Updates to Risk Factors for SHSP Emphasis Areas

Bicycle Crashes

PREPARED FOR

Massachusetts Department of Transportation

PREPARED BY

vhb

REPORT DATE: July 27, 2023

UPDATED: February 1, 2024

Purpose & Background

The Massachusetts Department of Transportation (MassDOT) is updating the risk-based network screening maps in the IMPACT tool to incorporate recent crash data and build on lessons learned from previous analyses. This document describes the updated systemic analysis performed by VHB for bicycle crashes using crash data from 2017 through 2021. For this analysis, VHB used the default "Bicycle" query[1] in the MassDOT IMPACT tool. The definition reads as: any crash involving "Non-motorist" in the "Person Type" field and a "cyclist" in the "Non-Motorist Type" field.[2]

Note that the purpose of this report is to identify the factors most correlated with the frequency and severity of bicycle-involved crashes; causality was not directly investigated. As such, agencies interested in developing targeted countermeasure programs are encouraged to perform some initial investigation into causality of the target crash in their jurisdiction. This will allow the agency to develop targeted countermeasures.

Data Analysis and Focus Crash Types

To establish context, VHB first used the MassDOT IMPACT "Test of Proportions" tool[3] to summarize fatal injury (K), suspected serious injury (A), and suspected minor injury (B) bicycle crashes. To identify overrepresented crash attributes, VHB compared KAB bicycle crashes to all KAB crashes in the State. Where the proportion for a given attribute is statistically larger than the proportion for the comparison group, that attribute is flagged as a potential risk factor. Statistical overrepresentation is checked by building 95 percent confidence intervals around the proportion using sampling errors. Figure 1 and Figure 2 show how the lower and upper bounds, respectively, are calculated based on the proportion of crashes (p) and the number of crashes in the sample (N). If the lower bound of bicycle KAB crashes is larger than the upper bound of the comparison group, the attribute was considered "overrepresented" for the data.

$$95\%\ Confidence\ Interval, Lower\ Bound\ =\ p - 1.96 * \sqrt{\frac{p(1-p)}{N}}$$

Figure 1. Calculation of the lower bound of the 95 percent confidence interval for the proportion of crashes with an attribute.

$$95\%\ Confidence\ Interval, Upper\ Bound\ =\ p + 1.96 * \sqrt{\frac{p(1-p)}{N}}$$

Figure 2. Calculation of the upper bound of the 95 percent confidence interval for the proportion of crashes with an attribute.

Table 1 summarizes notable overrepresentations found in the analysis. VHB included the following data elements in their analysis:

- Access Control.

[1] https://www.mass.gov/info-details/impact-emphasis-area-definitions

[2] MassDOT. *Impact Emphasis Area Definitions.* Available at: https://www.mass.gov/info-details/impact-emphasis-area-definitions. Accessed May, 2023.

[3] https://apps.impact.dot.state.ma.us/sat/TestofProportions

- Age of Driver – Oldest Known.
- Age of Driver – Youngest Known.
- Age of Non-Motorist – Oldest Known.
- Age of Non-Motorist – Youngest Known.
- Average Annual Daily Traffic.
- City/Town Name.
- County Name.
- Crash Day of Week.
- Crash Hour of Day.
- Crash Month.
- Crash Severity.
- Crash Status.
- Crash Year.
- Curb.
- Driver Contributing Circumstances.
- Driver Distracted By.
- Facility Type.
- Federal Functional Class.
- First Harmful Event.
- First Harmful Event Location.
- FMCSA Reportable.
- Functional Class.
- Geocoding Method.
- Hit and Run.
- Jurisdiction.
- Left Shoulder Type-linked.
- Left Shoulder Width-linked.
- Left Sidewalk Width-linked.
- Light Conditions.
- Locality.
- Manner of Collision.
- MassDOT District.

- Max Injury Severity Reported.
- Median Type.
- Median Width.
- Most Harmful Event.
- Non-Motorist Action.
- Non-Motorist Location.
- Non-Motorist Type.
- Number of Peak Hour Lanes.
- Number of Travel Lanes.
- Number of Vehicles.
- Operation.
- Opposite Number of Travel Lanes.
- Police Agency Type.
- Right Shoulder Type-linked.
- Right Shoulder Width-linked.
- Right Sidewalk Width-linked.
- Road Contributing Circumstances.
- Road Surface Condition.
- Roadway Junction Type.
- RPA Abbreviation.
- School Bus Related.
- Speed Limit.
- State Police Troops.
- Structural Conditions.
- Surface Type.
- Surface Width-linked.
- Terrain Type.
- Total Fatalities.
- Total Lanes.
- Total of Non-Fatal Injuries.
- Traffic Control Device Function.
- Traffic Control Device Type.

- Trafficway Description.
- Truck Route.
- Urban Area.
- Urban Location Type.
- Urban Type.
- Vehicle Actions Prior to Crash.
- Vehicle Configuration.
- Vehicle Emergency Use.
- Vehicle Sequence of Events.
- Vehicle Towed from Scene.
- Vehicle Travel Direction.
- Weather Conditions.
- Work Zone Related.

Table 1. Summary of Key Overrepresentation Findings

Crash Field	**Crash Attribute**	**Percent of Bicycle KAB Crashes**	**Percent of All KAB Crashes**
Access Control	No access control	95.0%	75.8%
Age of Driver – Youngest Known (crash level)	45-54	15.8%	10.7%
	55-64	15.4%	7.3%
	65-74	9.0%	3.4%
	75-84	5.4%	1.6%
	>84	1.6%	0.5%
Crash Hour of Day	2:00 PM-2:59 PM	8.3%	7.0%
	3:00 PM-3:59 PM	9.3%	7.6%
	4:00 PM-4:59 PM	10.6%	7.6%
	5:00 PM-5:59 PM	10.5%	7.8%
	6:00 PM-6:59 PM	7.6%	6.2%
Crash Month	May	10.3%	8.4%
	June	13.2%	9.4%
	July	15.5%	9.5%
	August	14.2%	9.5%
	September	13.5%	9.0%
	October	11.0%	9.5%
Light Conditions	Daylight	81.3%	64.4%
Road Surface Condition	Dry	88.2%	77.5%
Vehicle Travel Direction	Westbound	23.5%	21.2%
Weather Conditions	Clear	77.4%	66.4%
Urban Type	Large Urban Cluster	2.5%	1.4%
	Large Urbanized Area	89.3%	86.5%
	Small Urban Cluster	0.8%	0.2%

Crash Field	Crash Attribute	Percent of Bicycle KAB Crashes	Percent of All KAB Crashes
Speed Limit	20	2.0%	1.4%
	25	8.4%	5.1%
	30	26.4%	17.1%
Curb	Both sides	65.9%	45.8%
Median Type	Curbed	3.2%	2.0%
	None	87.3%	72.5%
	Raised Median	4.0%	3.1%
Federal Functional Class	Local	16.1%	12.2%
	Major Collector	12.1%	10.4%
	Minor Arterial	32.9%	29.0%
	Principal Arterial - Other	36.8%	28.4%
Functional Class	Local	16.1%	12.2%
	Rural minor arterial or urban principal arterial	30.6%	22.5%
	Urban collector or rural minor collector	11.9%	9.9%
	Urban minor arterial or rural major collector	32.8%	29.2%
Left Shoulder Type-linked	No Shoulder	73.8%	61.5%
Right Shoulder Type-linked	No Shoulder	70.2%	49.5%
Manner of Collision	Angle	43.2%	26.6%
	Sideswipe, same direction	11.6%	5.5%
	Unknown	2.8%	0.7%
Vehicle Configuration	Passenger Car	70.0%	64.4%
	Other e.g., farm equipment	0.9%	0.5%
Vehicle Actions Prior to Crash	Entering traffic lane	4.3%	3.3%
	Parked	4.9%	4.0%
	Turning left	18.3%	10.8%
	Turning right	16.2%	2.8%
Driver Contributing Circumstances	Failed to yield right of way	10.4%	7.5%
	Glare	2.5%	0.6%
	Inattention	11.2%	8.6%
	No Improper driving	40.9%	35.3%
	Visibility Obstructed	2.1%	0.7%
Vehicle Towed from Scene	No	84.0%	33.9%
Road Contributing Circumstance	None	81.1%	76.0%
Trafficway Description	One-way, not divided	7.7%	5.7%
	Two-way, divided, unprotected median	16.9%	15.1%
	Two-way, not divided	68.6%	58.5%
Number of Travel Lanes	2	86.3%	73.0%
Operation	One-way traffic	8.9%	6.7%
Opposite Number of Travel Lanes	0	87.1%	72.4%

Crash Field	Crash Attribute	Percent of Bicycle KAB Crashes	Percent of All KAB Crashes
Operation Number of Travel Lanes	1	1.8%	1.3%
Roadway Junction Type	Driveway	4.1%	1.8%
	Four-way intersection	23.3%	18.6%
	T-Intersection	33.1%	16.6%
	Traffic Circle	1.4%	0.9%
Traffic Control Device Type	Traffic control signal	20.5%	15.8%
	Stop signs	19.5%	12.6%

From a safety management perspective, it is notable that severe bike crashes were overrepresented on roadways with no access control, lower speed limits, and no shoulder. These crashes primarily take place in urban areas. Among these crashes, a disproportional number occur at T-intersections, followed by four-way intersections and driveways. Intersections with signal or stop control also witness a higher proportion of such crashes. Unsurprisingly, these crashes are more prevalent during the daytime, under clear weather conditions with dry road surfaces. They tend to occur more frequently in the summer through early fall and during the afternoon and evening hours, which aligns with the typical time people go biking. Moreover, severe bike crashes involving older individuals are also overrepresented. A disproportionate number of severe bike crashes occurred with turning vehicles. Other notable actions with a higher occurrence include crashes with parked vehicles and crashes when entering the travel lane. Among the contributing factors from the driver's perspective, failure to yield right of way, inattention, glare, and obstructed visibility are overrepresented. The higher number of crashes with westbound vehicles is likely due to visibility issues caused by the setting sun.

