). Road characteristics have been associated with pedestrian injury (Moudon, Lin et al., 2011), and vehicle speed and the width of a street were related to the severity of injury (Zajac and Ivan, 2003; Ewing, 2006; Rosen et al., 2011). Walkable streets can attract more people, which may result in larger pedestrian volumes, yet pedestrian collision risk may be lower in walking-friendly and traffic-tamed environments (Quistberg et al., 2015). In this study, we included the attributes of the road environment, such as the number of vehicular lanes and speed limits, and the characteristics of the road infrastructure, such as intersection density, presence of park and ride lots, and sidewalks We also included bike lanes as an important elements of the bicycle infrastructure.

Macro environmental factors relate to the characteristics of the population and the activities in MSH zones. Previous studies have used socio-economic factors such as population density, housing density, household income, and racial composition to estimate the relationship between macro-environmental factors and collisions (LaScala et al., 2000; Kim et al., 2006; Zahabi et al., 2011). Schools and various types of retail facilities have also been known to attract pedestrian and bicyclist activity (Wier et al., 2009; Zahabi et al., 2011). We used population and housing unit density as measures of potential demand for pedestrian or bicycle travel; income and race as proxies for the socioeconomic characteristics of the population; and various land uses as descriptors of activities taking place near intersections and at mid blocks. Macro environmental factors are *de facto* measures of exposure because actual figures on the number and characteristics of people who travel by foot or on bicycles are unavailable.

2. Methodology

Pedestrian and bicyclist collisions were analyzed by using all State Route intersection and mid-block locations within MSH zones in Washington state. Intersections and mid-blocks were clipped by using a 300-m dissolved buffer from the Main Street Highway network data. A 100-m radius circular buffer around each intersection and mid-block point was then created to measure micro-environmental characteristics (roadway characteristics and traffic condition variables). An 800-m radius circular buffer was created around each intersection and mid-block point to measure macro-environmental characteristics (neighborhood and land-use variables). The 100-m buffer was deemed adequate to capture the road environment at intersections and mid-blocks, while the 800-m buffer captured the built environment within a walkable (10-minute) distance of intersections or mid-blocks. The two environmental data sets (100-m, 800-m buffers) were merged by using a unique identifier for each intersection and mid-block. Finally, the completed built environment data were joined with the pedestrian and bicyclist collision data.

Data came from WSDOT, the U.S. Census Bureau, and its National Historical Geographic Information System (NHGIS). Statewide parcel data were used for land-use variables, and the National Center for Education Statistics (NCES) data archive supplied school data. Table 5 describes the built environment data structure, variable names, data sources, and measures.

Table 5. Built Environment Variables and Data

Domain	Name	Description	Data name	Data Source	Unit	GIS Data Type
Micro Environmental Characteristics (100-m Circular Buffer)						
Road Characteristics	Number of Lanes	Number of lanes	MSH geodatabase / wsdot_lanes_state_routes	WSDOT	Count	Polyline
	Roadway Width	The distance from side to side of a lane designated by pavement markings or other devices	MSH geodatabase / wsdot_lanes_state_routes	WSDOT	Feet	Polyline
	Speed Limits	Legal speed limits along state route	MSH geodatabase / wsdot_speedlimit	WSDOT	Mile / Hour	Polyline
Locational Characteristics	Intersection Density	Number of street intersections along state routes	MSH geodatabase / wsdot_intersection	WSDOT	Count	Point
	Park and Ride	A point dataset depicting 'park and ride' locations in Washington State	MSH geodatabase / wsdot_park_ride	WSDOT	Count	Point
	Bike Lane Length	Length of bike lanes on state routes. This data set is derived from Special Use Lanes in WSDOT GIS Archive	MSH geodatabase / wsdot_derived_state_route_bikelane	WSDOT	Feet	Polyline
Macro Environmental Characteristics (800-m Circular Buffer)						
Neighborhood	Housing Density	Number of housing units per area of census block	MSH geodatabase / census_block_2010	Census Bureau NHGIS	# / Km2	Polygon
	Household Income	Median household income by census block group	MSH geodatabase / wsdot_census_blockgroup_2012	Census Bureau WSDOT	$	Polygon
	Population Density	Total population per area of census block	MSH geodatabase / census_block_2010	Census Bureau NHGIS	# / Km2	Polygon
	Race	Racial composition (white vs non-white) by census block	MSH geodatabase / census_block_2010	Census Bureau NHGIS	%	Polygon
	School	Presence/absence of public schools	MSH geodatabase / School_xy	NCES	Count	Points
	Eat and Drink Retail	Presence/absence of retail establishments selling prepared foods and drinks for consumption on the premises	MSH geodatabase / Parcel_landuse_2010_merged	UFL	Count	Polygon
Land Use	LU - Manufacturing	Presence/absence of manufacturing land uses	MSH geodatabase / Parcel_landuse_2010_merged	UFL	Count	Polygon
	LU - Transportation	Presence/absence of transportation, communication and utilities land uses	MSH geodatabase / Parcel_landuse_2010_merged	UFL	Count	Polygon

	LU – Trade and Service	Presence/absence of trade and service land uses	MSH geodatabase / Parcel_landuse_2010_merged	UFL	Count	Polygon
	LU – Cultural	Presence/absence of cultural, entertainment and recreational land uses	MSH geodatabase / Parcel_landuse_2010_merged	UFL	Count	Polygon
	LU – Resource	Presence/absence of resource production and extraction land uses	MSH geodatabase / Parcel_landuse_2010_merged	UFL	Count	Polygon

3. Descriptive Statistics

There were 8,283 intersections and 8,149 mid-blocks within MSH zones in Washington state. In the total sample of 16,432 locations, 4,239 had at least one collision (25.8%) and 12,193 had no collisions (74.2%). The descriptive statistics of the built environment in these locations are shown below.

Locations with at Least One Collision

MHS zones contained 2,471 intersections and 1,768 mid-block locations that had at least one collision. Table 6 and Table 7 present the built environment descriptive statistics for those locations.

Table 6. Built Environment Statistics for Locations with at Least One Collision: Continuous Variables

Statistic	N	Mean	St. Dev.	Min	Median	Max
Road Width (feet)	4,239	20.2	8.7	5.5	21.0	48.0
Number of Intersections	4,239	3.2	2.6	0	2	17
Speed Limits (MPH)	4,239	30.9	9.2	10.0	30.0	55.0
Bike Lane Length (meter)	4,239	172.9	662.6	0.0	0.0	6,949.6
Household Income ($)	4,239	55,493.6	27,066.0	0	49,741	173,051
Housing Density	4,239	547.9	498.7	0.2	451.8	5,768.3
Population Density	4,239	1,190.5	883.6	0.5	1,035.0	6,981.7
Race - White Proportion	4,239	69.8	15.6	6.2	72.5	100.0
Race – Non White Proportion	4,239	30.2	15.6	0.0	27.5	93.8

Table 7. Built Environment Statistics for Locations with at Least One Collision: Dummy Variables

	Absence(0)	Presence(1)
Park and Ride	1,501	2,738
Bike Lane	3,862	377
School	1,625	2,614
Park	1,501	2,738
Eat and Drink Retail	824	3,415
Land Use for Manufacturing	1,835	2,404
Land Use for Transportation, Communication and Utilities	388	3,851
Land Use for Trade and Service	15	4,224
Land Use for Cultural, Entertainment and Recreational	312	3,927
Land Use for Resource Production and Extraction	2,624	1,615

Locations with No Collision

MHS zones contained 5,812 intersections and 6,381 mid-block locations that had no collision. Table 8 and Table 9 present the built environment descriptive statistics for those locations.

Table 8. Built Environment Statistics for Locations with No Collision: Continuous Variables

Statistic	N	Mean	St. Dev.	Min	Median	Max
Road Width (feet)	12,193	16.1	7.6	5.0	12.0	46.0
Number of Intersections	12,193	2.1	2.2	0	2	16
Speed Limits (MPH)	12,193	33.9	9.6	10.0	35.0	65.0
Bike Lane Length (meter)	12,193	94.0	405.9	0.0	0.0	5,378.6
Household Income ($)	12,193	55,609.0	24,457.3	0	50,938	173,051
Housing Density	12,193	257.9	336.7	0.0	139.6	4,914.8
Population Density	12,193	579.3	667.1	0.5	340.8	6,086.4
Race – White Proportion	12,193	74.4	17.9	4.3	79.6	100.0
Race – Non White Proportion	12,193	25.6	17.9	0.0	20.4	95.7

Table 9. Built Environment Statistics for Locations with No Collision: Dummy Variables

	Absence(0)	Presence(1)
Park and Ride	5,504	6,689
Bike Lane	3,862	377
School	6,186	6,007
Park	5,504	6,689
Eat and Drink Retail	4,474	7,719
Land Use for Manufacturing	5,397	6,796
Land Use for Transportation, Communication and Utilities	1,531	10,662
Land Use for Trade and Service	229	11,964
Land Use for Cultural, Entertainment and Recreational	1,778	10,415
Land Use for Resource Production and Extraction	4,807	7,386

4. Correlations

After the distributions of the data had been checked (see Figure A - 6 and Figure A - 7), correlations were calculated among all continuous variables. Correlation plots are shown below to help in visualizing the large set of data analyzed. Figure 5 shows the correlation of original variables, and Figure 6 shows the correlation of logarithmic variables. Blue indicates a positive relationship between two variables, and red indicates a negative one. The size of the circle represents the strength of the relationship.

Differences between the two figures are small. It appears that the number of collisions was closely related to roadway width, housing density, population density, and racial composition.

