The Vermont Agency of Transportation (VTrans) engaged Vanasse Hangen Brustlin, Inc (VHB) to develop a Vermont-specific network screening model to identify risk factors for intersection crashes. This assignment included developing a predictive methodology for applying the systemic safety approach to identify roadway features and locations associated with an increased risk of intersection crashes. This assignment also included the preparation of a quantifiable plan with prioritized strategies and locations for reducing intersection crashes.

This document is a compendium of the technical memoranda prepared by VHB for this project. In preparing this compendium, VTrans made some edits to capture information that was only provided via emails or to include information that was updated in subsequent memos.

This compendium consists of these five memoranda:

- Memorandum #1- Data Integration Memo
- Memorandum #2 - Crash Tree Memo
- Memorandum #3 - Risk Factor Identification Memo
- Memorandum #4 - Risk Maps Memo
- Memorandum #5 - Countermeasures & Implementation Plan Memo

Memorandum #1-Data Integration

The purpose of this memo is to describe the data acquisition, processing, and compilation efforts involved with building the systemic safety dataset. The memo was transmitted by VHB to VTrans on February 21, 2023.

Background

For this effort, VHB worked with VTrans to collect relevant datasets to identify focus crashes and focus facility types for intersection crashes, including for VRU crashes. An additional objective of this task was to obtain datasets that can be integrated for risk factor analysis, including traffic volume, intersection inventory data elements, and demographic and socioeconomic data. VTrans provided crash and intersection data, while VHB reviewed several resources to download and integrate additional data sets.

To support this task, VHB proposed specific intersection crash type definitions in this memorandum, which will be further refined in future tasks. These definitions were based on available data elements that are consistent with the FHWA definition for intersection and VRU crashes.

Data Acquisition

VHB acquired data from VTrans in the form of crash, intersection characteristics, traffic volume, and additional socioeconomic and demographic data intended for use. VHB compiled attributes from the data obtained from VTrans into an integrated crash database and an integrated intersection database. The crash database will support identification of focus crash types and focus facility types while the intersection database will support development of risk factors for focus crash types and facility types.

Crash Data

Following standard practice, five years of crash data were used. VTrans provided crash-level, vehicle-level, and person-level crash data for the years 2017 through 2021. These data included crash locations, crash severity, attributes for defining intersection crashes, and attributes for defining intersection crash types.

Spatial Data

VHB obtained spatial (GIS) data containing area type, intersection attributes, traffic volume, socioeconomic data, demographic data, and other data commonly used for VRU safety analyses[1]. The following spatial data sources were identified and integrated into the data set:

- Intersection Attributes at the node and leg level;
  - Area type (urban or rural).
  - Number of legs.
  - Intersection type.
  - Intersection geometry.
  - Leg ownership.
  - Present in school zone.
  - Bus stops within the area of the intersection.
  - Alcohol sales establishments within the area of the intersection.
  - Intersection skew angle.
  - Traffic control type.
  - Presence of intersection lighting.
  - Number of major and minor road left turn lanes.
  - Number of major and minor road right turn lanes.
  - Number of one way legs.
  - Number of legs which are divided.
  - Left turn phasing.
  - Legs with right turn on red prohibitions.
  - Maximum number of lanes cross by a pedestrian (at signalized intersections).
- Demographic and Socioeconomic Data;
  - Environmental Justice (EJ) maps and opportunity zones to note whether an intersection falls within an EJ area.
  - 2020 census block groups and associated data to quantify income, population, commuting, and other data in the intersection's block group.
- Other Data;
  - Locations of K-12 schools, libraries, and post-secondary schools to calculate the distance of an intersection from a potential trip generator.
  - Public transit data to calculate the distance of an intersection from a potential trip generator.
  - Building density near the intersection – urban density is likely correlated with pedestrian demand.

[1] These data, including school locations and transit, are typically correlated with walking and bicycle demand.

Data Processing

For this task, VHB used the data provided by VTrans and downloaded by VHB to generate, classify, and calculate attributes needed for the safety analysis. This primarily included identifying specific crash types. VRU crashes were confirmed using the person-level table for each crash. Whenever a person with Person Type "Pedestrian" was listed, that crash number was flagged as a "pedestrian crash" in the integrated crash data. The same process was used to flag bicycle crashes.