MassDOT should consider these findings when identifying potential countermeasures to reduce bike-involved crashes. The National Highway Traffic Safety Administration's (NHTSA) *Countermeasures that Work*[4] includes several strategies targeting bicycle crashes including bicycle helmet law, safe routes to school initiative, active lighting, and rider conspicuity. While these are notable results, they should not restrict the analysis from focusing on all bike crashes. These results should be considered when developing projects and countermeasures at bicycle risk sites. Ultimately, the focus crash type for this analysis is all bicycle crashes.

Crash Tree and Focus Facility Type

After concluding that the bicycle focus crash type should include all bicycle crashes, VHB developed crash trees to identify focus facility types and gain insight into bicycle involved in severe collisions. Figure 3 shows the crash tree. As expected, nearly all severe bicycle crashes occur on roads with no access control. Of those, more than half occur at traditional intersections – primarily stop controlled or uncontrolled intersections. Additionally, roughly 33 percent occur outside of intersections. Of those, nearly 85 percent are on other principal arterials, minor arterials, or major collectors and nearly 15 percent are on local roads.

[4] https://www.nhtsa.gov/book/countermeasures/bicycle-safety/countermeasures

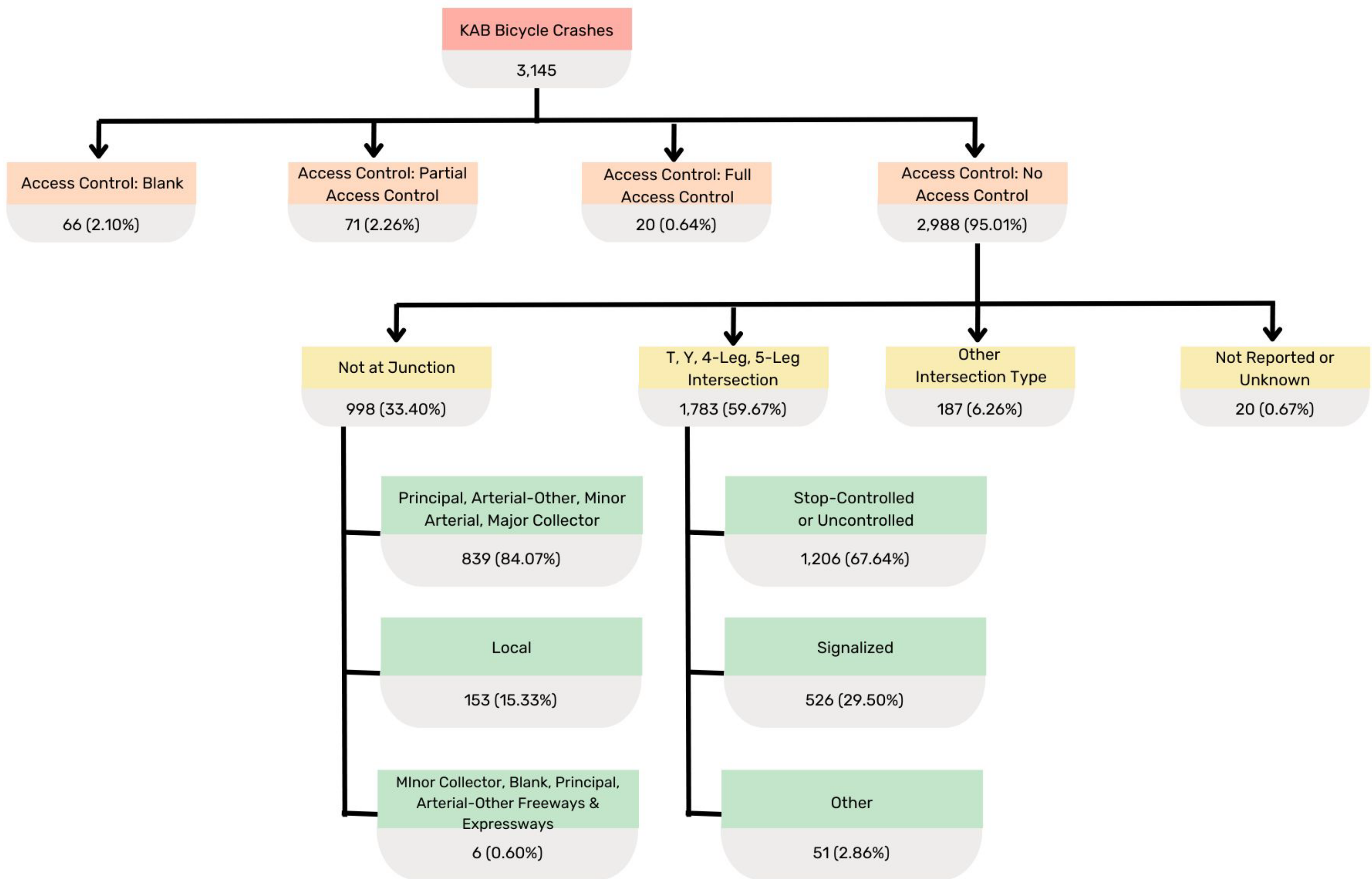

Figure 3. Crash tree summarizing KAB Bicycle crashes in Massachusetts.

Based on the crash tree in Figure 3, VHB recommends the following focus facility types:

- Bicycle KAB crashes at Principal Arterials
- Bicycle KAB crashes at Minor Arterials
- Bicycle KAB crashes at Major Collectors
- Bicycle KA crashes at all intersections (except roundabouts, other circular intersections, and non-conventional intersections)[5]

Risk Factor Analysis

After identifying focus crash types and trends, VHB proceeded with the risk factor analysis. The following sections describe the methodology, data, and results of this analysis.

Methodology

Due to the binary nature of the crash severity outcome of interest, the project team used binary logistic regression. This probabilistic modeling technique assesses the probability that an event has occurred (i.e., a KAB bicycle crash) on a given segment or (i.e., a KA bicycle crash) at a given intersection based on the model inputs. Agresti (2007) provides more background information on this method.[6] When modeling, VHB began with road exposure variables and added additional variables one at a time, monitoring the coefficients to ensure the inclusion of a variable did not result in large changes in magnitude. Additionally, VHB included variables with p-values upwards of 0.10 assuming the magnitude of the results made sense. VHB did not select a strict level of significance, as Hauer notes this could lead to misunderstanding or outright disregard for potentially noteworthy results.[7] The model estimates coefficients for each independent variable which are used to calculate Odds Ratios. An Odds Ratio greater than 1.0 indicates a positive correlation between the variable and the probability of a crash; an Odds Ratio less than 1.0 indicates a negative correlation between the variable and the probability of a crash.

Data

VHB used ArcGIS to manage and integrate data for this analysis. VHB aggregated data at the segment and intersection level. Due to limitations with crash data acquisition, VHB excluded the City of Boston from the analysis. MassDOT provided VHB with various sources of data, as described in the following sections.

Crash Data

VHB obtained road segment and intersection data from MassDOT and identified the segments and intersections which fit into the focus facility characteristics. If one or more KAB bicycle crashes occurred on a given segment (e.g., within 100 feet as calculated in GIS) or one or more KA bicycle crashes at a given intersection (e.g., within 125 feet radius) at any time between 2017 and 2021, VHB assigned that segment or intersection with a "1"; those without an observed crash received a value of "0."

[5] The sample of KA crashes was big enough for intersections, therefore B – level crashes were dropped from the analysis.

[6] Agresti, A. (2007). An Introduction to Categorical Data Analysis. Second Edition. John Wiley & Sons, Inc., New York.

[7] Hauer, E. (2004). The harm done by tests of significance. *Accident Analysis & Prevention*, *36*(3), 495-500.

Roadway Data

VHB downloaded the Massachusetts statewide Road Inventory 2021 file, available at https://geo-massdot.opendata.arcgis.com/datasets/342e8400ba3340c1bf5bf2b429ad8294/about. Based on discussions with MassDOT, VHB filtered the roadway data in ArcGIS using mileage counted (equal to 1), jurisdiction (not equal to null), and facility type (less than 7) to identify unique segments that were counted for the Highway Performance Monitoring System (HPMS). Filtering the roadway inventory in this way prevented potential double-counting of mileage and VMT for divided roads and roads with overlapping route numbers. MassDOT provided VHB with updated traffic volume data, which VHB integrated using GIS. Finally, somewhat simplified the roadway data by dissolving on common roadway characteristics, including route and street name, town, surface width, shoulder width and type, presence of curbing, traffic volume, etc.

Intersection Data

VHB received the Massachusetts statewide intersection data from a working version of the intersection inventory managed by MassDOT. Based on discussion with MassDOT, VHB filtered out roundabouts, any other circular intersections, or non-conventional intersections from the modeling database. Finally, the modeling dataset included all signalized intersections, stop-controlled (two-way and all-way), yield controlled and uncontrolled intersections.