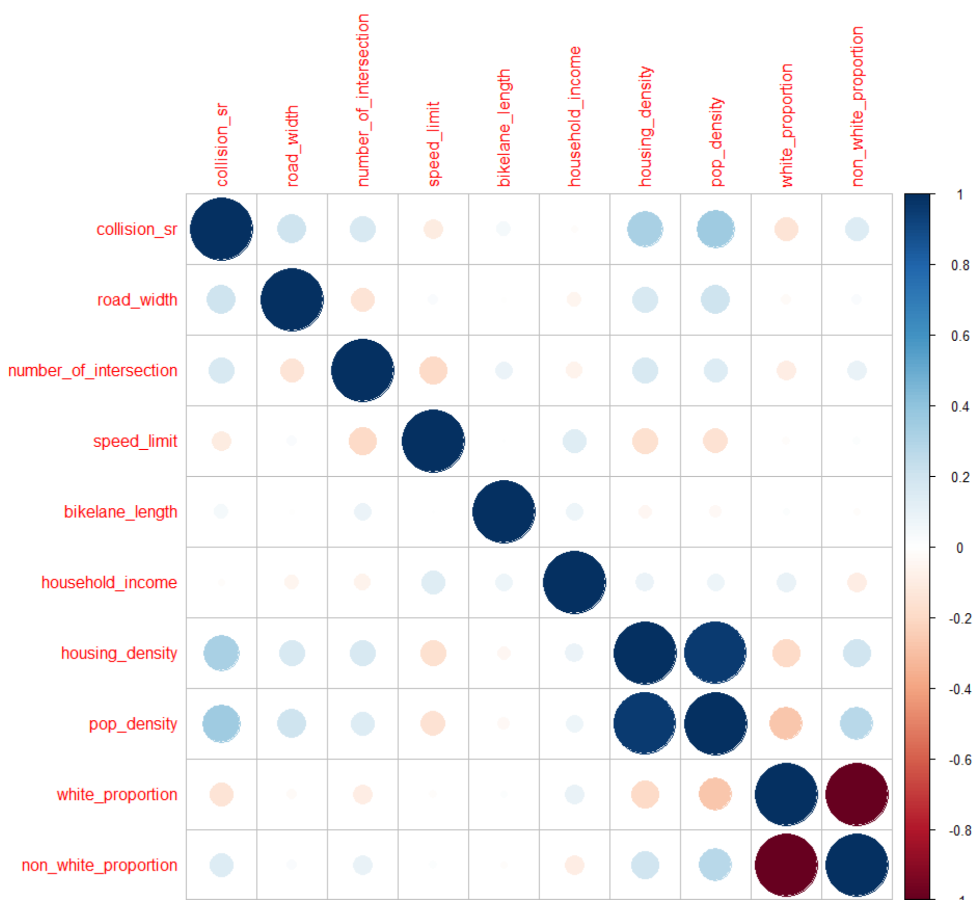

Figure 5. Correlations among Original Built Environment Variables

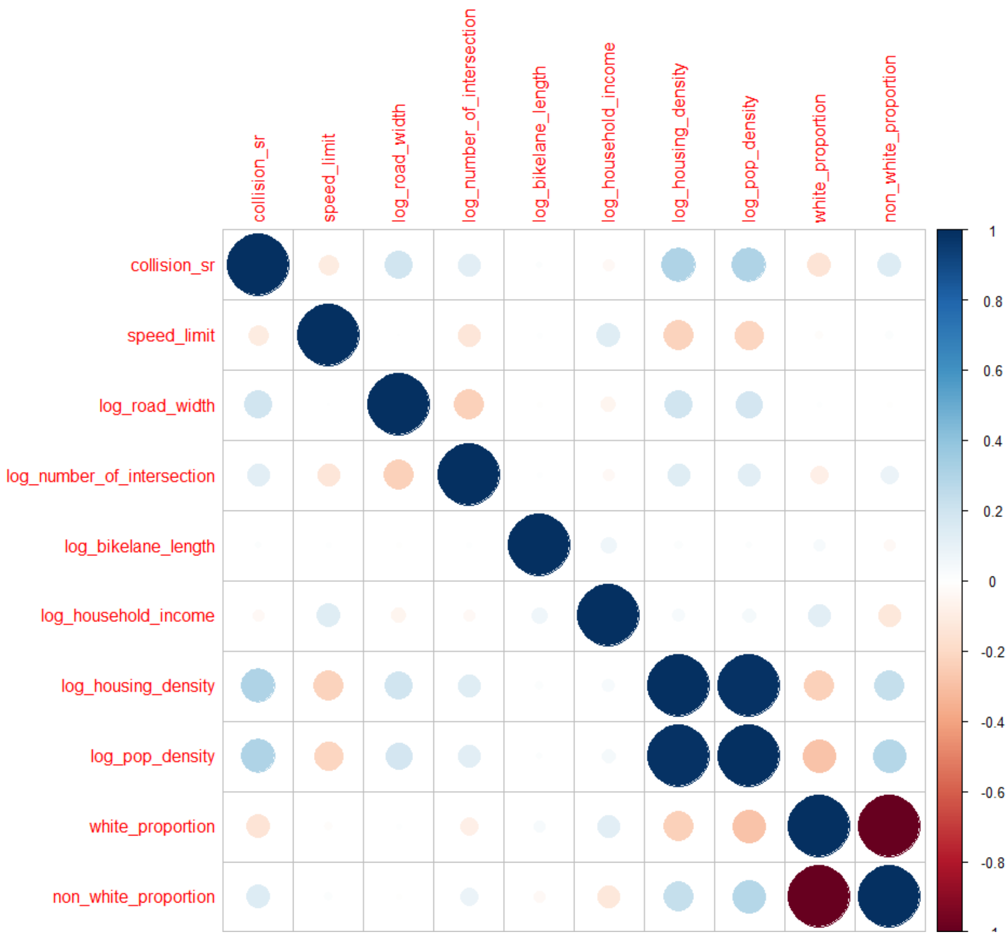

Figure 6. Correlations among Built Environment Logarithmic Variables

5. Model Options

A Case-Control Model was used to estimate the risk of a collision occurring. Poisson and Negative Binomial models served to estimate the number of collisions that could occur. Stepwise methods were used to find the fittest model.

Case-Control Model

The results of two models, full and fittest, run with the log-transformed variables, are presented in Table 10.

Table 10. Case-Control Model Results

	Case-Control Models	
	Occurrence of Collision	
	(1) Full Model (SE)	(2) Fittest Model (SE)
Location Type (0: Mid-Block, 1: Intersection)	0.23^{***} (0.04)	0.23^{***} (0.04)
Number of Lanes (2)	0.36^{***} (0.06)	0.36^{***} (0.06)
Number of Lanes (3)	0.40^{***} (0.14)	0.40^{***} (0.13)
Number of Lanes (4)	-10.38 (131.02)	-10.38 (131.11)
Road Width (log)	0.81^{***} (0.07)	0.81^{***} (0.07)
Park and Ride (Dummy)	-0.05 (0.05)	-
Intersection Density (log)	0.53^{***} (0.04)	0.53^{***} (0.04)
Speed Limits	-0.02^{***} (0.002)	-0.02^{***} (0.002)
Bike Lane (Dummy)	0.53^{***} (0.07)	0.53^{***} (0.07)
Household Income (log)	-0.03 (0.05)	-
Housing Density (log)	0.33^{***} (0.10)	0.32^{***} (0.10)
Population Density (log)	0.23^{**} (0.10)	0.23^{**} (0.10)
Race – Non-White Proportion	0.01^{***} (0.001)	0.01^{***} (0.001)
School (Dummy)	-0.003 (0.04)	-
Eat and Drink Retail (Dummy)	0.29^{***} (0.05)	0.30^{***} (0.05)
LU – Manufacturing (Dummy)	-0.06 (0.04)	-0.06 (0.04)
LU – Transportation (Dummy)	0.03 (0.07)	-
LU – Trade and Service (Dummy)	-0.25 (0.29)	-
LU – Cultural (Dummy)	0.16^{**} (0.08)	0.13^{*} (0.07)
LU – Resource (Dummy)	-0.14^{***} (0.05)	-0.14^{***} (0.05)
Constant	-6.38^{***} (0.65)	-6.92^{***} (0.28)
Observations	16,432	16,432
Log Likelihood	-7,671.38	-7,672.65
Akaike Inf. Crit.	15,384.77	15,377.29
Note:		*p0.1; **p0.05; ***p0.01

Negative Binomial Model

Table 11 shows the results of the Negative Binomial model[2] used with log-transformed variables. The fittest model was estimated by using the stepwise method.

Table 11. Negative Binomial Model Results

	Negative Binomial Models	
	Number of Collisions	
	(1) Full Model (SE)	(2) Fittest Model (SE)
Location Type (0: Mid-Block, 1: Intersection)	0.15*** (0.03)	0.15*** (0.03)
Number of Lanes (2)	0.26*** (0.05)	0.26*** (0.05)
Number of Lanes (3)	0.21** (0.10)	0.20** (0.10)
Number of Lanes (4)	-20.24 (17,069.62)	-14.72 (1,081.10)
Road Width (log)	0.72*** (0.05)	0.72*** (0.05)
Park and Ride (Dummy)	-0.06 (0.04)	-0.06* (0.04)
Intersection Density (log)	0.45*** (0.03)	0.45*** (0.03)
Speed Limits	-0.02*** (0.002)	-0.02*** (0.002)
Bike Lane (Dummy)	0.42*** (0.06)	0.41*** (0.06)
Household Income (log)	-0.02 (0.04)	-
Housing Density (log)	0.48*** (0.08)	0.52*** (0.02)
Population Density (log)	0.04 (0.08)	-
Race – Non-White Proportion	0.01*** (0.001)	0.01*** (0.001)
School (Dummy)	0.05 (0.03)	0.05 (0.03)
Eat and Drink Retail (Dummy)	0.27*** (0.04)	0.28*** (0.04)
LU – Manufacturing (Dummy)	-0.07** (0.03)	-0.07** (0.03)
LU – Transportation (Dummy)	-0.11** (0.06)	-0.11** (0.06)
LU – Trade and Service (Dummy)	-0.05 (0.28)	-
LU – Cultural (Dummy)	0.21*** (0.07)	0.21*** (0.07)
LU – Resource (Dummy)	-0.21*** (0.04)	-0.20*** (0.04)
Constant	-6.08*** (0.53)	-6.35*** (0.21)
Observations	16,432	16,432
Log Likelihood	-12,805.06	-12,805.46
theta	0.89*** (0.04)	0.88*** (0.04)
Akaike Inf. Crit.	25,652.12	25,646.91
Note:		*p0.1; **p0.05; ***p0.01

[2] The Poisson model assumes that the response variable Y has a Poisson distribution. And the data showed an over-dispersion ratio of larger than 2, which suggested that a Negative Binomial model should be used instead of the Poisson Model. A full and the fittest Poisson models are presented in Table A - 6.

Model diagnostics were performed, including an analysis of residuals and the AIC (Akaike Information Criterion) or BIC (Bayesian Information Criterion) score. Figure 7 shows Q-Q plots based on three log-transformed models, which confirmed that the Negative Binomial Model was slightly better than the Poisson model and that the Case-Control Model fit better than those two other models.

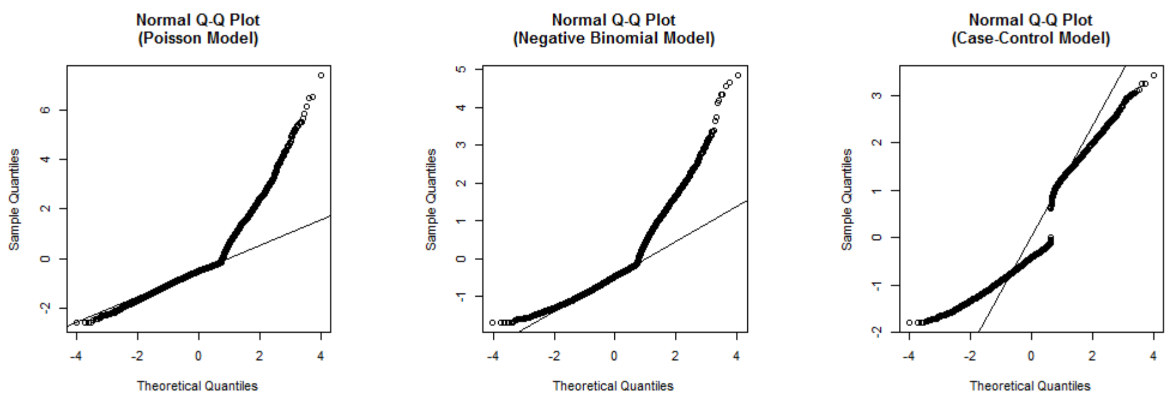

Figure 7. Q-Q Plot Comparisons

Application of the AIC and BIC scores showed that the Case-Control Model had the lowest AIC and BIC (Table 12).

Table 12. AIC and BIC

	Poisson Model		Negative Binomial Model		Case-Control Model	
	Full	Fittest	Full	Fittest	Full	Fittest
AIC	27,657.93	27,655.39	25,652.12	25,646.91	15,384.77	15,377.29
BIC	27,819.78	27,801.82	25,821.67	25,793.34	15,546.62	15,500.60

6. Final Models

Table 13 shows the results of the final models. It includes the three fittest models of the Poisson, Negative Binomial, and Case-Control analyses. Figure 8 shows the coefficients and their confidence intervals for the three models. These models were stable, as the coefficient signs of each variable were similar across different models.

Table 13. Final Models

	Final Models		
	Number of Collision		Occurrence of Collision
	(1) Poisson (SE)	(2) Negative Binomial(SE)	(3) Case-Control(SE)
Location (1: Intersection, 0: Midblock)	0.13*** (0.02)	0.15*** (0.03)	0.23*** (0.04)
Number of Lanes (2) (Ref. 1 Lane)	0.26*** (0.04)	0.26*** (0.05)	0.36*** (0.06)
Number of Lanes (3) (Ref. 1 Lane)	0.23*** (0.07)	0.20** (0.10)	0.40*** (0.13)
Number of Lanes (4) (Ref. 1 Lane)	-10.29 (115.01)	-20.24 (17,074.59)	-10.38 (131.11)
Roadway Width (log)	0.68*** (0.04)	0.72*** (0.05)	0.81*** (0.07)
Park and Ride (Dummy)	-0.06** (0.03)	-0.06* (0.04)	-
School (dummy)	-	0.05 (0.03)	-
Intersection Density (log)	0.43*** (0.02)	0.45*** (0.03)	0.53*** (0.04)
Speed Limit	-0.01*** (0.001)	-0.02*** (0.002)	-0.02*** (0.002)
Bike Lane (Dummy)	0.35*** (0.04)	0.41*** (0.06)	0.53*** (0.07)
Household Income (log)	-0.07*** (0.03)	-	-
Housing Density (log)	0.43*** (0.06)	0.52*** (0.02)	0.32*** (0.10)
Population Density (log)	0.09 (0.06)	-	0.23** (0.10)
Non-White Proportion	0.01*** (0.001)	0.01*** (0.001)	0.01*** (0.001)
Eat and Drink Retail (Dummy)	0.25*** (0.03)	0.28*** (0.04)	0.30*** (0.05)
LU-Manufacturing (Dummy)	-0.09*** (0.02)	-0.07** (0.03)	-0.06 (0.04)
LU-Transportation (Dummy)	-0.15*** (0.04)	-0.11** (0.06)	-
LU-Cultural (Dummy)	0.18*** (0.05)	0.21*** (0.07)	0.13* (0.07)
LU-Resource Production (Dummy)	-0.20*** (0.03)	-0.20*** (0.04)	-0.14*** (0.05)
Constant	-5.38*** (0.33)	-6.35*** (0.21)	-6.92*** (0.28)
Observations	16,432	16,432	16,432
Log Likelihood	-13,808.70	-12,805.46	-7,672.65
theta	-	0.88*** (0.04)	-
Akaike Inf. Crit.	27,655.39	25,646.91	15,377.29
Note:			*p0.1; **p0.05; ***p0.01