Additionally, VHB aggregated several attributes from the Direction of Collision field for proposed combined crash types. These only include vehicle crashes – pedestrian and bicycle crashes are excluded and categorized separately, regardless of the Direction of Collision. These categories were created:

- Left-Turn Crash.
    - Left and Right Turns Simultaneous Turn Crash.
    - Left Turn and Thru, Angle Broadside.
    - Left Turn and Thru, Broadside.
    - Left Turn and Thru, Head On.
    - Left Turn and Thru, Same Direction Sideswipe/Angle Crash.
    - Left Turns, Opposite Directions, Head On/Angle Crash.
    - Left Turns, Same Direction, Rear End.
- Rear End Crash.
    - Rear End.
    - Left Turns, Same Direction, Rear End.
    - Right Turn, Same Direction, Rear End.
- Right Turn Crash.
    - Left and Right Turns, Simultaneous Turn Crash.
    - Right Turn and Thru, Angle Broadside.
    - Right Turn and Thru, Broadside.
    - Right Turn and Thru, Head On.
    - Right Turn and Thru, Same Direction Sideswipe/Angle Crash.
    - Right Turn, Same Direction, Rear End.
- Angle/Broadside Crash.
    - Left Turn and Thru, Angle Broadside.
    - Left Turns, Opposite Directions, Head On/Angle Crash.
    - Left Turn and Thru, Broadside.
    - No Turns, Thru Moves Only, Broadside.

- Right Turn and Thru, Angle Broadside.
- Right Turn and Thru, Broadside.

- Head On Crash.
  - Head On.
  - Left Turn and Thru, Head On.
  - Right Turn and Thru, Head On.
  - Left Turns, Opposite Directions, Head On/Angle Crash.
- Single Vehicle Crash.
  - Single Vehicle Crash.

Two pedestrian crash subcategories were created based on the "PedestrianCycleLocation" field in the persons table:

- Pedestrian in marked crosswalk at intersection
- Pedestrian at intersection but no crosswalk

VTrans provided crash attributes in spreadsheet format and crash locations via a GIS feature service. To enable spatial analysis, VHB matched these two sources in GIS and created a point feature class (spatial GIS layer) representing all crashes. VHB located crashes using the linear referencing system, then applied to the intersection using Spatial Join. VHB then used the feature class to spatially attribute roadway characteristics and traffic volume data to crashes.

Data Compilation

For this task, VHB used the data provided by VTrans to identify attributes to integrate in the crash database and intersection database. Intersection zones were created by measuring 250 feet along each intersection leg with a 50-foot lateral buffer. Intersection legs were identified in the road centerlines file using the StartNodeID and EndNodeID fields. For continuity, road centerlines were connected across all 2-leg nodes and across multi-leg nodes where the TWN_LR field matched. For closely spaced intersections, overlaps were removed by dividing the overlapping area equally between adjacent intersections.

The attributes were then compiled from their respective sources onto a single spatial intersection GIS layer. This was done by spatially overlaying the various input layers and transferring the data to the intersections using the Spatial Join tool in GIS. Additionally, desired leg data were aggregated to the intersection level using Microsoft Excel. VHB also used Spatial Join to assign crashes to intersections – a crash was assigned to an intersection if it fell within its influence zone polygon as described above. Figure 1 is an example of how the crashes fell relative to the intersection polygons. VHB transferred several intersection data elements to the relevant crashes for the purpose of identifying focus facility types.