School Location Data

VHB obtained primary and secondary school location data from the Massachusetts Bureau of Geographic Information (MassGIS) open data portal (https://www.mass.gov/info-details/massgis-data-massachusetts-schools-pre-k-through-high-school). VHB identified if any schools were present within a half mile of each segment.

College and University Data

VHB accessed college and university location data from the MassGIS open data portal (https://www.mass.gov/info-details/massgis-data-colleges-and-universities). Although these data contain several categories of trade schools and other atypical technical training institutions, VHB only included "Colleges, universities, and professional schools," "Fine arts schools," "Junior colleges," and "Other technical and trade schools" for the purposes of this analysis. VHB identified if any schools were present within a half mile of geographical boundaries of each segment and a quarter mile radius of each intersection.

Land Use Data

The proximity of origins and destinations that encourage bicycle travel can be obtained from a dense mix of different land uses. VHB employed an approximation of land-use mix described by Frank, Andersen, and Schmid (2004) using the intersection-level land use data provided by MassDOT[8].

$$Land\ Use\ Mix = -\sum_{i=1}^{n} \rho_i \frac{\ln \rho_i}{\ln n}$$

Figure 4: Calculation of Land-use mix from Frank, Andresen, and Schmid (2004).

---

[8] Frank, L.D., Andresen, M.A. and Schmid, T.L., (2004). Obesity relationships with community design, physical activity, and time spent in cars. *American journal of preventive medicine*, *27*(2), pp.87-96.

Where:

ρ_i = proportion of estimated area attributed to land use i.

n = number of land uses within quarter mile radius of an intersection.

This metric assesses the distribution of four land-use types—residential, commercial, industrial, and institutional—within a quarter mile radius of an intersection. A totally uniform land use within the quarter mile buffer would produce a value of "0," whereas a completely even distribution of all four land uses would produce a value of "1."

Additional Data

VHB obtained several additional data sources for integration into the data set, including census and American Community Survey (ACS) data, public health data from the Massachusetts Department of Public Health (DPH), environmental justice (EJ) data provided by Environmental Justice Community Block Group Data Update, EJScreen data, disadvantaged community data from the USDOT, climate and economic justice data from U.S. Climate Resilience Toolkit, and social vulnerability data from Centers for Disease Control and Prevention (CDC) and land cover data provided by MassDOT. Note that, regarding EJ data, the reports may change if the final layers were used but they were not available at the time the analyses were performed. The version of Massachusetts 2020 Environmental Justice Block Group data available at the time of the analysis was a preliminary version that was later updated with a final.

Results

The following sections describe the results of the binary logistic regression modeling effort. To account for unobserved influences on the segments due to road facilities and traffic exposure, VHB established a base model that included the natural log of the length of the segment. Before including additional variables in the binary logistic, VHB developed a correlation matrix of input variables. Highly correlated variables are indicators of potential complications in the model development process. The following sections include correlation matrices for each model.

Bicycle KAB Crashes at Principal Arterials

The binary logistic regression model for bicycle KAB crashes at principal arterials is summarized in Table 2. As expected, crash probability increases with increased exposure, as shown by the odds ratios for the natural log of segment length.

The model shows odds ratios greater than one for segments with AADTs or 9,000 or more veh/day, no shoulder, no median, curb on both sides, two-way traffic, and a speed limit lower than 30 mph. This indicates busier roads with lower speed limits are at an elevated risk for severe bicycle crashes. Dense, more urban segments are correlated with more risk, as illustrated by the odds ratios greater than 1.0 for biking potential of "High"[9], the presence of alcohol sales within a quarter mile, population density in the block group over 8000 people per square mile, and proximity to commercial and mixed-use other zoning within 100 feet. Disadvantaged communities are also correlated with more risk, as shown by the higher odds ratio for segments in block groups classified as Environmentally Disadvantaged, a "proximity to hazardous waste" score of less than 1.5 per the Environmental Protection Agency[10], and a higher percentage of the elderly population. Bike trails within a half mile are correlated with more risk of a severe

[9] Biking potential was determined in another previous analysis. For our analysis, "High" biking potential was any segment with a biking potential over 0.298 as calculated by that previous analysis.

[10] https://www.epa.gov/system/files/documents/2023-06/PPSM%20Final%20Peer%20Review%20Report.pdf.

bicycle crash, likely indicating a higher bicyclist demand and exposure. There is also a positive correlation with proximity to open land zoning within 100 feet.

Table 2. Binary Logistic Regression Model Results- Bicycle KAB Crashes on Principle Arterials.

Variable (Number)	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval	
Natural Log of the length of the segment (1)	2.02	0.15	9.58	0.00	1.75	2.34
AADT over 9,000 veh/day (2)	1.90	0.35	3.44	<0.01	1.32	2.73
No shoulder on the segment (3)	1.17	0.14	1.31	0.19	0.93	1.47
No median present on the segment (4)	1.48	0.29	2.01	0.04	1.01	2.16
Curb on both sides (5)	1.62	0.25	3.08	<0.01	1.19	2.19
Traffic is two-way (6)	2.62	0.72	3.49	0.00	1.52	4.50
Speed Limit over 30 mph (7)	0.53	0.07	-4.78	0.00	0.41	0.69
Location within a quarter mile of the segment sells alcohol (8)	2.87	0.59	5.16	0.00	1.92	4.28
Bike Potential is "High" (9)	1.43	0.17	3.03	<0.01	1.13	1.80
Bike trails within a half mile of the segment (10)	1.63	0.19	4.29	0.00	1.31	2.05
The segment is in a Census Tract classified as "Environmentally Disadvantaged" by the USDOT (11)	4.17	0.70	8.54	0.00	3.00	5.78
Population density of the block group is over 8000 people per square mile (12)	1.80	0.29	3.73	0.00	1.32	2.46
Proximity to hazardous waste score less than 1.5 (13)	1.49	0.19	3.12	<0.01	1.16	1.90
Segment is within 100 ft of area zoned as "Commercial" (14)	2.19	0.32	5.36	0.00	1.64	2.92
Segment is within 100 ft of area zoned as "Mixed Use Other" (15)	1.39	0.21	2.25	0.02	1.04	1.86
Segment is within 100 ft of area zoned as "Open Land" (16)	1.27	0.14	2.15	0.03	1.02	1.57
Percentage of the population over 64 years old (17)	8.10	6.57	2.58	0.01	1.65	39.72
Constant (18)	0.00073	0.00035	-14.94	0.00	0.00028	0.00189

Note: Number of observations = 43,417; Log likelihood = -1853.4789; Pseudo R2 = 0.1166; LR chi2(17) = 489.33; Prob > chi2 = 0.0000.

Table 3 is a correlation matrix identifying correlation between any two variables. The highest correlation is between variables 8 (location within a quarter mile of the segment sells alcohol) and 14 (segment is within 100 ft of area zoned as "Commercial"); however, model results were stable when included, so VHB elected to keep both variables in the model.

Table 3. Correlation Matrix for Binary Logistic Regression Model of Bicycle KAB crashes at Principal Arterials.

Variable No	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
2	1															
3	-0.061	1														
4	0.064	0.074	1													
5	0.211	-0.029	0.012	1												
6	0.033	0.020	-0.013	-0.026	1											
7	-0.068	0.059	-0.009	-0.379	0.148	1										
8	0.172	-0.020	0.010	0.330	-0.092	-0.258	1									
9	0.083	-0.040	0.015	0.235	-0.156	-0.212	0.237	1								
10	0.042	-0.001	-0.009	0.131	-0.082	-0.170	0.114	-0.032	1							
11	0.074	-0.040	0.028	0.136	-0.143	-0.152	0.124	0.093	0.185	1						
12	-0.055	0.256	-0.024	-0.045	0.033	0.060	-0.029	-0.054	0.004	0.003	1					
13	0.004	-0.208	0.109	0.024	-0.056	-0.085	0.036	0.041	0.025	0.067	-0.353	1				
14	0.155	-0.009	0.003	0.212	-0.041	-0.142	0.434	0.178	0.065	0.078	-0.016	0.025	1			
15	0.023	-0.015	-0.022	0.074	0.017	-0.068	0.107	0.021	0.033	-0.004	-0.011	0.001	0.121	1		
16	-0.041	0.014	-0.002	-0.112	0.017	0.105	-0.031	-0.008	-0.053	-0.038	0.029	-0.038	0.032	-0.026	1	
17	-0.103	0.041	-0.008	-0.262	0.135	0.251	-0.121	-0.196	-0.031	-0.196	-0.031	0.071	-0.078	-0.032	0.015	1

Bicycle KAB Crashes at Minor Arterials

The binary logistic regression model for bicycle KAB crashes at minor arterials is summarized in Table 4. As expected, crash probability increases with increased exposure, as shown by the odds ratios for the natural log of segment length.

The model shows odds ratios greater than one for wide and busy segments, specifically those with AADTs of 5,000 or more veh/day, and shoulder present. Dense, more urban segments are correlated with more risk, as illustrated by the odds ratios greater than one for segments with sidewalk, speed limits under 45 mph, in block groups with employee density over 5000 per square mile, a percentage of commuters that walk, bike, or use transit over 10 percent, and proximity to commercial, mixed use other, and mixed-use residential zoning within 100 feet. Bike trails within a half mile are correlated with more risk of a severe bicycle crash, likely indicating a higher bicyclist demand and exposure. A lower percentage of the population under 5 years old is also correlated to a higher risk of crashes.

Table 4. Binary Logistic Regression Model Results- Bicycle KAB Crashes on Minor Arterials.