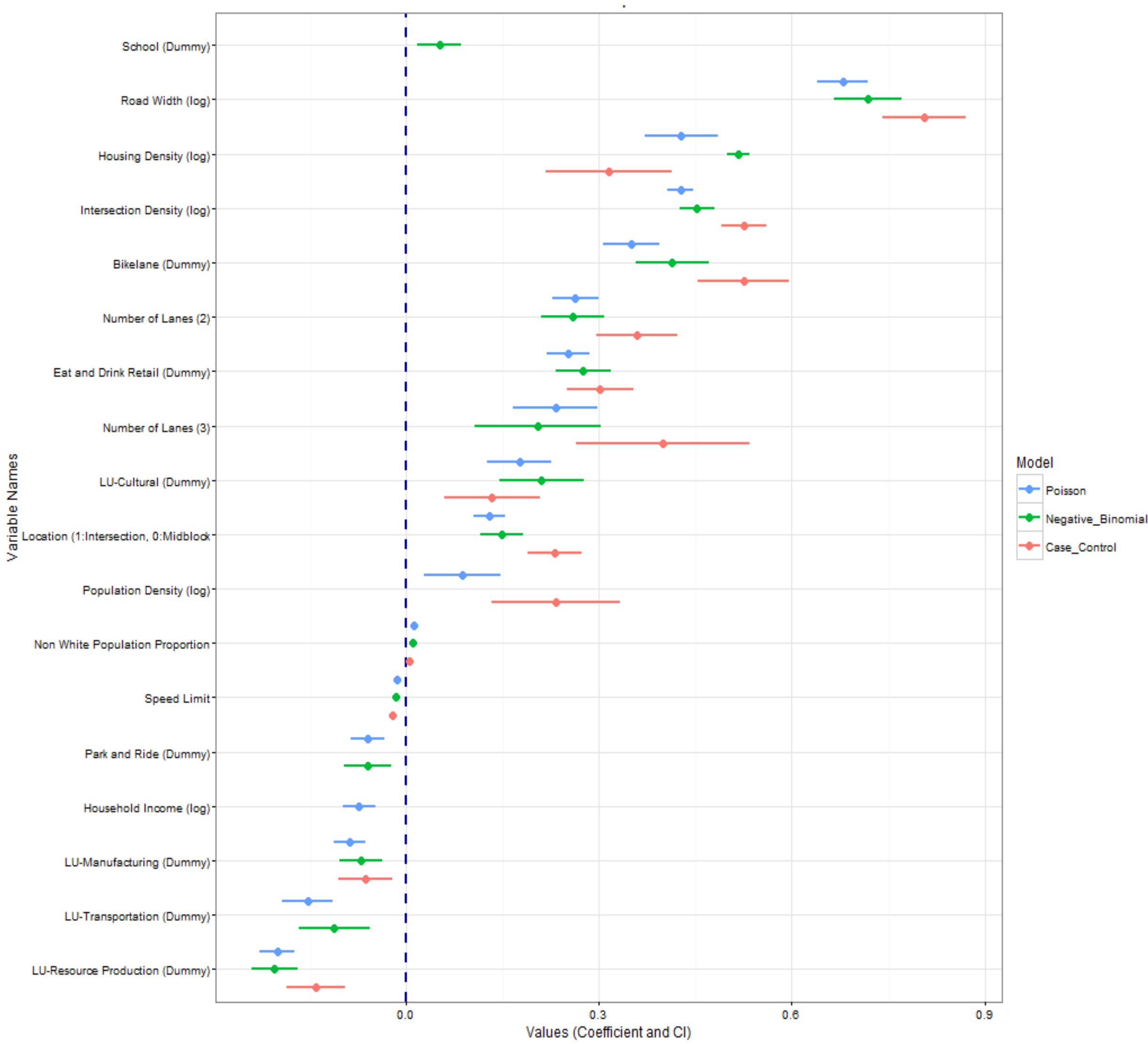

Figure 8. Model Comparison

7. Marginal Effects

Marginal effects (predicted marginal probabilities) in the Case-Control Model were plotted with all co-variates set to the mean value (Figure 9). Density measures, number of intersections, road width, and speed limits had the strongest effects. The number of lanes showed a decrease in risk at more than three lanes, suggesting that road facilities with more lanes served little pedestrian or bicycling activity.

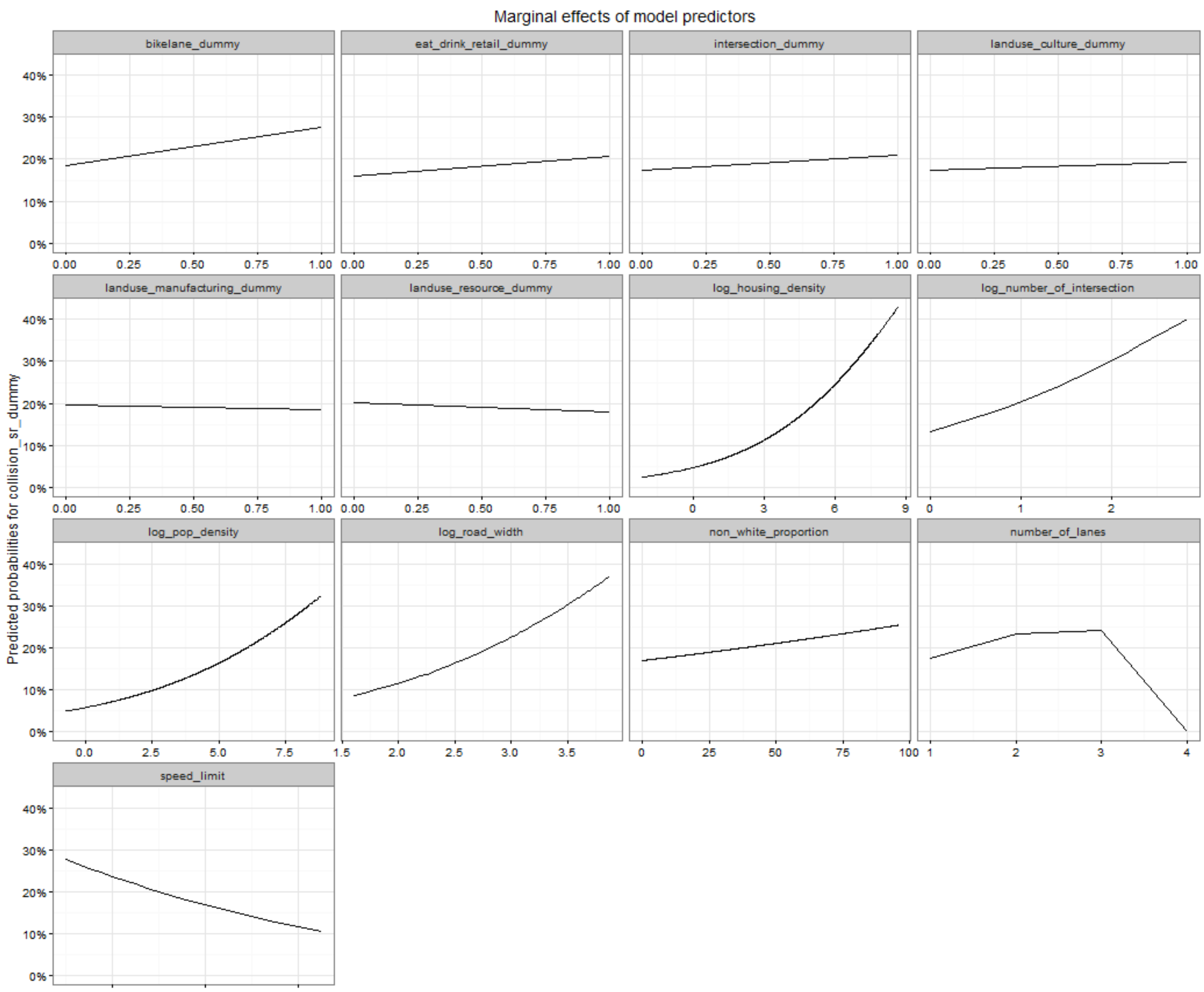

Figure 9. Marginal Effects in the Case-Control Model

8. Discussion

The objective of this analysis was to identify road and neighborhood environmental and socio-economic factors that are associated with pedestrian and bicyclist collisions at intersections and mid-blocks on main street highways. The study hypothesized that pedestrian and bicyclist collisions were more likely to occur on more trafficked state routes with complex road configurations and features. Also, collisions were more likely to occur along stretches of road with surrounding built environmental factors that support pedestrian and bicyclist travel. Finally, neighborhood socio-economic factors would also be related to the occurrence of pedestrian and bicyclist collision.

In all models, intersection locations were found to have a higher probability of collision occurrence than mid-block locations. This result was expected, as intersections have more complex road design and signal systems than mid-blocks. Also, they are used more often by pedestrians and bicyclists because they provide opportunities for changing travel direction. Micro-environmental factors that were positively related to collision occurrence included intersection density and roadway width, confirming the results of previous studies (Siddiqui et al., 2012; Quistberg et al., 2015). As expected, the presence of bike lanes had a positive relationship with the risk of collision occurrence.

In relation to macro-environmental and socio-economic factors, population density, which served as a surrogate measure for pedestrian exposure (Siddiqui et al., 2012), had a positive relationship with the risk of collision occurrence, thus confirming the results of several studies (LaScala et al., 2000; Loukaitou-Sideris et al., 2007; Wier et al., 2009). Collisions were also positively associated with housing density. A higher number of housing units implies more residents, who in turn generate more pedestrian and bike activity. On the other hand, neighborhood household income had a negative association with pedestrian-bicyclist collisions, confirming that low income areas have a higher probability of crashes. It follows that a higher proportion of non-white populations have a positive association with collision risk. The relationship between minority populations and crashes has been supported by previous studies (Laflamme and Diderichsen, 2000; Loukaitou-Sideris et al., 2007; Cottrill and Thakuriah, 2010; Siddiqui et al., 2012). Minority populations typically have lower vehicle ownership (Dawkins et al., 2005) and therefore tend to travel using non-motorized modes and public transportation. These populations are more vulnerable to collisions because they are more often exposed to traffic.

Pedestrian and bicyclist volumes are closely related to land use. To control for the confounding effects of land-use pattern, the study included major land-use categories as dummy variables in the models. Among land-use categories, the cultural-entertainment-recreational land-use type had a positive relationship with collision occurrence. This land-use category includes cultural activities, amusements, public assembly, and green space, which often attract walking or bicycling trips.

This study focused on identifying the characteristics of locations with a high risk of collision occurrence. Further research should consider individual-level factors (e.g., alcohol use, weather), to complement this study. Also, more precise results could be obtained if pedestrian and bicyclist volumes at specific locations were available to better estimate exposure.

IV. Conclusion

The results of this study can be used to guide and improve pedestrian and bicyclist safety measures. The hotspots detected in MSH zones will help transportation agencies prioritize the locations of future interventions to reduce the risk of collision. Models estimating the risk of a collision showed that intersections were more dangerous than mid-blocks. Study results suggested that collisions were more likely to occur on wider roads, roads with bike lanes, and roads passing through low income and non-white neighborhoods. The risk of a collision occurring was also higher at intersections surrounded by land uses that attract pedestrian and bicycle activity. Safety measures protecting pedestrians and bicyclists should be applied to the types of roads and neighborhoods identified ion this study.