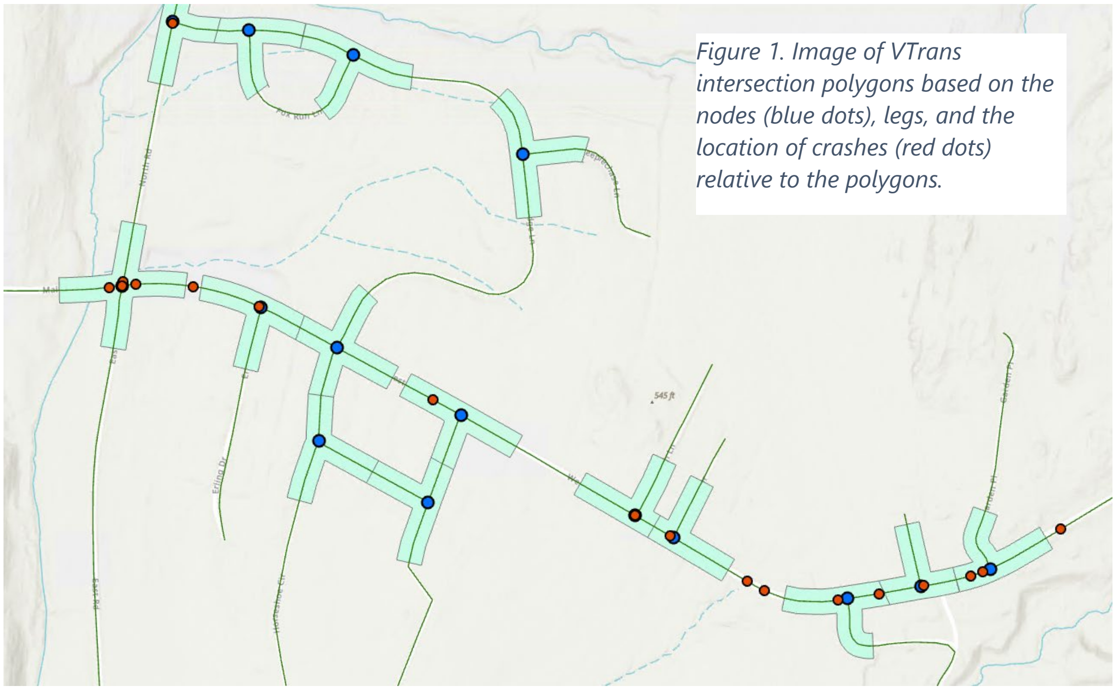


Figure 1. Image of VTrans intersection polygons based on the nodes (blue dots), legs, and the location of crashes (red dots) relative to the polygons.

Attributes Compiled in the Integrated Crash Data

VHB integrated the following attributes in the crash data:

- Intersection flag.
- Left-turn crash flag.
- Right-turn crash flag.
- Rear end crash flag.
- Head on crash flag.
- Angle/broadside crash flag.
- Single vehicle crash flag.
- Area type (urban or rural).
- Number of legs.
- Intersection type.
- Intersection geometry.
- Traffic control type.

Attributes Compiled in the Integrated Intersection Data:

VHB integrated the following attributes in the intersection data:

- Area type (urban or rural).
- Number of legs.
- Intersection type.
- Intersection geometry.

- Traffic control type.
- Intersection leg ownership.
- Crash counts for fatal and suspected serious injury (KA) crashes, suspected minor injury crashes (B), and possible injury crashes (C).
    - Left-turn crashes
    - Right-turn crash flag.
    - Rear end crash flag.
    - Head on crash flag.
    - Angle/broadside crash flag.
    - Single vehicle crash flag.
- Relation to school zone.
- Number of transit stops within the area of the intersection.
- Number of alcohol sales establishments within the area of the intersection.
- Intersection skew angle.
- Presence of intersection lighting.
- Number of major and minor road left turn lanes.
- Number of major and minor road right turn lanes.
- Number of one-way legs.
- Number of legs which are divided.
- Left-turn phasing (at signalized intersections).
    - Number of legs with protected left turns.
    - Number of legs with protected-permitted or permitted-protected left turns.
    - Number of legs with permissive left turns.
- Number of legs with right turn on red prohibitions (at signalized intersections).
- Maximum number of lanes cross by a pedestrian (at signalized intersections).
- Presence and type of EJ flag for the surrounding block group.
- Percent of non-vehicle commuters in the surrounding block group.
- Number of schools in the area of the intersection.
- Land cover in the area of the intersection.
- Building density in the area of the intersection.