Variable (Number)	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval	
Natural log of the length of the segment (1)	1.93	0.14	9.16	0.00	1.68	2.23
No shoulder present (2)	1.47	0.20	2.88	<0.01	1.13	1.91
Speed limit is under 45 mph (3)	1.39	0.19	2.47	0.01	1.07	1.82
Sidewalk is present (4)	2.03	0.32	4.48	0.00	1.49	2.77
AADT is over 5,000 veh/day (5)	1.66	0.28	3.01	<0.01	1.19	2.31
Bike trails are within a half mile of the segment (6)	1.46	0.17	3.22	<0.01	1.16	1.84
Employee density is over 5000 employees per square mile in the block group the segment is in (7)	2.08	0.30	5.03	0.00	1.56	2.76
Percentage of commuters walking, biking and using transit is over 10 percent (8)	1.58	0.19	3.81	0.00	1.25	2.00
Percentage of the population under 5 years old in the block group (9)	0.02	0.03	-2.58	0.01	<0.01	0.39
Segment is within 100 ft of area zoned as "Commercial" (10)	2.33	0.28	7.13	0.00	1.85	2.94
Segment is within 100 ft of area zoned as "Mixed Use Other" (11)	1.61	0.27	2.82	0.01	1.16	2.24
Segment is within 100 ft of area zoned as "Mixed Use Residential" (12)	1.32	0.19	1.97	0.05	1.00	1.75
Constant (13)	0.00309	0.00079	-22.71	0.00	0.00188	0.00509

Note: Number of observations = 86,641; Log likelihood = -2057.8029; Pseudo R2 = 0.0835; LR chi2(12) = 374.90; Prob > chi2 = 0.0000.

Table 5 is a correlation matrix identifying correlation between any two variables. The highest correlation is between variables 7 (employee density is over 5000 employees per square mile) and 8 (percentage of commuters walking, biking and using transit is over 10 percent); and also, between variables 2 (no shoulder present) and 4 (sidewalk is present). However, model results were stable when included, so VHB elected to keep both variables in the model.

Table 5. Correlation Matrix for Binary Logistic Regression Model of Bicycle KAB crashes at Minor Arterials.

Variable No	2	3	4	5	6	7	8	9	10	11	12
2	1										
3	0.199	1									
4	0.282	0.168	1								
5	0.077	0.128	0.252	1							
6	0.113	0.078	0.134	0.073	1						
7	0.219	0.056	0.220	0.123	0.141	1					
8	0.164	0.099	0.258	0.137	0.107	0.282	1				
9	0.046	0.051	0.084	0.095	0.026	0.091	0.036	1			
10	0.138	0.027	0.192	0.128	0.101	0.137	0.100	0.036	1		
11	0.061	0.030	0.057	0.003	0.037	0.045	0.041	0.006	0.141	1	
12	0.088	0.008	0.060	0.004	0.027	0.112	0.046	0.024	0.142	0.150	1

Bicycle KAB Crashes at Major Collectors

The binary logistic regression model for bicycle KAB crashes at major collectors is summarized in Table 6. As expected, crash probability increases with increased exposure, as shown by the odds ratios for the natural log of segment length.

The model shows odds ratios greater than one for segments that are busy, specifically those with AADTs of 4,000 or more veh/day, with a median present, and that have more than five feet of sidewalk. Segments that are in urban areas are correlated with a higher risk, as illustrated by the odds ratios greater than one for segments with alcohol sold within a quarter mile, transit present in a quarter mile, a biking potential of "Medium" or "High", and proximity to commercial zoning within 100 feet. Proximity within 100 feet to agriculture, open land, and water zoning is also correlated with a higher risk. Disadvantaged communities are also correlated with more risk, as shown by the odds ratio greater than one for segments with a low proximity to hazardous waste score, a higher percentage of low-income population, and over 3 percent of the population being Black or African American. Bike trails within a half mile are correlated with more risk of a severe bicycle crash, likely indicating a higher bicyclist demand and exposure.

Table 6. Binary Logistic Regression Model Results- Bicycle KAB Crashes on Major Collectors.

Variable (Number)	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval	
Natural Log of the length of the segment (1)	2.43	0.30	7.31	0.00	1.92	3.09
AADT over 4,000 veh/day (2)	1.81	0.34	3.18	<0.01	1.26	2.61
Sidewalk is over 5 feet wide (3)	2.28	0.59	3.20	<0.01	1.38	3.78
Median is present (4)	3.21	1.68	2.24	0.03	1.16	8.93
Alcohol sold within a quarter mile (5)	1.58	0.37	1.96	0.05	1.00	2.49
Biking potential is "Medium" or "High" (6)	2.92	0.87	3.62	0.00	1.63	5.23
Bike trails are within a half mile of the segment (7)	1.41	0.28	1.72	0.09	0.95	2.09
Transit is within a quarter mile of the segment (8)	2.47	0.58	3.87	0.00	1.56	3.90
Percentage of the population with low-income in the block group the segment is in (9)	3.04	1.57	2.16	0.03	1.11	8.38
Segment is within a mile and a half from hazardous waste (10)	2.03	0.52	2.77	0.01	1.23	3.35
Segment is within 100 ft of area zoned as "Agriculture" (11)	2.31	0.93	2.08	0.04	1.05	5.08
Segment is within 100 ft of area zoned as "Commercial" (12)	1.54	0.30	2.19	0.03	1.05	2.25
Segment is within 100 ft of area zoned as "Open Land" (13)	1.52	0.28	2.28	0.02	1.06	2.19
Segment is within 100 ft of area zoned as "Water" (14)	3.55	1.11	4.04	0.00	1.92	6.57
Percentage of Black or African American population is over 3 percent (15)	1.38	0.28	1.58	0.11	0.93	2.05
Constant (16)	0.00077	0.00034	-16.07	0.00	0.00032	0.00185

Note: Number of observations = 66,858; Log likelihood = -850.09562; Pseudo R2 = 0.1146; LR chi2(15) = 220.06; Prob > chi2 = 0.0000.

Table 7 is a correlation matrix identifying correlation between any two variables. There is no significant correlation between any of the variables. The highest correlation is between variables 3 (Sidewalk is over 5 feet wide) and 8 (Transit is within a quarter mile of the segment); however, model results were stable when included, so VHB elected to keep both variables in the model.

Table 7. Correlation Matrix for Binary Logistic Regression Model of Bicycle KAB crashes at Major Collectors.

Variable No	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	1													
3	0.187	1												
4	0.035	-0.003	1											
5	0.099	0.401	0.033	1										
6	0.132	0.378	0.034	0.336	1									
7	0.085	0.265	0.007	0.235	0.130	1								
8	0.184	0.476	0.049	0.324	0.246	0.284	1							
9	-0.020	0.317	0.021	0.303	0.257	0.083	0.045	1						
10	-0.253	-0.466	-0.041	-0.277	-0.389	-0.234	-0.405	-0.214	1					
11	-0.058	-0.124	-0.011	-0.105	-0.154	-0.054	-0.087	-0.050	0.150	1				
12	0.080	0.202	0.030	0.380	0.187	0.106	0.137	0.225	-0.138	-0.043	1			
13	-0.046	-0.130	-0.021	-0.039	-0.093	-0.062	-0.112	0.028	0.130	0.045	0.060	1		
14	-0.020	-0.029	-0.007	0.001	-0.049	0.009	-0.021	0.012	0.050	0.023	0.014	0.076	1	
15	0.166	0.322	0.037	0.207	0.266	0.105	0.206	0.298	-0.365	-0.073	0.113	-0.030	-0.035	1

Bicycle KA Crashes at Intersections

The binary logistic regression model for bicycle KA crashes at intersections is summarized in Table 8. The model shows that odds ratios are greater than one for busy intersections, and the odds ratios get higher with higher ranges of traffic volume on the major roads.

Additionally, four-legged intersections, signalized intersections, yield-controlled intersections, or intersections with three or more through lanes on minor roads are at an elevated risk for severe bicycle crashes. Intersections in urban areas are correlated with more risk, as illustrated by the odds ratios greater than one for intersections with higher number of alcohol shops, at least one or more transit stops within a quarter mile radius or higher biking potential. Towns where the intersections are located meet three environmental justice criteria also experienced increasingly higher severe bicycle crashes. Intersections with lighting facilities demonstrated a higher likelihood of bicycle crashes. The presence of lighting at an intersection may attract cyclists, increasing exposure. Without exposure, the presence of lighting is therefore likely to capture unobserved effects. Lastly, severe bicycle crashes are more likely to occur on intersections with higher land-use mix due to the closer proximity of origins and destinations.

Table 8: Binary Logistic Regression Model Results- Bicycle KA Crashes at Intersections.