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Appendices

1. Main Street Highways Statistics

Table A - 1. Main Street Highway Zones by State Route

State Route Number	Number of MSH	Length (km)	Size (acre)		
			100m Buffer	200m Buffer	300m Buffer
2	17	43.40	2297.67	4880.74	7734.38
3	1	3.19	163.66	340.05	529.84
4	4	10.89	598.84	1307.76	2102.91
6	1	1.46	79.15	172.70	280.69
7	5	9.18	499.72	1078.79	1733.26
9	7	10.97	607.06	1325.57	2150.01
12	7	15.96	852.77	1813.63	2880.98
14	7	15.74	834.55	1777.61	2828.93
16	4	5.04	279.79	621.52	1025.26
17	4	11.71	609.72	1281.48	2015.25
18	9	14.08	765.70	1670.96	2715.83
20	15	49.04	2555.15	5348.49	8374.33
21	4	5.59	315.74	697.03	1135.74
22	3	3.48	199.51	445.69	738.24
23	2	2.49	137.96	305.82	503.95
24	1	1.46	80.08	175.69	286.82
25	4	3.45	201.75	465.55	791.32
26	3	0.91	68.22	182.94	344.14
27	13	22.04	1193.54	2592.24	4193.05
28	6	14.08	742.66	1578.41	2507.21
31	3	3.57	199.54	445.51	737.76
41	1	0.66	40.54	96.59	168.16
92	1	1.22	68.09	151.68	250.78
96	1	4.11	210.93	437.38	679.30
97	5	17.00	884.06	1844.51	2879.83
99	14	65.99	3375.98	6969.11	10777.41
100	1	1.83	105.05	238.99	401.19
101	13	52.03	2691.93	5609.69	8745.82
103	1	3.79	194.82	405.17	630.99
104	5	10.15	567.24	1240.49	1989.55
105	4	8.41	445.43	949.77	1512.65
108	1	3.58	182.95	378.11	586.17
109	3	8.44	440.35	927.23	1460.58
124	2	2.09	117.69	265.75	444.65
129	4	4.81	268.00	586.99	961.97

141	2	3.16	185.57	407.76	658.47
142	1	2.39	126.00	267.46	424.27
150	3	5.90	322.18	697.96	1116.41
155	6	8.87	482.27	1050.90	1704.74
161	7	12.50	678.78	1478.32	2398.16
162	3	5.42	289.85	624.28	1004.47
163	3	5.42	299.01	660.08	1083.21
164	2	9.63	491.41	1013.48	1565.86
165	1	1.70	99.67	217.78	347.95
166	2	7.11	365.13	758.52	1176.92
167	7	11.65	630.49	1363.55	2199.71
169	5	17.89	922.86	1923.19	3000.58
170	1	1.85	106.92	233.83	374.85
171	2	6.09	316.29	663.49	1041.63
172	1	1.32	72.43	159.30	260.61
173	2	4.92	265.48	570.64	901.55
174	2	3.71	199.03	429.03	689.90
181	2	9.74	496.90	1024.78	1583.31
195	3	6.57	347.66	741.68	1181.98
202	6	28.03	1433.80	2935.80	4479.40
203	4	5.13	284.46	630.92	1039.41
215	2	9.40	482.98	995.79	1537.91
224	2	5.86	305.05	641.09	1008.15
225	1	4.11	211.04	436.87	676.19
231	3	2.97	169.66	381.39	633.81
240	3	6.19	329.02	704.59	1126.67
241	1	1.96	119.94	282.20	458.69
260	3	5.68	304.05	654.61	1051.72
263	1	0.53	34.17	83.86	149.06
270	3	8.28	430.55	902.54	1413.89
272	3	1.79	111.77	270.07	474.73
274	1	0.73	43.75	102.99	177.66
278	1	1.80	95.96	206.20	330.98
281	2	1.84	106.41	243.83	412.30
285	3	9.52	492.96	1031.42	1615.42
290	4	20.46	1041.61	2143.56	3305.63
291	1	6.13	318.31	667.55	1047.38
292	1	0.43	29.00	73.50	133.51
303	2	4.98	261.69	553.90	876.85
304	2	4.37	226.85	477.56	756.26
305	2	15.59	785.86	1602.48	2449.75
310	1	2.97	153.99	322.94	506.56
395	4	14.86	780.66	1653.39	2608.35
397	1	6.33	319.30	652.16	998.46

409	1	0.87	50.73	116.76	197.94
410	3	10.55	544.65	1135.81	1773.35
411	3	2.68	162.36	375.20	631.25
500	3	5.39	288.77	621.74	999.07
501	5	18.03	928.94	1931.77	3006.94
502	2	2.47	137.44	305.92	505.43
503	3	9.08	476.92	1000.10	1569.06
505	2	3.20	173.60	377.97	612.66
506	1	1.21	67.56	150.61	249.19
507	11	22.00	1171.47	2508.27	4010.89
508	1	1.68	90.57	196.53	317.78
509	10	10.24	601.21	1374.86	2317.17
510	1	2.05	109.10	233.72	373.82
513	1	5.39	274.03	563.49	868.28
515	2	7.98	409.37	848.92	1318.88
516	5	22.16	1155.05	2425.16	3779.10
518	1	0.97	55.39	126.27	212.65
522	5	18.09	940.45	1966.21	3060.56
524	6	11.76	627.14	1342.69	2145.82
525	2	8.39	437.64	921.81	1452.42
526	4	7.38	398.23	858.24	1379.83
527	3	15.74	800.90	1646.13	2532.22
528	2	5.46	285.48	601.99	949.49
529	6	11.84	630.36	1351.15	2162.62
530	5	3.71	221.59	519.47	893.72
531	3	6.26	355.73	782.41	1265.96
532	1	3.83	196.79	409.10	636.88
536	2	1.96	112.00	253.09	423.43
538	1	5.21	272.92	568.23	876.90
543	1	1.64	88.95	193.39	313.34
544	1	3.44	177.79	369.75	575.62
547	1	0.75	44.61	104.73	180.37
548	1	3.66	188.33	391.88	610.68
823	2	2.93	161.55	353.74	576.53
900	6	14.36	755.50	1601.21	2533.83
902	2	5.43	286.71	603.28	949.51
903	2	5.54	287.50	602.34	945.99
904	3	5.56	298.00	642.56	1033.62
908	3	10.79	552.68	1144.45	1775.08
Total	405	1007.19	53264.54	113067.77	179100.09

The total number of State Routes that include MSH Zones is 118.

Table A - 2. Main Street Highway Zones by City

City	Number of MSH	Length (km)	Size (acre)		
			100m Buffer	200m Buffer	300m Buffer
Aberdeen	7	16.79	881.04	1864.08	2949.94
Airway Heights	2	3.21	174.28	379.60	615.96
Anacortes	2	16.31	819.65	1665.72	2538.67
Arlington	6	9.58	555.01	1232.83	2012.39
Asotin	2	2.01	113.94	247.98	407.08
Auburn	10	21.07	1118.86	2392.75	3821.21
Bainbridge Islan	1	11.06	554.38	1124.05	1708.96
Battle Ground	4	8.32	442.40	946.87	1513.37
Benton City	1	4.11	211.04	436.87	676.19
Bingen	2	2.53	142.50	315.89	520.12
Black Diamond	2	3.79	202.71	436.42	701.15
Blaine	2	5.30	277.28	585.27	924.02
Bonney Lake	2	6.73	348.32	727.67	1138.06
Bothell	3	10.82	557.68	1160.04	1802.30
Bremerton	5	12.32	642.52	1354.40	2139.68
Brewster	1	1.67	90.24	195.95	317.16
Bridgeport	1	3.25	175.23	374.69	584.39
Buckley	1	3.82	196.33	408.14	635.28
Bucoda	1	1.26	69.76	155.02	255.73
Burien	7	7.13	406.78	922.08	1545.80
Burlington	1	3.74	191.31	396.04	614.05
Camas	7	12.37	665.44	1437.04	2314.75
Carnation	1	1.61	87.10	189.68	307.75
Castle Rock	1	1.42	85.21	190.83	309.01
Cathlamet	2	2.64	161.63	375.91	634.44
Centralia	5	8.84	474.41	1024.27	1650.38
Chelan	4	12.83	677.08	1422.19	2222.85
Cheney	3	5.56	298.00	642.56	1033.62
Chewelah	1	1.65	89.39	194.28	314.69
Clarkston	3	5.33	286.81	620.05	999.68
Cle Elum	1	3.05	157.64	329.07	515.30
Colfax	4	4.48	252.58	567.01	943.16
Colton	1	1.24	69.08	153.66	253.76
Colville	3	5.67	333.71	761.31	1268.77
Concrete	1	2.56	134.01	283.51	448.41
Connell	1	2.99	155.35	326.20	512.57
Cosmopolis	2	1.98	113.33	257.67	433.04
Coulee Dam	1	2.54	132.44	278.30	437.92
Covington	4	5.52	303.93	669.93	1097.94

Creston	1	0.96	58.41	132.39	221.87
Darrington	1	2.92	151.43	317.09	497.07
Davenport	3	2.34	138.96	324.46	556.51
Dayton	1	2.29	131.35	279.21	442.03
Des Moines	3	4.50	245.72	537.38	873.95
Duvall	2	2.06	117.25	265.51	444.81
Eatonville	1	2.61	143.64	316.71	520.10
Edgewood	1	5.40	274.65	563.09	864.07
Edmonds	6	14.89	807.51	1717.84	2709.02
Electric City	1	1.34	73.87	163.23	268.11
Elmer City	1	1.24	68.92	153.34	253.27
Entiat	1	5.12	260.55	536.60	828.17
Enumclaw	2	3.90	208.18	447.07	716.76
Ephrata	2	7.43	382.58	796.19	1240.84
Everett	9	22.53	1181.84	2498.83	3947.94
Everson	1	3.44	177.79	369.75	575.62
Federal Way	4	15.51	797.49	1656.98	2578.55
Fife	1	1.40	76.24	166.95	272.17
Forks	1	5.76	294.22	603.98	929.17
Garfield	1	1.83	97.80	209.44	334.86
Gig Harbor	4	5.04	279.79	621.52	1025.26
Gold Bar	1	3.43	177.35	370.23	578.63
Goldendale	1	2.39	126.00	267.46	424.27
Grand Coulee	3	5.41	290.83	628.13	1011.79
Granite Falls	1	1.22	68.09	151.68	250.78
Harrington	1	1.17	64.83	144.09	238.12
Hoquiam	5	17.24	897.43	1884.72	2961.98
Ilwaco	2	4.38	238.12	519.40	843.18
Ione	1	1.46	80.07	175.61	286.53
Issaquah	2	3.29	178.09	387.13	627.03
Kahlotus	3	2.01	130.23	314.02	542.21
Kelso	4	3.97	225.05	508.41	851.05
Kenmore	1	3.38	182.46	389.86	610.11
Kennewick	5	15.16	788.06	1653.71	2596.27
Kent	4	26.99	1386.00	2872.07	4427.83
Kirkland	1	6.90	345.14	698.69	1060.53
Lake Forest Park	2	6.07	315.35	661.38	1038.08
Latah	1	1.29	71.14	156.61	256.50
Leavenworth	1	2.05	109.16	233.81	373.98
Lind	1	2.87	148.44	310.51	487.28
Long Beach	1	3.79	194.82	405.17	630.99
Longview	1	6.41	340.04	724.57	1137.60
Lynnwood	4	11.65	606.74	1275.53	2006.36

Mansfield	1	1.32	72.43	159.30	260.61
Maple Valley	2	9.31	475.67	982.37	1519.97
Marcus	1	1.32	72.85	161.23	265.08
Marysville	5	7.87	427.73	933.03	1515.85
McCleary	1	3.58	182.95	378.11	586.17
Medical Lake	2	5.43	286.71	603.28	949.51
Metaline	1	1.52	82.89	181.29	295.20
Metaline Falls	1	0.58	36.57	88.62	156.03
Mill Creek	2	8.89	454.93	940.78	1457.54
Milton	2	2.08	118.30	267.62	447.96
Monroe	2	5.30	285.25	617.04	995.31
Morton	2	2.66	146.72	324.33	532.70
Moses Lake	5	16.17	838.00	1753.47	2746.36
Mount Vernon	3	7.17	384.92	821.32	1300.33
Mukilteo	3	9.41	498.19	1058.19	1679.79
Newport	4	4.35	250.18	560.12	930.06
Nooksack	1	1.91	100.91	215.75	345.55
Normandy Park	2	2.74	168.50	385.44	647.20
North Bend	1	3.74	191.94	398.33	619.01
Northport	1	1.52	82.71	180.91	294.58
Oak Harbor	1	6.44	326.06	667.06	1022.28
Oakesdale	1	1.87	99.37	212.94	341.33
Oakville	1	1.01	57.72	130.96	219.71
Odessa	2	3.52	190.92	411.62	662.24
Okanogan	1	5.34	271.47	558.46	860.97
Omak	3	6.11	326.77	694.27	1100.50
Oroville	1	2.37	124.80	265.06	420.75
Orting	1	3.69	188.96	391.48	608.73
Othello	1	1.46	80.08	175.69	286.82
Palouse	4	3.65	210.81	478.60	802.24
Pasco	1	6.33	319.30	652.16	998.46
Pateros	1	1.50	82.06	179.62	292.70
Pe Ell	1	1.46	79.15	172.70	280.69
Pomeroy	1	4.62	235.90	487.31	754.18
Port Angeles	2	10.71	551.33	1147.11	1787.35
Port Orchard	2	7.11	365.13	758.52	1176.92
Port Townsend	1	4.45	227.02	469.26	726.94
Poulsbo	1	4.53	231.49	478.43	740.79
Prescott	1	1.21	67.40	150.30	248.70
Pullman	9	13.96	765.50	1681.00	2740.69
Puyallup	5	6.60	365.31	802.63	1312.99
Quincy	4	6.27	340.89	743.84	1208.81
Rainier	1	1.80	96.56	208.61	336.19