Data Summary

VHB spatially aggregated all crashes within an intersection influence zone. Crashes on interstate mainlines (identified by the LRSNUMBER field) were removed to reduce extraneous data. To remove parking lot crashes, VHB excluded crashes if "AOTRoadwayGroup" was equal to 8 or 9. Several crashes remained where "Road Characteristics" was equal to "Parking lot" – VHB removed these as well. The distribution of intersection crashes by attributes for this element include:

- Crossover: 29.
- Driveway: 490.
- Five-point or more: 100.
- Four-way intersection: 4,255.
- Not at a junction: 8,085.
- Off ramp: 195.
- On ramp: 103.
- Other – explain in narrative: 517.
- Railway grade crossing: 29.
- Shared-use path or trail: 24.
- T-intersection: 4,721.
- Traffic circle/roundabout: 335.
- Unknown: 48.
- Y-intersection: 562.
- (blank): 8,445.

The VTrans intersection data includes an "Ownership" element which lists the predominant agency responsible for the intersection. After investigating further, VHB identified 11 combinations of intersections based on intersection leg ownership. Crash totals for these combinations include:

- Local[2]-Local: 13,619.
- Local-Other[3]: 11.
- Local-Private: 2,322.
- Other-Other: 1.
- Private-Private: 94.
- State-Local: 7,767.
- State-Local-Other: 3.
- State-Local-Private: 532.
- State-Other: 42.
- State-Private: 1,751.
- State-State: 1,796.

The following provides an overview of the crash sample sizes by type and severity (2017 to 2021 total):

- Number of crashes: 27,938.

[2] "Local" indicates attribute 3 (Town or Township Highway Agency) and 4 (City or Municipal Highway Agency).
[3] "Other" indicates all leg ownership attributes except for those under "Local", "State" (1), and "Private" (26).

- Number of K severity crashes: 98.
- Number of A severity crashes: 461.
- Number of B severity crashes: 2,715.
- Urban crashes: 16,836.
- Rural crashes: 11,099.
- Left-turn crashes: 2,240.
- Rear end crashes: 5,511.
- Right-turn crashes: 571.
- Angle/broadside crashes: 3,932.
- Head-on crashes: 1,191.
- Single-vehicle crashes: 3,792.
- Pedestrian crashes: 347.
- Bicycle crashes: 273.

Finally, VHB prepared several general facility types (i.e., geometry and traffic control) which will be considered in the analysis. Crash totals for these facility types include:

- Four-leg signalized[4] intersections: 6,251 total / 81 ped / 83 bicycle.
- Four-leg minor stop-control[5]: 3,013 total / 45 ped / 39 bicycle.
- Signalized t-intersection: 1,280 total / 15 ped / 16 bicycle.
- Uncontrolled t-intersection: 3,147 total / 38 ped / 24 bicycle.
- Minor stop-control t-intersection: 9,947 total / 110 ped / 85 bicycle.
- Four-leg all-way stop-controlled intersection: 818 total / 16 ped / 7 bicycle.
- Minor stop-controlled y-intersection: 276 total / 1 ped / 2 bicycle.
- Roundabout: 325 total / 1 ped / 0 bicycle.

Next Steps

VHB will proceed to employ the integrated dataset by selecting focus crashes and focus facility types. After confirming the selection of the crash and facility type combinations with VTrans, VHB will use statistical regression to identify risk factors each combination.

---

[4] Includes “Signals fully actuated (2 phase)”, “Signals fully actuated (multi-phase)”, “Signals semi-actuated (2 phase)”, “Signals semi-actuated (multi-phase)”, and “Other signalized”.
[5] “Stop signs on cross street only”

Memorandum #2-Crash Trees

The purpose of this memo is to describe the crash trees created to identify the focus crash type-focus facility type combinations for analysis. The memo was transmitted by VHB to VTrans on March 10, 2023.