Variable	Odds Ratio	Std Error	z-value	P>|z|	95% Confidence Interval	
Major AADT between 5,000 and 9,999 Vehicles per Day (1)	1.349	0.283	1.420	0.155	0.893	2.036
Major AADT between 10,000 and 14,999 Vehicles per Day (2)	1.566	0.365	1.920	0.054	0.991	2.474
Major AADT 15,000 and above Vehicles per Day (3)	1.896	0.423	2.860	0.004	1.224	2.936
Minor AADT 1,500 and above Vehicles per Day (4)	1.924	0.322	3.910	0.000	1.385	2.671
Indicator for presence of lighting (5)	4.639	2.374	3.000	0.003	1.701	12.650
Respective town meets three environmental justice criteria (6)	1.335	0.221	1.750	0.081	0.965	1.847
Indicator of at least one or more transit stops within 0.25 mi (7)	1.696	0.282	3.180	0.001	1.224	2.349
Number of alcohol shops within 0.25mi radius (8)	1.023	0.011	2.160	0.031	1.002	1.044
Indicator for four leg intersection (9)	1.644	0.269	3.040	0.002	1.193	2.264
Three or more lanes on minor road (10)	2.340	0.590	3.370	0.001	1.428	3.835
Biking Potential (11)	1.026	0.344	0.080	0.939	0.531	1.981
Indicator for signalized intersection (12)	1.444	0.309	1.720	0.086	0.950	2.196
Indicator for yield (13)	2.887	2.085	1.470	0.142	0.701	11.890
Indicator for urban area (14)	2.931	2.971	1.060	0.289	0.402	21.363
Land Use Mix (15)	2.615	1.135	2.210	0.027	1.117	6.124
Constant (16)	0.000	0.000	-8.820	0.000	0.000	0.000
Note: Number of observations = 50,720; Log likelihood = -1170.1725; Pseudo R2 = 0.0891; LR chi2(14) = 228.83; Prob > chi2 = 0.0000.						

Table 9: Correlation Matrix for Binary Logistic Regression Model of Bicycle KA crashes at Intersections

Variable No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1														
2	-0.257	1													
3	-0.251	-0.157	1												
4	0.045	0.128	0.130	1											
5	0.043	0.056	0.076	0.046	1										
6	0.019	0.056	0.082	-0.018	0.172	1									
7	-0.012	0.022	0.132	-0.055	0.183	0.260	1								
8	-0.021	0.079	0.122	0.064	0.132	0.257	0.301	1							
9	0.004	0.038	0.052	0.142	0.129	0.125	0.084	0.119	1						
10	-0.024	0.038	0.146	0.191	0.026	0.034	0.014	0.062	0.092	1					
11	0.017	0.130	0.141	0.084	0.143	0.419	-0.014	0.349	0.129	0.089	1				
12	-0.021	0.091	0.224	0.308	0.086	0.108	0.106	0.143	0.321	0.304	0.160	1			
13	-0.008	-0.007	0.003	0.018	-0.029	-0.021	-0.012	-0.003	-0.013	-0.005	-0.008	-0.018	1		
14	0.098	0.075	0.078	0.002	0.281	0.144	0.120	0.094	0.039	0.026	0.169	0.059	-0.038	1	
15	0.017	0.088	0.107	0.088	0.087	0.089	0.069	0.199	0.019	0.067	0.202	0.108	-0.001	0.094	1

Table 9 presents the correlation matrix identifying correlation between any two variables. There is no significant correlation between any of the variables. The highest correlation is between variables 6 (respective town meets three environmental justice criteria) and 11 (biking Potential); however, model results were stable when included, so VHB elected to keep both variables in the model.

Conclusions and Recommendations

The purpose of this analysis is to identify segment-level risk factors for fatal, serious injury, and non-incapacitating injury bicycle crashes and intersection-level risk factors for fatal and serious injury crashes. Instead of using the coefficients in the binary logistic regressions results from, VHB recommends that MassDOT assign risk scores between 0 and 1 based on the character of the risk factor. VHB and MassDOT made this decision to avoid overly weighting any one risk factor, especially considering potential data issues with the risk factor data which may cause biases. Table 10 to Table 13 summarize the suggested risk scoring schema for severe bicycle crashes on principal arterials, minor arterials, major collectors, and intersections respectively.

Table 10. Segment-level risk factors for Bicycle KAB Crashes on Principal Arterials.

Variable	Suggested Scoring
Natural Log of the length of the segment	No score
AADT over 9,000 veh/day	1 if true; 0 otherwise.
No shoulder on the segment	1 if true; 0 otherwise.
No median present on the segment	1 if true; 0 otherwise.
Curb on both sides	1 if true; 0 otherwise.
Traffic is two-way	1 if true; 0 otherwise.
Speed Limit over 30 mph	0 if true; 1 otherwise.
Alcohol sold within a quarter mile	1 if true; 0 otherwise.
Bike Potential is “High”	1 if true; 0 otherwise.
There are bike trails within a half mile of the segment	1 if true; 0 otherwise.
The segment is classified as Environmentally disadvantaged	1 if true; 0 otherwise.
The population density of the block group the segment is in is over 8000 people per square mile	1 if true; 0 otherwise.
The segment is within a mile and a half from hazardous waste	1 if true; 0 otherwise.
Segment is within 100 ft of area zoned as “Commercial”	0.33 if true; 0 otherwise.
Segment is within 100 ft of area zoned as “Mixed Use Other”	0.33 if true; 0 otherwise.
Segment is within 100 ft of area zoned as “Open Land”	0.33 if true; 0 otherwise.
Percentage of the population over 64 years old	Continuous from 0 to 1 for range of values
Maximum potential score for a town:	**14.00**

Table 11. Segment-level risk factors for Bicycle KAB Crashes on Minor Arterials.

Risk Factor for Bicycle KAB Crashes on Minor Arterials	**Suggested Scoring**
Natural log of the length of the segment	No score
No shoulder present	1 if true; 0 otherwise.
Speed limit is under 45 mph	1 if true; 0 otherwise.
Sidewalk is present	1 if true; 0 otherwise.
AADT is over 5,000 veh/day	1 if true; 0 otherwise.
Bike trails are within a half mile of the segment	1 if true; 0 otherwise.
The employee density is over 5000 employees per square mile in the block group the segment is in	1 if true; 0 otherwise.
The percentage of commuters walking, biking and using transit is over 10 percent	1 if true; 0 otherwise.
The percentage of the population under 5 years old in the block group	Continuous from 0 to 1 for range of values of 0 to 35 percent.
Segment is within 100 ft of area zoned as "Commercial"	0.33 if true; 0 otherwise.
Segment is within 100 ft of area zoned as "Mixed Use Other"	0.33 if true; 0 otherwise.
Segment is within 100 ft of area zoned as "Mixed Use Residential"	0.33 if true; 0 otherwise.
Maximum potential score for a town:	**9.00**

Table 12. Segment-level risk factors for Bicycle KAB Crashes on Major Collectors.

Risk Factor for Bicycle KAB Crashes on Major Collectors	**Suggested Scoring**
The Natural Log of the length of the segment	No score
AADT over 4,000 veh/day	1 if true; 0 otherwise.
Sidewalk is over 5 feet wide	1 if true; 0 otherwise.
A Median is present	1 if true; 0 otherwise.
Alcohol is sold within a quarter mile	1 if true; 0 otherwise.
Biking potential is “Medium” or “High”	1 if true; 0 otherwise.
Bike trails are within a half mile of the segment	1 if true; 0 otherwise.
Transit is within a quarter mile of the segment	1 if true; 0 otherwise.
Percentage of the population with low-income in the block group the segment is in	Continuous from 0 to 1 for range of values.
The segment is within a mile and a half from hazardous waste	1 if true; 0 otherwise.
Segment is within 100 ft of area zoned as “Agriculture”	0.25 if true; 0 otherwise.
Segment is within 100 ft of area zoned as “Commercial”	0.25 if true; 0 otherwise.
Segment is within 100 ft of area zoned as “Open Land”	0.25 if true; 0 otherwise.
Segment is within 100 ft of area zoned as “Water”	0.25 if true; 0 otherwise.
Percentage of Black or African American population is over 3 percent	1 if true; 0 otherwise.
Maximum potential score for a town:	**11.00**

Table 13: Intersection-level risk factors for Bicycle KA Crashes at Intersections.

Risk Factor for Bicycle KA Crashes at Intersections	**Suggested Scoring**
Major AADT between 5,000 and 9,999 Vehicles per Day	0.33 if true; else
Major AADT between 10,000 and 14,999 Vehicles per Day	0.66 if true; else
Major AADT 15,000 and above Vehicles per Day	1 if true; 0 otherwise
Minor AADT 1,500 and above Vehicles per Day	1 if true; 0 otherwise
Indicator for presence of lighting	1 if true; 0 otherwise
Respective town meets three environmental justice criteria	0.33 if 1; 0.66 if 2; 1 if 3; 0 otherwise
Indicator of at least one or more transit stops within 0.25mi	1 if true; 0 otherwise
Number of alcohol shops within 0.25mi radius	Scored from 0 to 1 for range of values (min to max)
Indicator for four leg intersection	1 if true; 0 otherwise
Three or more lanes on minor road	1 if true; 0 otherwise
Biking Potential	Continuous from 0 to 1 for range of values
Indicator for signalized intersection	0.5 if true; else
Indicator for yield	1 if true; 0 otherwise
Indicator for urban area	1 if true; 0 otherwise
Land Use Mix	Scored from 0 to 1 (Variable is continuous from 0 to 1)
Maximum potential score for an intersection:	**12.50**

Table 14 provides an example application of the risk factors on a hypothetical segment on principal arterials. To balance prioritization across the different risk scoring schemes, VHB recommends normalizing the segment risk scores against the total possible score for each schema – producing a normalized risk score for each segment ranging from 0 to 100. The example segment has a total risk score of 7.51 out of 14, resulting in a normalized risk score of 53.6 percent. Table 15 presents an example application of risk factors at a hypothetical intersection. The example intersection has a total risk score of 7.85 out of 12.50, resulting in a normalized risk score of 62.8 percent.

Table 14. Example Risk Score Calculation for Bicycle KAB Crashes on Principle Arterials.