Raymond	2	7.61	391.69	814.27	1266.77
Reardan	3	2.07	125.76	298.07	516.89
Redmond	5	19.02	975.54	2005.25	3065.62
Renton	6	23.35	1199.59	2488.56	3863.63
Republic	1	2.63	137.07	287.61	451.45
Ridgefield	2	4.79	252.02	534.66	847.39
Rockford	1	1.80	95.96	206.20	330.98
Roslyn	1	2.49	129.86	273.27	430.69
Roy	1	2.04	109.53	233.59	372.35
Ruston	1	0.82	48.33	112.17	191.52
SeaTac	1	6.26	317.03	649.57	997.58
Seattle	8	40.20	2048.80	4221.29	6516.82
Sedro-Woolley	4	7.11	384.73	830.74	1337.40
Selah	2	2.93	161.55	353.74	576.53
Shelton	1	3.19	163.66	340.05	529.84
Shoreline	2	5.95	309.67	650.37	1022.04
Snoqualmie	1	4.45	234.98	487.03	753.35
Soap Lake	2	2.07	117.86	266.73	446.63
South Bend	1	4.89	256.94	535.11	826.97
South Prairie	1	0.88	51.01	117.52	199.55
Spokane	6	27.51	1412.88	2931.81	4556.19
Spokane Valley	5	21.15	1084.14	2245.85	3485.16
Springdale	2	2.87	156.75	340.04	548.51
St. John	1	1.32	73.12	161.73	265.83
Stanwood	1	3.83	196.79	409.10	636.88
Stevenson	1	1.21	67.39	150.29	248.70
Sultan	1	4.82	245.79	507.11	783.94
Sumas	3	2.61	151.84	349.30	592.94
Sumner	1	0.85	49.89	115.28	196.20
Sunnyside	1	1.96	119.94	282.20	458.69
Tacoma	7	14.01	761.50	1648.40	2656.25
Tekoa	2	2.87	155.85	339.93	553.17
Tenino	2	3.90	207.62	444.71	710.86
Toledo	1	1.03	58.81	133.04	222.46
Tonasket	3	1.83	113.81	274.14	481.02
Toppenish	3	3.48	199.51	445.69	738.24
Tukwila	1	2.62	137.35	290.17	458.38
Twisp	1	3.49	180.20	375.89	587.09
Uniontown	1	1.75	94.23	203.95	329.20
Vader	1	1.21	67.56	150.61	249.19
Vancouver	3	13.25	676.93	1397.11	2159.55
Waitsburg	2	2.98	161.54	352.39	573.04
Warden	1	1.85	106.92	233.83	374.85

Washougal	1	5.40	274.62	564.77	870.39
Washtucna	1	1.55	84.27	184.04	299.32
Waterville	1	2.06	116.03	256.56	406.72
Wenatchee	3	9.52	492.96	1031.42	1615.42
West Richland	2	5.86	305.05	641.09	1008.15
Westport	1	4.77	242.45	497.54	765.01
White Salmon	1	2.78	158.93	339.12	532.51
Wilbur	2	2.27	127.63	285.87	474.58
Wilkeson	1	1.70	99.67	217.78	347.95
Winlock	1	2.17	114.79	244.93	390.20
Winthrop	1	2.78	147.18	308.57	484.25
Woodinville	1	4.71	238.89	490.96	755.96
Woodland	1	3.22	171.96	359.14	561.12
Woodway	1	0.36	33.28	97.58	182.43
Yelm	2	6.22	322.69	675.80	1059.20
Total	405	1007.19	53264.55	113067.77	179100.09

The total number of cities that have MSH Zones is 183.

Table A - 3. Main Street Highway Zones by County

County	Number of MSH	Length (km)	Size (acre)		
			100m Buffer	200m Buffer	300m Buffer
ADAMS	3	5.88	312.79	670.24	1073.42
ASOTIN	5	7.34	400.75	868.03	1406.75
BENTON	8	25.13	1304.15	2731.67	4280.60
CHELAN	9	29.51	1539.74	3224.02	5040.42
CLALLAM	3	16.47	845.56	1751.09	2716.51
CLARK	17	44.13	2311.40	4880.45	7705.45
COLUMBIA	1	2.29	131.35	279.21	442.03
COWLITZ	7	15.02	822.26	1782.95	2858.78
DOUGLAS	3	6.63	363.69	790.55	1251.72
FERRY	1	2.63	137.07	287.61	451.45
FRANKLIN	5	11.32	604.88	1292.38	2053.23
GARFIELD	1	4.62	235.90	487.31	754.18
GRANT	18	40.54	2150.93	4585.41	7297.38
GRAYS HARBOR	17	45.36	2374.92	5013.06	7915.85
ISLAND	1	6.44	326.06	667.06	1022.28
JEFFERSON	1	4.45	227.02	469.26	726.94
KING	78	239.51	12485.14	26205.58	41078.05
KITSAP	9	35.02	1793.51	3715.41	5766.34
KITTITAS	2	5.54	287.50	602.34	945.99
KLICKITAT	4	7.70	427.42	922.47	1476.90
LEWIS	11	17.36	941.43	2049.87	3325.63
LINCOLN	12	12.33	706.51	1596.50	2670.21
MASON	1	3.19	163.66	340.05	529.84
OKANOGAN	14	28.86	1537.88	3283.59	5235.64
PACIFIC	6	20.66	1081.57	2273.94	3567.92
PEND OREILLE	7	7.91	449.72	1005.63	1667.83
PIERCE	29	57.01	3071.76	6615.63	10622.78
SKAGIT	11	36.88	1914.62	3997.33	6238.85
SKAMANIA	1	1.21	67.39	150.29	248.70
SNOHOMISH	44	112.71	5995.13	12752.46	20214.88
SPOKANE	20	65.95	3423.10	7165.92	11227.91
STEVENS	8	13.02	735.41	1637.77	2691.63
THURSTON	6	13.17	696.62	1484.14	2361.98
WAHKIAKUM	2	2.64	161.63	375.91	634.44
WALLA WALLA	3	4.19	228.94	502.69	821.74
WHATCOM	7	13.26	707.81	1520.07	2438.12
WHITMAN	24	32.98	1818.33	4008.27	6564.24
YAKIMA	6	8.36	480.99	1081.63	1773.45
Total	405	1007.19	53264.55	113067.77	179100.09

There are 39 counties in Washington State. This table includes 38 counties because San Juan County doesn't have any main street highways designated by WSDOT.Five MSHs are located in two counties. In this case, this study included the longer portion of each pair.
King County contains 23.8 percent of the total length of MSHs in Washington state.

Table A - 4. Main Street Highway Collisions by County

County	MSH Zones					
	100m Buffer		200m Buffer		300m Buffer	
Adams	0	0.0%	1	0.0%	1	0.0%
Asotin	15	0.3%	20	0.3%	23	0.3%
Benton	26	0.4%	36	0.5%	41	0.5%
Chelan	111	1.9%	154	2.1%	171	1.9%
Clallam	113	1.9%	131	1.8%	133	1.5%
Clark	249	4.2%	268	3.6%	290	3.3%
Columbia	4	0.1%	5	0.1%	5	0.1%
Cowlitz	157	2.7%	181	2.4%	208	2.4%
Douglas	4	0.1%	6	0.1%	8	0.1%
Ferry	2	0.0%	2	0.0%	2	0.0%
Franklin	7	0.1%	7	0.1%	11	0.1%
Garfield	1	0.0%	3	0.0%	3	0.0%
Grant	83	1.4%	110	1.5%	127	1.4%
Grays Harbor	152	2.6%	190	2.5%	202	2.3%
Island	43	0.7%	50	0.7%	56	0.6%
Jefferson	24	0.4%	27	0.4%	30	0.3%
King	2,386	40.7%	3,245	43.5%	3,987	45.2%
Kitsap	276	4.7%	310	4.2%	368	4.2%
Kittitas	10	0.2%	12	0.2%	13	0.1%
Klickitat	4	0.1%	6	0.1%	8	0.1%
Lewis	66	1.1%	79	1.1%	85	1.0%
Lincoln	7	0.1%	7	0.1%	7	0.1%
Mason	26	0.4%	32	0.4%	35	0.4%
Okanogan	41	0.7%	52	0.7%	59	0.7%
Pacific	29	0.5%	31	0.4%	33	0.4%
Pend Oreille	2	0.0%	2	0.0%	3	0.0%
Pierce	368	6.3%	456	6.1%	530	6.0%
Skagit	146	2.5%	173	2.3%	211	2.4%
Skamania	3	0.1%	3	0.0%	3	0.0%
Snohomish	754	12.9%	1,005	13.5%	1,211	13.7%
Spokane	582	9.9%	658	8.8%	736	8.3%
Stevens	20	0.3%	22	0.3%	26	0.3%
Thurston	49	0.8%	54	0.7%	55	0.6%
Wahkiakum	1	0.0%	1	0.0%	2	0.0%
Walla Walla	2	0.0%	2	0.0%	3	0.0%
Whatcom	10	0.2%	12	0.2%	15	0.2%
Whitman	65	1.1%	75	1.0%	84	1.0%
Yakima	27	0.5%	32	0.4%	45	0.5%
Total	5,865	100.0%	7,460	100.0%	8,830	100.0%

There are 39 counties in Washington State. This table includes 38 counties because San Juan County doesn't have MSHs.

Table A - 5. Main Street Highway Collisions by City

City	MSH Zones					
	100m Buffer		200m Buffer		300m Buffer	
Aberdeen	92	1.6%	122	1.6%	132	1.8%
Airway Heights	5	0.1%	6	0.1%	7	0.1%
Anacortes	25	0.4%	33	0.4%	38	0.5%
Arlington	29	0.5%	45	0.6%	53	0.7%
Auburn	90	1.5%	124	1.7%	160	2.1%
Bainbridge Island	36	0.6%	47	0.6%	53	0.7%
Battle Ground	25	0.4%	28	0.4%	31	0.4%
Benton City	6	0.1%	7	0.1%	7	0.1%
Black Diamond	4	0.1%	8	0.1%	9	0.1%
Blaine	5	0.1%	5	0.1%	6	0.1%
Bonney Lake	23	0.4%	25	0.3%	30	0.4%
Bothell	49	0.8%	69	0.9%	86	1.2%
Bremerton	203	3.5%	222	3.0%	266	3.6%
Brewster	2	0.0%	3	0.0%	6	0.1%
Bridgeport	2	0.0%	3	0.0%	4	0.1%
Buckley	6	0.1%	6	0.1%	7	0.1%
Burien	29	0.5%	65	0.9%	91	1.2%
Burlington	27	0.5%	30	0.4%	43	0.6%
Camas	21	0.4%	23	0.3%	28	0.4%
Carnation	4	0.1%	4	0.1%	4	0.1%
Castle Rock	9	0.2%	10	0.1%	12	0.2%
Cathlamet	1	0.0%	1	0.0%	1	0.0%
Centralia	60	1.0%	70	0.9%	75	1.0%
Chelan	10	0.2%	13	0.2%	13	0.2%
Cheney	28	0.5%	29	0.4%	31	0.4%
Chewelah	6	0.1%	6	0.1%	7	0.1%
Clarkston	15	0.3%	20	0.3%	23	0.3%
Cle Elum	8	0.1%	9	0.1%	9	0.1%
Colfax	16	0.3%	17	0.2%	17	0.2%
College Place	0	0.0%	0	0.0%	1	0.0%
Colville	14	0.2%	16	0.2%	19	0.3%
Connell	0	0.0%	0	0.0%	2	0.0%
Cosmopolis	1	0.0%	1	0.0%	1	0.0%
Coulee Dam	1	0.0%	1	0.0%	1	0.0%
Covington	28	0.5%	35	0.5%	36	0.5%
Darrington	1	0.0%	1	0.0%	2	0.0%
Davenport	6	0.1%	6	0.1%	6	0.1%
Dayton	4	0.1%	5	0.1%	5	0.1%
Des Moines	41	0.7%	57	0.8%	66	0.9%

Duvall	4	0.1%	5	0.1%	6	0.1%
Eatonville	10	0.2%	13	0.2%	14	0.2%
Edgewood	9	0.2%	10	0.1%	10	0.1%
Edmonds	133	2.3%	152	2.0%	170	2.3%
Electric City	1	0.0%	1	0.0%	1	0.0%
Enumclaw	21	0.4%	29	0.4%	32	0.4%
Ephrata	13	0.2%	22	0.3%	23	0.3%
Everett	167	2.8%	306	4.1%	375	5.0%
Everson	3	0.1%	3	0.0%	4	0.1%
Federal Way	147	2.5%	173	2.3%	187	2.5%
Fife	9	0.2%	20	0.3%	20	0.3%
Forks	11	0.2%	12	0.2%	12	0.2%
Gig Harbor	3	0.1%	7	0.1%	12	0.2%
Gold Bar	3	0.1%	4	0.1%	5	0.1%
Goldendale	2	0.0%	2	0.0%	4	0.1%
Grand Coulee	1	0.0%	1	0.0%	1	0.0%
Granite Falls	6	0.1%	11	0.1%	14	0.2%
Hoquiam	49	0.8%	53	0.7%	55	0.7%
Ione	0	0.0%	0	0.0%	1	0.0%
Issaquah	6	0.1%	9	0.1%	9	0.1%
Kelso	58	1.0%	69	0.9%	84	1.1%
Kenmore	51	0.9%	64	0.9%	64	0.9%
Kennewick	11	0.2%	19	0.3%	24	0.3%
Kent	454	7.7%	497	6.7%	580	7.8%
Kirkland	10	0.2%	13	0.2%	15	0.2%
Lake Forest Park	43	0.7%	45	0.6%	49	0.7%
Leavenworth	5	0.1%	5	0.1%	5	0.1%
Long Beach	15	0.3%	15	0.2%	15	0.2%
Longview	79	1.3%	90	1.2%	97	1.3%
Lynnwood	170	2.9%	198	2.7%	237	3.2%
Maple Valley	26	0.4%	31	0.4%	32	0.4%
Marysville	47	0.8%	51	0.7%	56	0.8%
McCleary	3	0.1%	5	0.1%	5	0.1%
Medical Lake	5	0.1%	5	0.1%	5	0.1%
Mill Creek	63	1.1%	69	0.9%	79	1.1%
Millwood	1	0.0%	3	0.0%	6	0.1%
Milton	12	0.2%	15	0.2%	17	0.2%
Monroe	34	0.6%	45	0.6%	51	0.7%
Morton	2	0.0%	3	0.0%	3	0.0%
Moses Lake	56	1.0%	68	0.9%	79	1.1%
Mount Vernon	69	1.2%	83	1.1%	99	1.3%
Mountlake Terrace	0	0.0%	3	0.0%	8	0.1%
Mukilteo	51	0.9%	54	0.7%	65	0.9%