Variable	Segment Characteristic	Risk Factor	Risk Score
AADT over 9,000 veh/day	10,000 veh/day	1 if true; 0 otherwise.	1
No shoulder on the segment	False	1 if true; 0 otherwise.	0
No median present on the segment	True	1 if true; 0 otherwise.	1
Curb on both sides	False	1 if true; 0 otherwise.	0
Traffic is two-way	True	1 if true; 0 otherwise.	1
Speed Limit over 30 mph	40 mph	0 if true; 1 otherwise.	0
Alcohol sold within a quarter mile	True	1 if true; 0 otherwise.	1
Bike Potential is “High”	True	1 if true; 0 otherwise.	1
There are bike trails within a half mile of the segment	True	1 if true; 0 otherwise.	1
The segment is classified as Environmentally disadvantaged	False	1 if true; 0 otherwise.	0
The population density of the block group the segment is in is over 8000 people per square mile	True	1 if true; 0 otherwise.	1
The segment is within a mile and a half from hazardous waste	False	1 if true; 0 otherwise.	0
Segment is within 100 ft of area zoned as “Commercial”	False	0.33 if true; 0 otherwise.	0
Segment is within 100 ft of area zoned as “Mixed Use Other”	True	0.33 if true; 0 otherwise.	0.33
Segment is within 100 ft of area zoned as “Open Land”	False	0.33 if true; 0 otherwise.	0
Percentage of the population over 64 years old	15 percent (range is between 0 and 82 percent)	Continuous from 0 to 1 for range of values	0.18
		Total Risk Score:	**7.51**
		Risk Percent Score (Out of 14):	**53.6**

Table 15. Example Risk Score Calculation for Bicycle KA Crashes at Intersections.

Variable	Intersection Characteristic	Risk Factor	Risk Score
Major AADT between 5,000 and 9,999 Vehicles per Day	Major AADT is 8,000 veh/day	0.33 if true; else	0.33
Major AADT between 10,000 and 14,999 Vehicles per Day	Major AADT is 8,000 veh/day	0.66 if true; else	
Major AADT 15,000 and above Vehicles per Day	Major AADT is 8,000 veh/day	1 if true; 0 otherwise	
Minor AADT 1,500 and above Vehicles per Day	Minor AADT is 2,000 veh/day	1 if true; 0 otherwise	1
Indicator for presence of lighting	True	1 if true; 0 otherwise	1
Respective town meets three environmental justice criteria	Meets two EJ criteria	0.33 if 1; 0.66 if 2; 1 if 3; 0 otherwise	0.66
Indicator of at least one or more transit stops within 0.25mi	True	1 if true; 0 otherwise	1
Number of alcohol shops within 0.25mi radius	50 (range between 0 and 134)	Scored from 0 to 1 for range of values (min to max)	0.37
Indicator for four leg intersection	True	1 if true; 0 otherwise	1
Three or more lanes on minor road	False	1 if true; 0 otherwise	0
Biking Potential	0.76 (range between 0 and 1.57)	Continuous from 0 to 1 for range of values	0.48
Indicator for signalized intersection	True	0.5 if true; else	0.5
Indicator for yield	False	1 if true; 0 otherwise	0
Indicator for urban area	True	1 if true; 0 otherwise	1
Land Use Mix	0.53 (range between 0 and 1.06)	Scored from 0 to 1 (Variable is continuous from 0 to 1)	0.5
		Total Risk Score:	**7.85**
		Risk Percent Score (Out of 12.5):	**62.8**

MassDOT ranked the segments and intersections at both the Statewide and MPO levels using the normalized risk score and the percentile score of ranking (rank kind equal to weak) function in ArcGIS. For each normalized risk score, a percentile rank for the given score was computed relative to all the normalized risk scores. If there are repeated occurrences of the same normalized risk score, then the percentile rank corresponds to values that are less than or equal to the given score. The advantage of the weak ranking approach is that it guarantees that the highest normalized score will receive a percentile rank of 100%. For bicycle crashes at intersections, normalized risk scores range from 0.04 to 0.88. The maximum value (0.88) received a percentile rank of 100 and other values received a percentile rank accordingly. For example, an intersection with a normalized risk score of 0.58, the calculated state percentile rank was 89.33, and fell in the secondary risk category. MassDOT then assigned risk categories using the computed ranks. For example, segments/intersections ranked in the top 5 percentile (95 through 100) were categorized as "Primary Risk Site" and segments/intersections ranked in the next 10 percentile (85 through 95) were categorized as "Secondary Risk Site"; the remaining segments/intersections were not categorized. In instances where there are large, repeated occurrences of the same normalized risk score, the percentage of segments/intersections computed for top 5% or next 10% may not be equal to 5 or 10%. This is a byproduct of the weak ranking approach.

Table 16 and Table 17 show the distribution of focus facility type segments with the normalized risk score (presented as percentages) across these categories for Statewide and MPO rankings, respectively. Similarly, Table 18 and Table 19 show the distribution of intersections with the normalized risk score (presented as percentages) across these categories for Statewide and MPO rankings, respectively. Note the goal was to see a higher proportion of target crashes for primary and secondary risk sites than proportion of segments/intersections. Figure 5 is a map of the risk segments ranked statewide, while Figure 6 is a map of the risk segments ranked by MPO. Similarly, Figure 7 is a map of the risk intersections ranked statewide, while Figure 8 is a map of the risk intersections ranked by MPO. There are a total of 2,170 segments in the primary risk category (top 5 percent), that captured 13.78 percent of the severe bicycle crashes. Similarly, there are 4,388 segments in the secondary risk category (next top 10 percent), which captured an additional 25.98 percent of the severe bicycle crashes. The highest number of primary risk category segments were in Boston Region MPO (915 segments), followed by Pioneer Valley Planning Commission (222 segments) and Central Massachusetts Regional Planning Commission (169 segments).

There are a total of 2,706 intersections in the primary risk category (top 5 percent), that captured 27.11 percent of the severe bicycle crashes at intersections. Similarly, there are 5,411 intersections in the secondary risk category (next top 10 percent), which captured an additional 23.03 percent of the severe bicycle crashes. The highest number of primary risk category intersections were in Boston Region MPO (1,195 intersections), followed by Pioneer Valley Planning Commission (283 intersections) and Southeastern Regional Planning and Economic Development District (233 intersections).

Table 16. Statewide Risk Categories for Segments.

State	Risk Category	Minimum Normalized Risk Score Percentage	Maximum Normalized Risk Score Percentage	Number of Segments	Percent of Scored State Segments	Percent of Target Crashes
MA	Primary Risk Site	71.00%	99.67%	2,170	5.00%	13.78%
	Secondary Risk Site	60.11%	70.98%	4,338	10.00%	25.98%

Table 17. Distribution of Risk Segments by MPO.

MPO	Risk Category	Minimum Normalized Risk Score Percentage	Maximum Normalized Risk Score Percentage	Number of Segments	Percent of Scored MPO Segments	Percent of Target Crashes in MPO
Berkshire Regional Planning Commission	Primary Risk Site	62.87%	79.04%	80	5.00%	0.00%
	Secondary Risk Site	54.07%	62.64%	160	10.00%	33.33%
Boston Region MPO	Primary Risk Site	77.69%	99.67%	915	5.00%	7.86%
	Secondary Risk Site	65.54%	77.69%	1,829	10.00%	27.14%
Cape Cod Commission	Primary Risk Site	49.34%	59.80%	268	10.04%	26.92%
	Secondary Risk Site	1.08%	49.31%	2,268	84.94%	38.46%
Central Massachusetts Regional Planning Commission	Primary Risk Site	61.14%	93.69%	169	5.01%	22.22%
	Secondary Risk Site	53.10%	61.12%	337	10.00%	11.11%
Franklin Regional Council of Governments	Primary Risk Site	56.07%	75.83%	49	5.41%	0.00%
	Secondary Risk Site	46.88%	55.99%	87	9.60%	0.00%
Martha's Vineyard Commission	Primary Risk Site	58.61%	72.89%	11	6.01%	50.00%
	Secondary Risk Site	51.13%	58.28%	17	9.29%	50.00%
Merrimack Valley Planning Commission	Primary Risk Site	67.62%	88.18%	108	5.07%	16.67%
	Secondary Risk Site	56.80%	67.50%	212	9.95%	0.00%
Montachusett Regional Planning Commission	Primary Risk Site	62.99%	92.36%	117	5.03%	20.00%
	Secondary Risk Site	54.05%	62.91%	233	10.01%	20.00%
Nantucket Planning and Economic Development Commission	Primary Risk Site	69.42%	76.75%	9	5.92%	0.00%
	Secondary Risk Site	60.41%	68.46%	14	9.21%	0.00%
Northern Middlesex Council of Governments	Primary Risk Site	72.81%	84.93%	82	5.02%	14.29%
	Secondary Risk Site	61.50%	72.80%	163	9.99%	71.43%

MPO	Risk Category	Minimum Normalized Risk Score Percentage	Maximum Normalized Risk Score Percentage	Number of Segments	Percent of Scored MPO Segments	Percent of Target Crashes in MPO
Pioneer Valley Planning Commission	Primary Risk Site	64.80%	95.82%	222	5.05%	11.54%
	Secondary Risk Site	55.62%	64.80%	439	9.98%	0.00%
Old Colony Planning Council	Primary Risk Site	62.48%	84.81%	121	5.01%	0.00%
	Secondary Risk Site	54.01%	62.43%	241	9.99%	54.55%
Southeastern Regional Planning and Economic Development District	Primary Risk Site	62.71%	92.49%	166	5.01%	0.00%
	Secondary Risk Site	53.83%	62.67%	331	9.99%	22.22%

Table 18. Statewide Risk Categories for Intersections.