Newport	2	0.0%	2	0.0%	2	0.0%
Nooksack	1	0.0%	1	0.0%	1	0.0%
Normandy Park	14	0.2%	16	0.2%	16	0.2%
North Bend	9	0.2%	13	0.2%	20	0.3%
Oak Harbor	41	0.7%	48	0.6%	54	0.7%
Oakville	1	0.0%	2	0.0%	2	0.0%
Okanogan	5	0.1%	8	0.1%	10	0.1%
Omak	24	0.4%	31	0.4%	33	0.4%
Oroville	4	0.1%	4	0.1%	4	0.1%
Orting	6	0.1%	7	0.1%	8	0.1%
Othello	0	0.0%	1	0.0%	1	0.0%
Palouse	2	0.0%	2	0.0%	2	0.0%
Pasco	7	0.1%	7	0.1%	9	0.1%
Pateros	1	0.0%	1	0.0%	1	0.0%
Pe Ell	2	0.0%	3	0.0%	3	0.0%
Pomeroy	1	0.0%	3	0.0%	3	0.0%
Port Angeles	102	1.7%	119	1.6%	121	1.6%
Port Orchard	17	0.3%	19	0.3%	20	0.3%
Port Townsend	24	0.4%	27	0.4%	30	0.4%
Poulsbo	12	0.2%	14	0.2%	15	0.2%
Pullman	46	0.8%	53	0.7%	62	0.8%
Puyallup	55	0.9%	63	0.8%	67	0.9%
Quincy	8	0.1%	14	0.2%	16	0.2%
Rainier	3	0.1%	3	0.0%	3	0.0%
Raymond	7	0.1%	9	0.1%	11	0.1%
Redmond	82	1.4%	127	1.7%	138	1.8%
Renton	152	2.6%	191	2.6%	216	2.9%
Republic	2	0.0%	2	0.0%	2	0.0%
Richland	1	0.0%	1	0.0%	1	0.0%
Ridgefield	5	0.1%	5	0.1%	5	0.1%
Rockford	1	0.0%	1	0.0%	1	0.0%
Roslyn	2	0.0%	3	0.0%	4	0.1%
Roy	3	0.1%	4	0.1%	4	0.1%
Ruston	1	0.0%	1	0.0%	2	0.0%
SeaTac	74	1.3%	84	1.1%	95	1.3%
Seattle	892	15.2%	1,395	18.7%	1,871	25.1%
Sedro-Woolley	19	0.3%	21	0.3%	25	0.3%
Selah	10	0.2%	13	0.2%	22	0.3%
Shelton	26	0.4%	31	0.4%	34	0.5%
Shoreline	119	2.0%	144	1.9%	160	2.1%
Snoqualmie	11	0.2%	12	0.2%	12	0.2%
Soap Lake	1	0.0%	1	0.0%	2	0.0%
South Bend	7	0.1%	7	0.1%	7	0.1%

South Prairie	1	0.0%	1	0.0%	1	0.0%
Spokane	453	7.7%	516	6.9%	571	7.7%
Spokane Valley	87	1.5%	96	1.3%	112	1.5%
St. John	1	0.0%	1	0.0%	1	0.0%
Stanwood	4	0.1%	8	0.1%	16	0.2%
Stevenson	3	0.1%	3	0.0%	3	0.0%
Sultan	7	0.1%	9	0.1%	10	0.1%
Sumas	1	0.0%	1	0.0%	2	0.0%
Sumner	2	0.0%	5	0.1%	7	0.1%
Tacoma	218	3.7%	263	3.5%	311	4.2%
Tekoa	0	0.0%	1	0.0%	1	0.0%
Tenino	7	0.1%	8	0.1%	8	0.1%
Toledo	1	0.0%	1	0.0%	1	0.0%
Toppenish	13	0.2%	15	0.2%	19	0.3%
Tukwila	19	0.3%	24	0.3%	25	0.3%
Twisp	1	0.0%	1	0.0%	1	0.0%
Vancouver	192	3.3%	203	2.7%	215	2.9%
Waitsburg	2	0.0%	2	0.0%	2	0.0%
Warden	3	0.1%	3	0.0%	4	0.1%
Washougal	6	0.1%	9	0.1%	11	0.1%
Waterville	0	0.0%	1	0.0%	2	0.0%
Wenatchee	95	1.6%	135	1.8%	151	2.0%
West Richland	8	0.1%	9	0.1%	9	0.1%
Westport	6	0.1%	7	0.1%	7	0.1%
White Salmon	2	0.0%	4	0.1%	4	0.1%
Wilbur	1	0.0%	1	0.0%	1	0.0%
Wilkeson	0	0.0%	1	0.0%	1	0.0%
Winlock	1	0.0%	1	0.0%	2	0.0%
Winthrop	3	0.1%	3	0.0%	3	0.0%
Woodinville	12	0.2%	18	0.2%	22	0.3%
Woodland	11	0.2%	12	0.2%	15	0.2%
Yakima	2	0.0%	2	0.0%	2	0.0%
Yelm	36	0.6%	39	0.5%	40	0.5%
Total	5,865	100.0%	7,460	100.0%	7,460	100.0%

The total number of cities that contain MSH Zones is 183. This table includes only the cities where collisions have occurred on MHSs. The numbers of cities with collisions in MSH zones is 151 (100 m), 156 (200 m), and 159 (300 m).

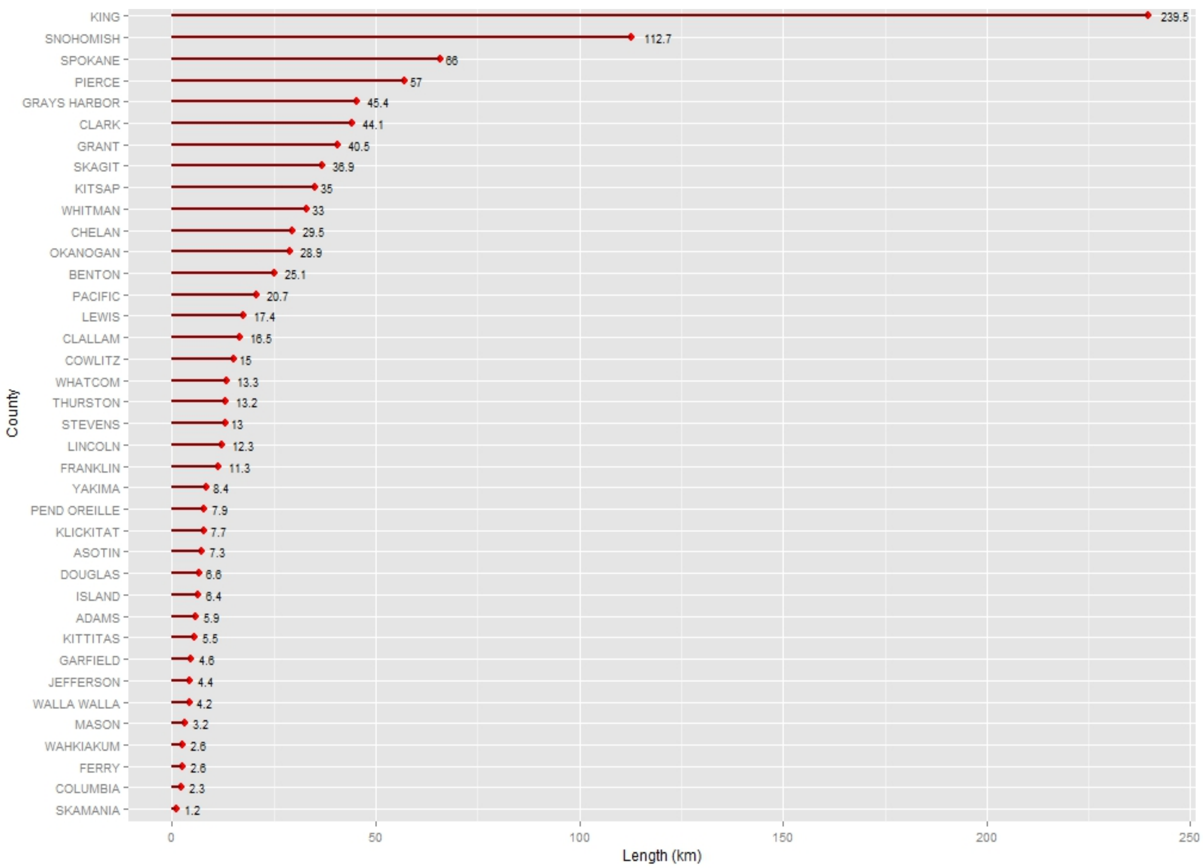


Figure A - 1. Total Length of Main Street Highways by County

2. Frequency of Collisions by State Route

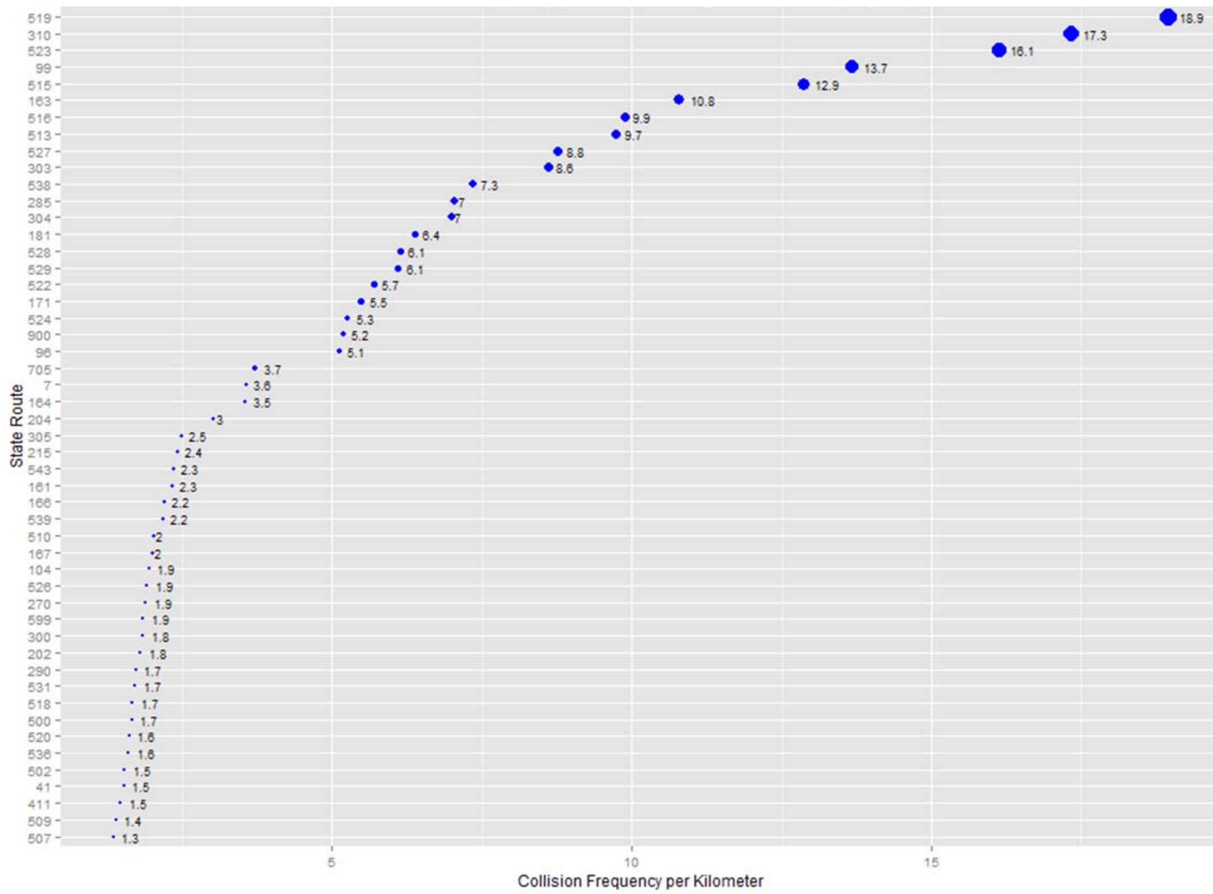


Figure A - 2. Pedestrian and Bicyclist Collision Frequency per Kilometer by State Route