State	Risk Category	Minimum Normalized Risk Score Percentage	Maximum Normalized Risk Score Percentage	Number of Intersections	Percent of Scored State Intersections	Percent of Target Crashes
MA	Primary Risk Site	64.34%	90.10%	2,706	5.0%	27.11%
	Secondary Risk Site	55.14%	64.34%	5,411	10.0%	23.03%

Table 19. Distribution of Risk Intersections by MPO.

MPO	Risk Category	Minimum Normalized Risk Score Percentage	Maximum Normalized Risk Score Percentage	Number of Segments	Percent of Scored MPO Segments	Percent of Target Crashes in MPO
Berkshire Regional Planning Commission	Primary Risk Site	60.46%	78.93%	65	5.04%	31.82%
	Secondary Risk Site	52.22%	60.35%	129	10.01%	22.73%
Boston Region MPO	Primary Risk Site	67.44%	90.10%	1,195	5.00%	27.91%
	Secondary Risk Site	57.99%	67.44%	2,388	10.00%	24.15%
Cape Cod Commission	Primary Risk Site	57.06%	79.52%	149	5.00%	33.78%
	Secondary Risk Site	47.94%	57.05%	298	10.01%	25.68%
Central Massachusetts Regional Planning Commission	Primary Risk Site	60.32%	89.01%	215	5.02%	23.73%
	Secondary Risk Site	50.59%	60.26%	428	9.99%	32.20%
Franklin Regional Council of Governments	Primary Risk Site	54.66%	73.99%	46	5.02%	28.57%
	Secondary Risk Site	46.86%	54.59%	92	10.04%	14.29%
Martha's Vineyard Commission	Primary Risk Site	48.79%	57.18%	8	5.67%	50.00%
	Secondary Risk Site	45.71%	48.64%	14	9.93%	0.00%
Merrimack Valley Planning Commission	Primary Risk Site	62.20%	87.71%	143	5.01%	25.00%
	Secondary Risk Site	52.79%	62.18%	286	10.02%	17.50%

MPO	Risk Category	Minimum Normalized Risk Score Percentage	Maximum Normalized Risk Score Percentage	Number of Segments	Percent of Scored MPO Segments	Percent of Target Crashes in MPO
Montachusett Regional Planning Commission	Primary Risk Site	57.97%	86.08%	112	5.02%	18.75%
	Secondary Risk Site	50.41%	57.96%	223	10.00%	18.75%
Nantucket Planning and Economic Development Commission	Primary Risk Site	48.09%	55.97%	7	5.04%	0.00%
	Secondary Risk Site	44.86%	47.94%	14	10.07%	20.00%
Northern Middlesex Council of Governments	Primary Risk Site	61.76%	82.44%	123	5.03%	24.07%
	Secondary Risk Site	51.99%	61.75%	244	9.98%	18.52%
Pioneer Valley Planning Commission	Primary Risk Site	61.73%	84.79%	283	5.01%	0.00%
	Secondary Risk Site	52.70%	61.72%	564	9.99%	0.00%
Old Colony Planning Council	Primary Risk Site	62.11%	86.96%	134	5.03%	18.75%
	Secondary Risk Site	52.74%	61.94%	266	9.99%	18.75%
Southeastern Regional Planning and Economic Development District	Primary Risk Site	63.49%	81.64%	233	5.02%	19.28%
	Secondary Risk Site	55.40%	63.45%	464	9.99%	24.10%

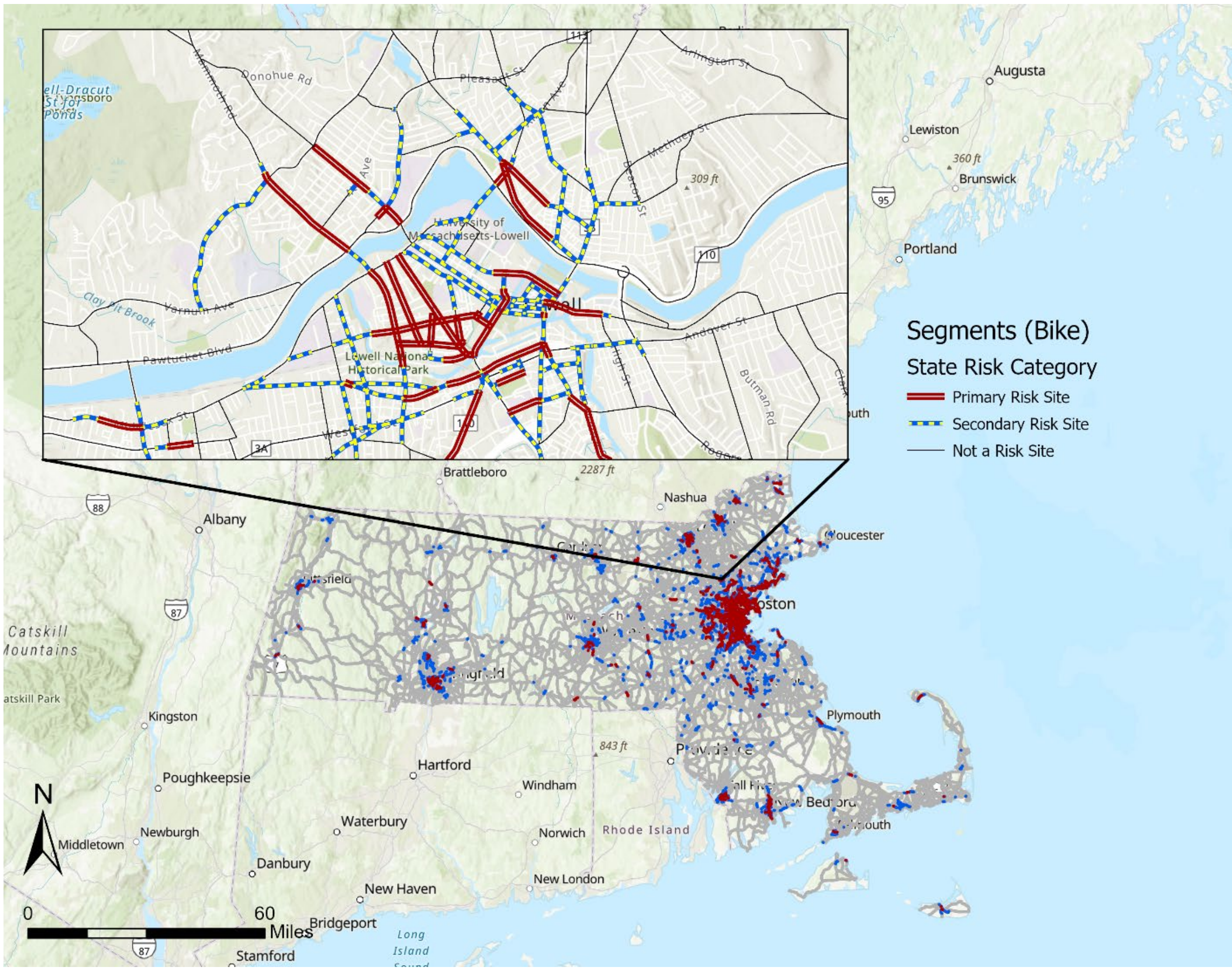

Figure 5. Map depicting the primary and secondary risk segments for KAB bicycle crashes, ranked statewide.

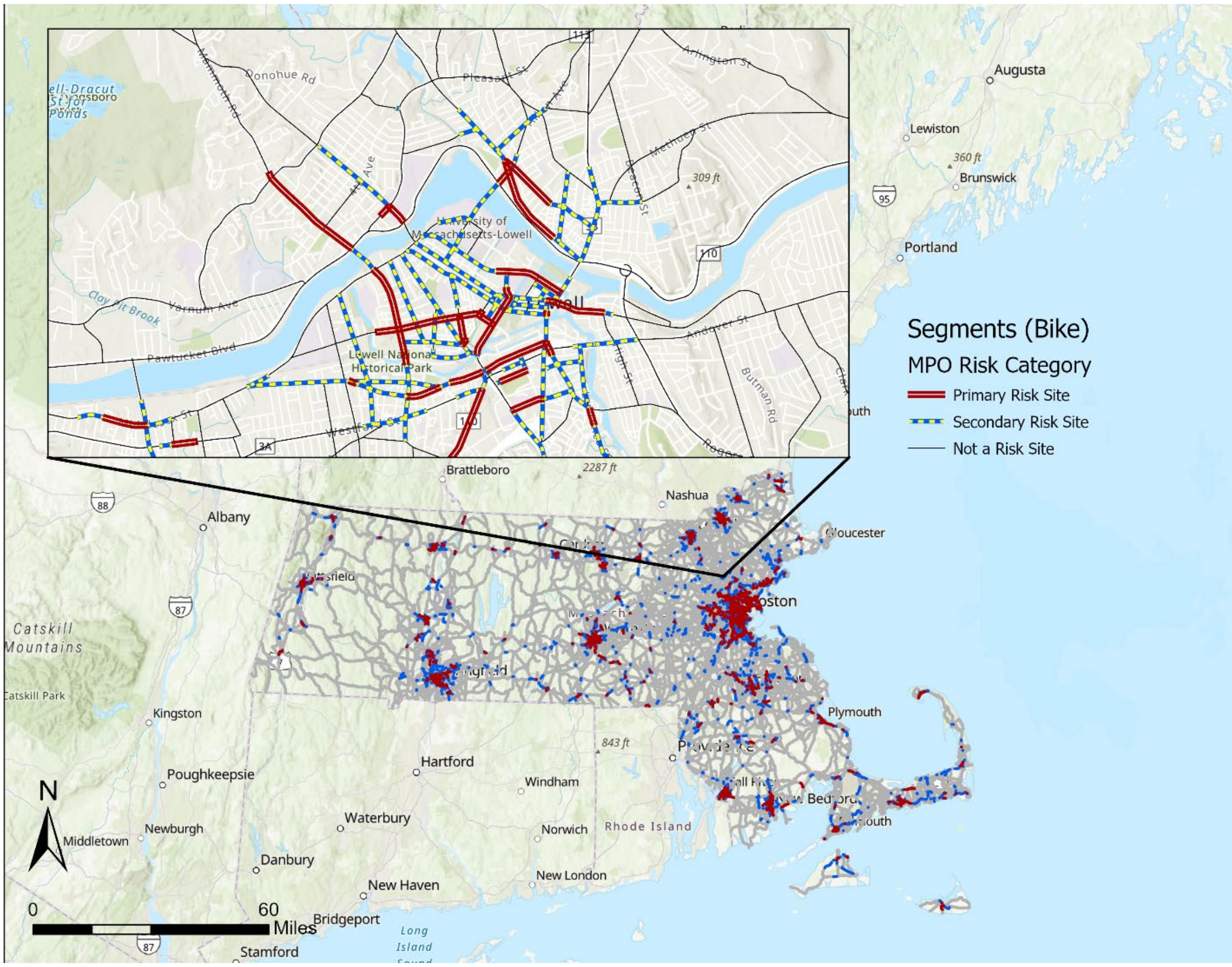

Figure 6. Map depicting the primary and secondary risk segments for KAB bicycle crashes, ranked by MPO.

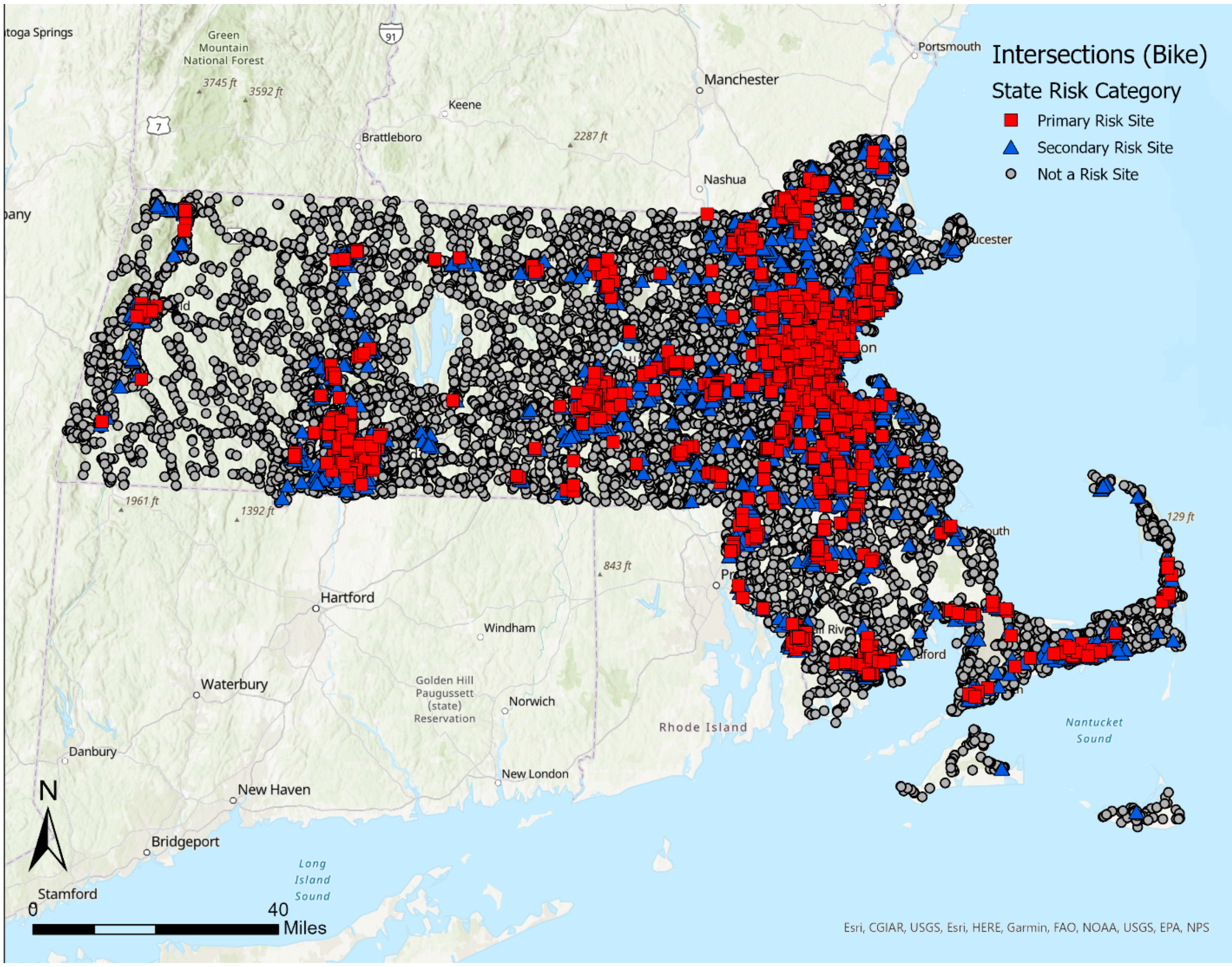

Figure 7. Map depicting the primary and secondary risk intersections for KA bicycle crashes, ranked statewide.

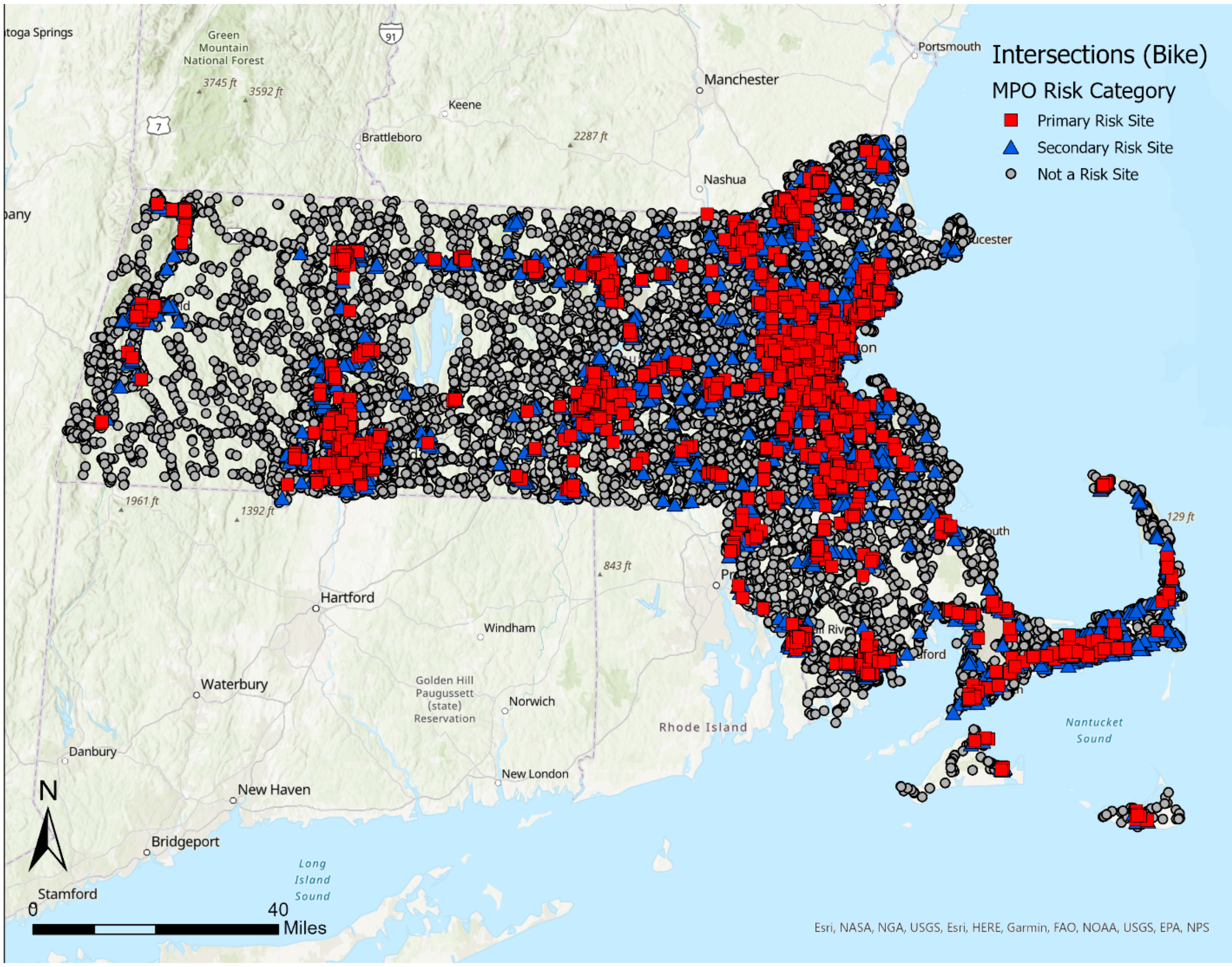

Figure 8. Map depicting the primary and secondary risk intersections for KA bicycle crashes, ranked by MPO.