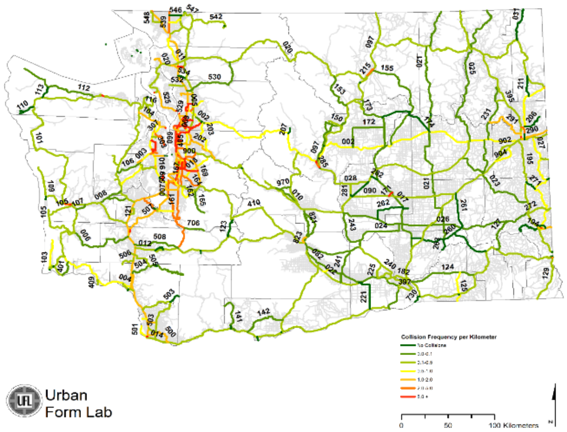
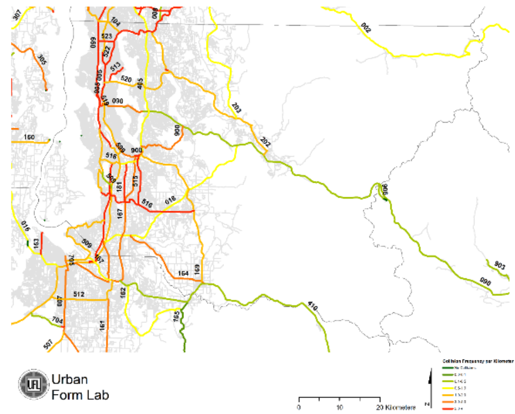
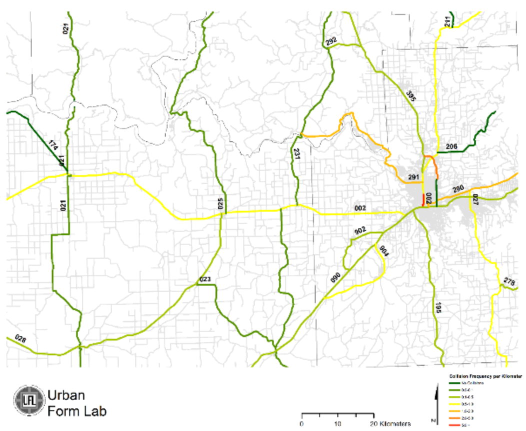
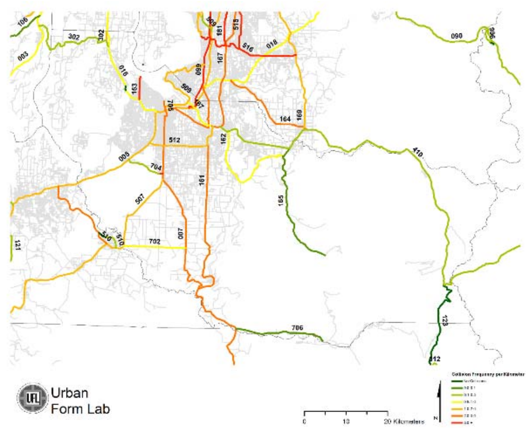
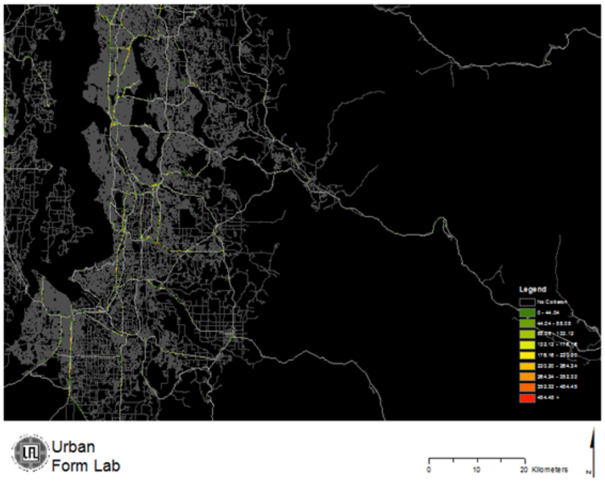
Washington State	King County
	
Spokane County	**Pierce County**
	

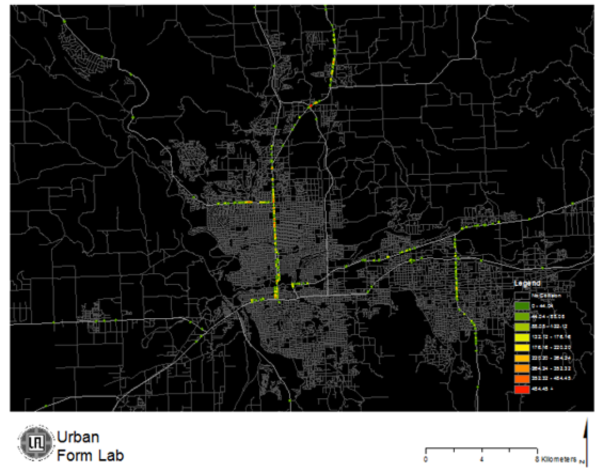
Figure A - 3. Pedestrian and Bicyclist Collision Frequency per Kilometer per State Route

3. Additional KDE Maps

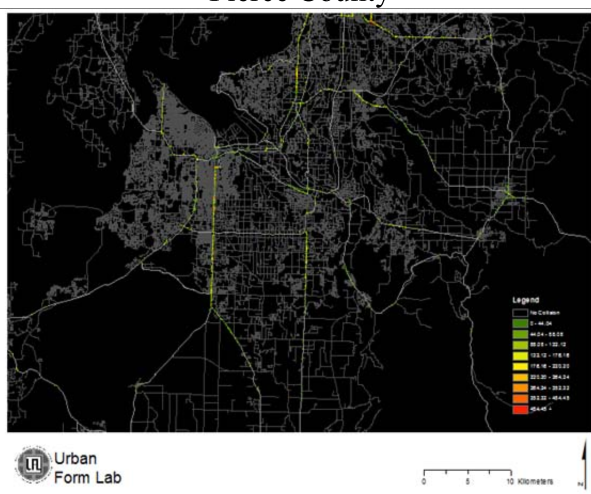
King County



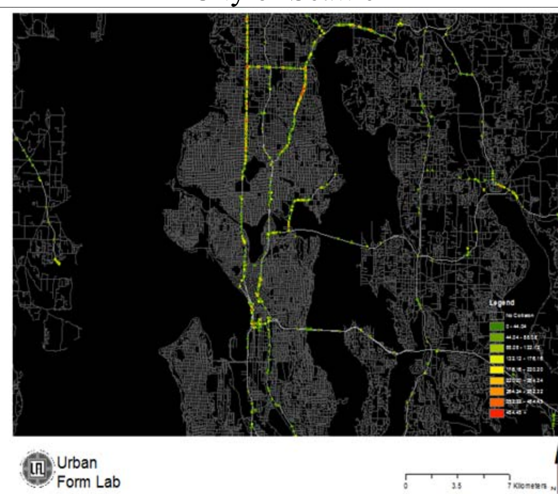
Spokane County



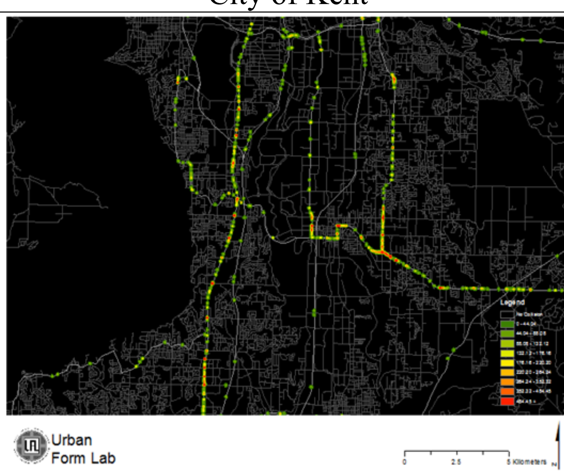
Pierce County



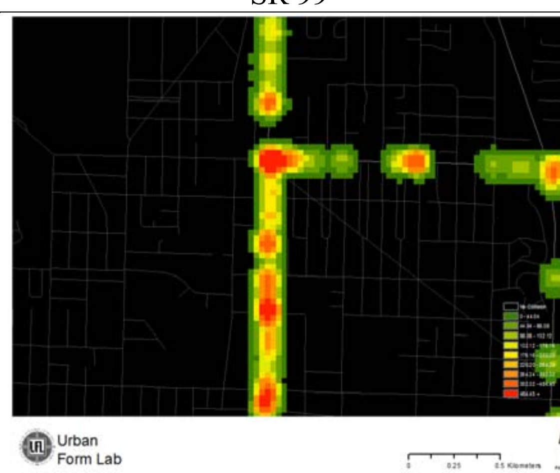
City of Seattle



City of Kent



SR 99



SR 522

SR 2 & SR 291

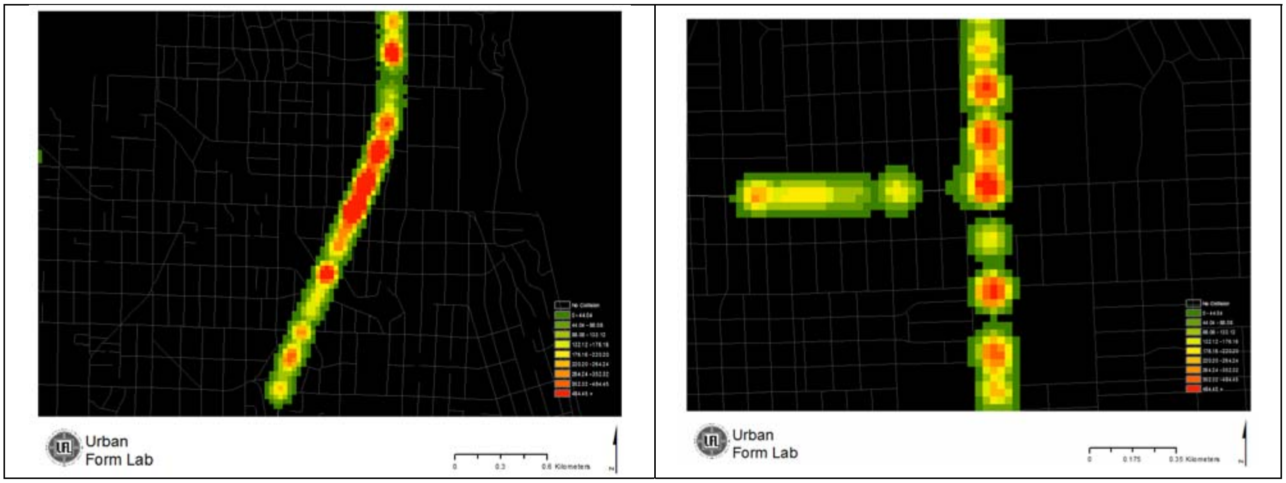


Figure A - 4. Additional Planar KDE Maps

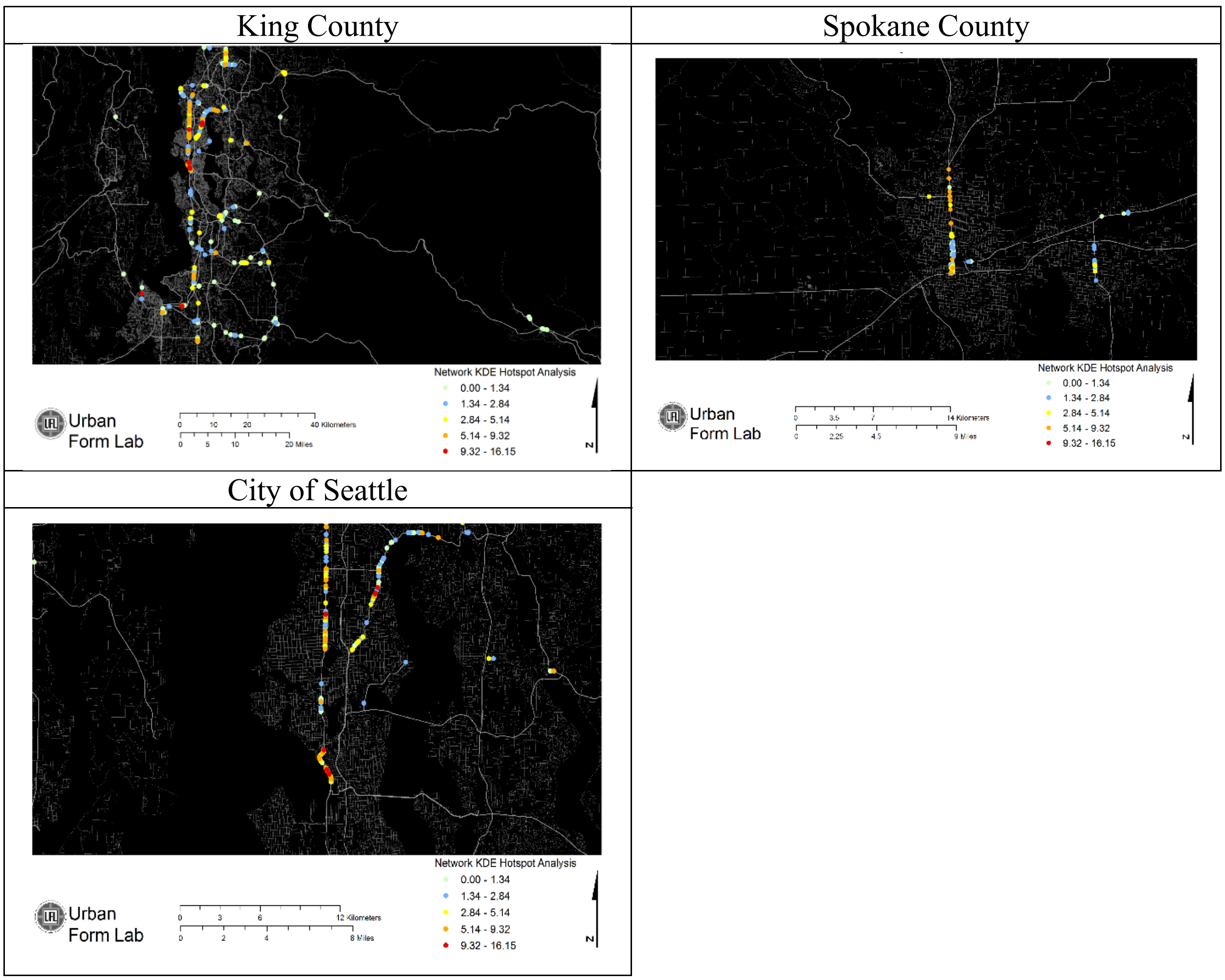


Figure A - 5. Additional Network KDE Maps

4. Distribution of the Built Environment Data

The following figures show the distribution of the data. Figure A - 6 shows histograms of all continuous variables. As we can see, most variables were skewed and did not fit a normal distribution. In this case, it is usually better to use logarithmic variables for a better fit. Figure A - 7 shows the distribution of all variables after log-transformation (green histograms). Speed limits and racial composition variables did not show a better distribution after log-transformation, so they remained the same. The bike lane length (red histogram) also did not improve after log transformation. The distribution of bike lanes suggested that it would be better to use a dummy variable.

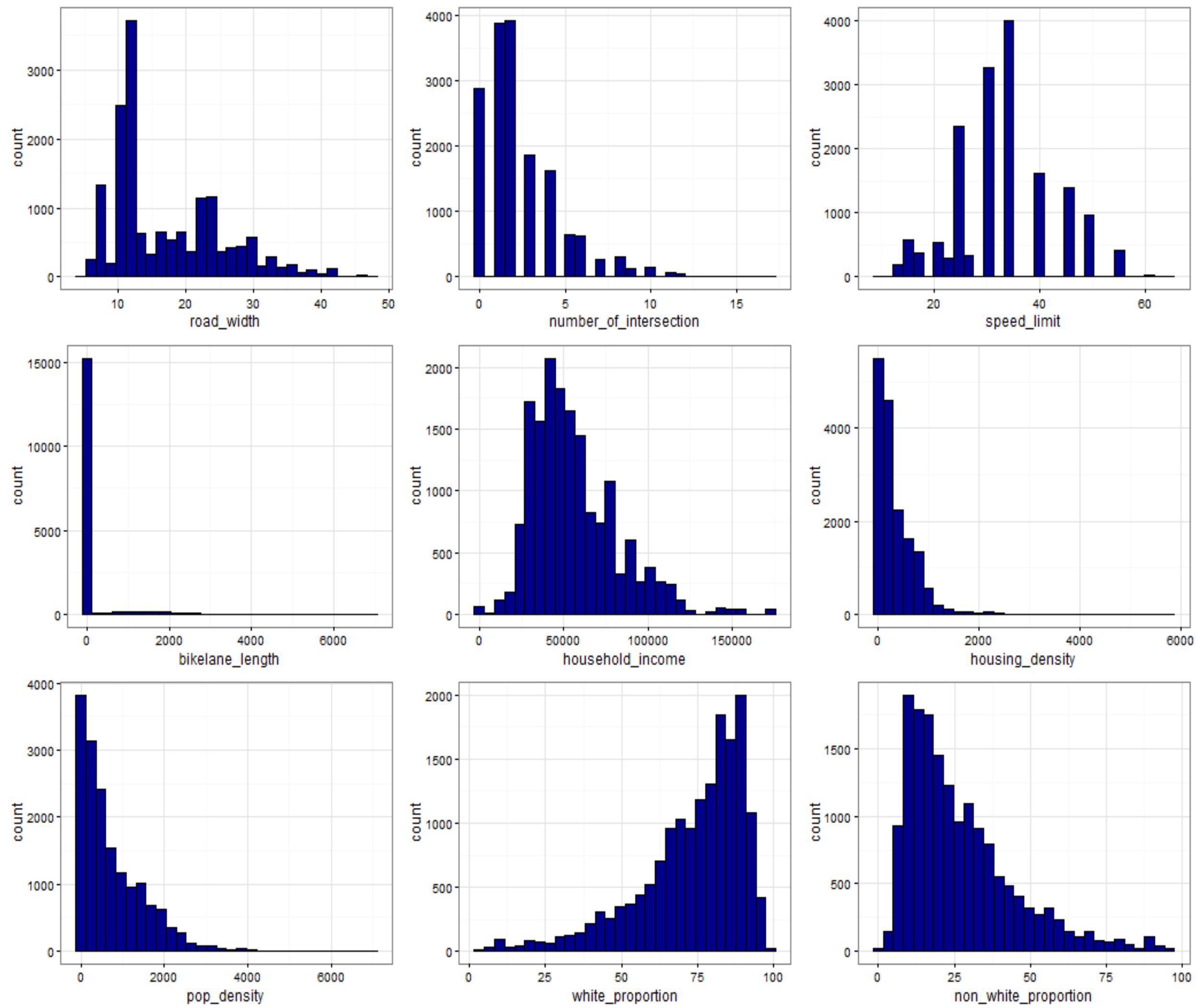


Figure A - 6. Distribution of Original Built Environment Variables

Figure A - 7 shows that logarithmic variables (in green) had a better fit. Because most of our samples did not have any bike lanes (most of them have zeros), the bike length variable had an abnormal distribution even after log-transformation.

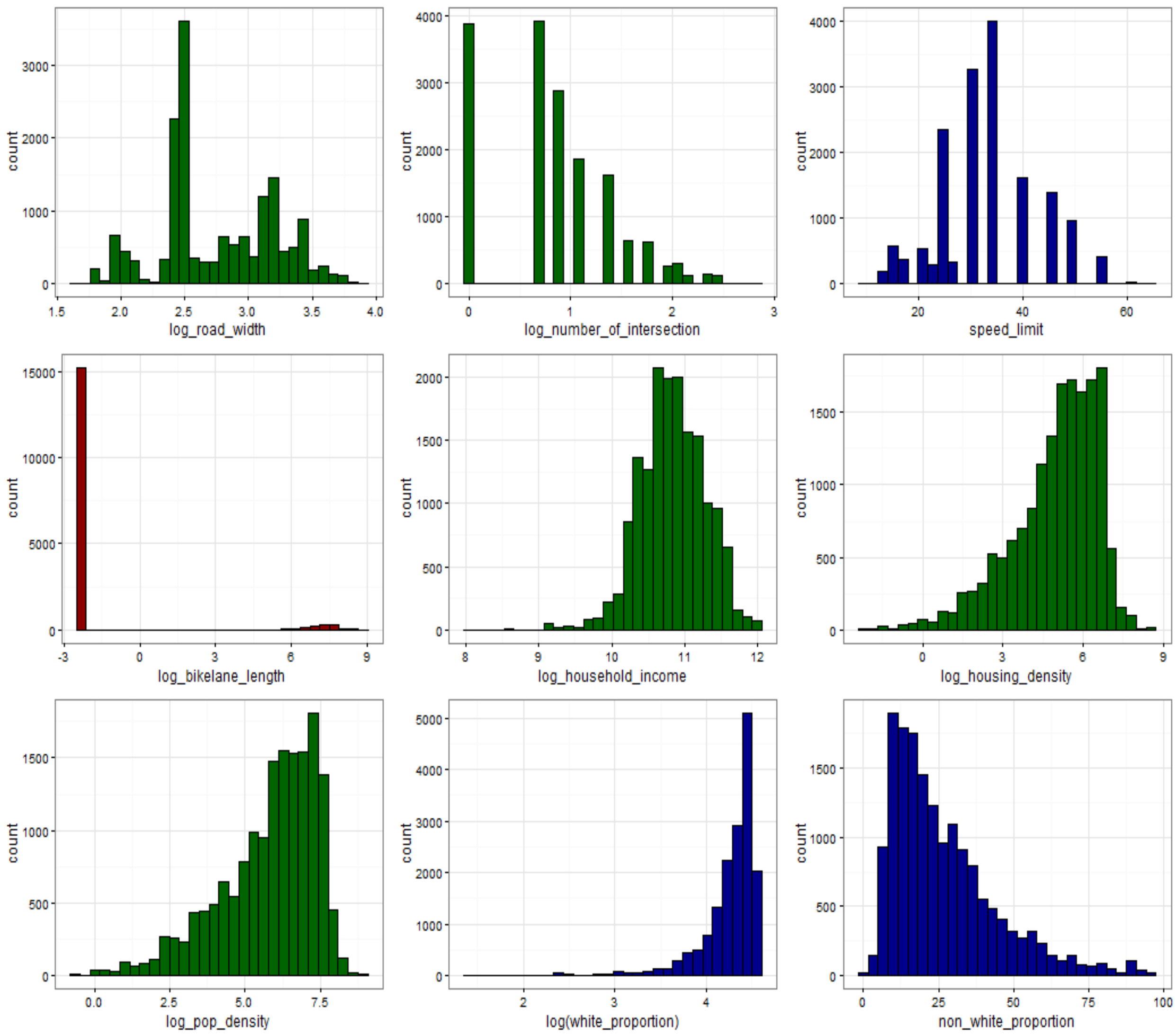


Figure A - 7. Distribution of Built Environment Log-Transformed Variables

5. Poisson Model

Table A - 6 shows the results for the full and fittest Poisson models.

Table A - 6. Poisson Regression Model Results

	Poisson Models	
	Number of Collisions	
	(1) Full Model (SE)	(2) Fittest Model (SE)
Location Type (0: Mid-Block, 1: Intersection)	0.13*** (0.02)	0.13*** (0.02)
Number of Lanes (2)	0.27*** (0.04)	0.26*** (0.04)
Number of Lanes (3)	0.24*** (0.07)	0.23*** (0.07)
Number of Lanes (4)	-10.28 (115.02)	-10.29 (115.01)
Road Width (log)	0.67*** (0.04)	0.68*** (0.04)
Park and Ride (Dummy)	-0.06** (0.03)	-0.06** (0.03)
Intersection Density (log)	0.43*** (0.02)	0.43*** (0.02)
Speed Limits	-0.01*** (0.001)	-0.01*** (0.001)
Bike Lane (Dummy)	0.35*** (0.04)	0.35*** (0.04)
Household Income (log)	-0.07*** (0.03)	-0.07*** (0.03)
Housing Density (log)	0.43*** (0.06)	0.43*** (0.06)
Population Density (log)	0.09 (0.06)	0.09 (0.06)
Race – Non-White Proportion	0.01*** (0.001)	0.01*** (0.001)
School (Dummy)	0.03 (0.03)	-
Eat and Drink Retail (Dummy)	0.25*** (0.03)	0.25*** (0.03)
LU – Manufacturing (Dummy)	-0.09*** (0.02)	-0.09*** (0.02)
LU – Transportation (Dummy)	-0.15*** (0.04)	-0.15*** (0.04)
LU – Trade and Service (Dummy)	0.03 (0.26)	-
LU – Cultural (Dummy)	0.17*** (0.05)	0.18*** (0.05)
LU – Resource (Dummy)	-0.20*** (0.03)	-0.20*** (0.03)
Constant	-5.40*** (0.42)	-5.38*** (0.33)
Observations	16,432	16,432
Log Likelihood	-13,807.97	-13,808.70
Akaike Inf. Crit.	27,657.93	27,655.39
Note:		*p0.1; **p0.05; ***p0.01