Background

In the previous memorandum, VHB described working with VTrans to identify focus crash types. VHB acquired crash, intersection characteristics, and related data from VTrans and integrated them in a crash database and an intersection database. The intersection database supports the identification of risk factors for focus crash types. Using GIS, VHB joined the intersection database and the crash database into a single layer and the defined attribute classifications were compiled within it. Based on the need to identify focus crash types specific to target safety strategies, VHB recommended, and VTrans confirmed, several focus crash types, including:

- Left-turn crashes.
- Rear-end crashes.
- Right-turn crashes.
- Angle/broadside crashes.
- Head-on crashes.
- Single-vehicle crashes.
- Vehicle-pedestrian crashes.
- Vehicle-bicycle crashes.

VHB recommended these crashes based on the frequency of these types of crashes at Vermont intersections, and their status as common focus crash types for intersection safety analyses.

Focus Facility Types

After selecting the focus crash types, VHB used crash trees to discern where on the roadway network these crashes are occurring. A crash tree is a method of splitting out crashes by facility type. Per FHWA's *Systemic Safety Project election Tool*[6], the data are typically split by urban and rural, ownership (state or local), intersection, segment type, and intersection control type. By examining the crash trees, VHB and VTrans will select focus facility types for each focus crash type.

To identify focus facility types, VHB created crash trees for each focus crash type. While limiting data to fatal and suspected serious injury (KA) crashes is ideal, sample sizes (i.e., fewer than 100 crashes in a category) dictated the need to use all injury crashes (KAB) instead.

VHB used several elements to create the crash trees, with some variance based on the individual focus crash type. Elements used in the crash trees include intersection type (the combination of number of legs and traffic control),

[6] https://safety.fhwa.dot.gov/systemic/fhwasa13019/sspst.pdf

ownership of intersection legs (State and Non-state), and setting (urban or rural). For single vehicle crashes, the trees include collision with object (yes or no). Some focuses also have lighting condition and time of day (day or night).

Based on the crash trees, VHB recommends the following combinations of crash severities, crash types, and facility types for risk factor analysis:

1. KAB left turn crashes at minor stop-controlled intersections (237 crashes). This includes four-leg minor stop-control intersections, minor stop-control t-intersections, and minor stop-control y-intersections.
2. KAB left turn crashes on rural, minor stop-controlled intersections with at least one state-owned leg (102 crashes). This includes rural four-leg minor stop-control intersections, minor stop-control t-intersections, and minor stop- control y-intersections classified as "State vs State" and "State vs Nonstate".
3. KAB rear-end crashes at three-leg and four-leg unsignalized intersections (371 crashes). This includes four-leg minor stop-control intersections, uncontrolled t-intersections, minor stop-control t-intersections and y-intersections, and four-leg all-way stop-control intersections.
4. KAB rear-end crashes at signalized intersections with at least one non-state leg (178 crashes). This includes signalized four-leg intersections and signalized t-intersections.
5. KAB angle/broadside crashes at urban four-leg signalized intersections with no state legs (124 crashes).
6. KAB angle/broadside crashes at minor stop-controlled T-intersections with one or more nonstate legs (212 crashes).
7. KAB angle/broadside crashes at three-leg (t-intersections and y-intersections) and four-leg minor stop-controlled intersections (421 crashes).
8. KAB head-on crashes at minor stop-control T-intersections with at least 1 nonstate leg (140 crashes).
9. KAB single vehicle crashes at minor stop-control T-intersections with one or more nonstate legs (385 crashes).
10. KAB single vehicle crashes involving a collision with a fixed object (482 crashes).
11. KAB pedestrian-vehicle crashes at intersections (266 crashes). Given the small sample size, VHB elected not to identify a focus facility type.
12. KABCO pedestrian-vehicle crashes with a pedestrian in marked crosswalk at intersection (138 pedestrians in 131 crashes).
13. KABCO pedestrian-vehicle crashes with a pedestrian not in a marked crosswalk [location not coded "marked crosswalk at intersection" or "non-intersection crosswalk"] (211 pedestrians in 197 crashes).
14. KAB bicycle-vehicle crashes at intersection (170 crashes). Given the small sample size, VHB elected not to identify a focus facility type.
15. KABC pedestrian vehicle-crashes at intersections occurring at night (112 crashes).

The crash trees used for these definitions are appended to this memo.

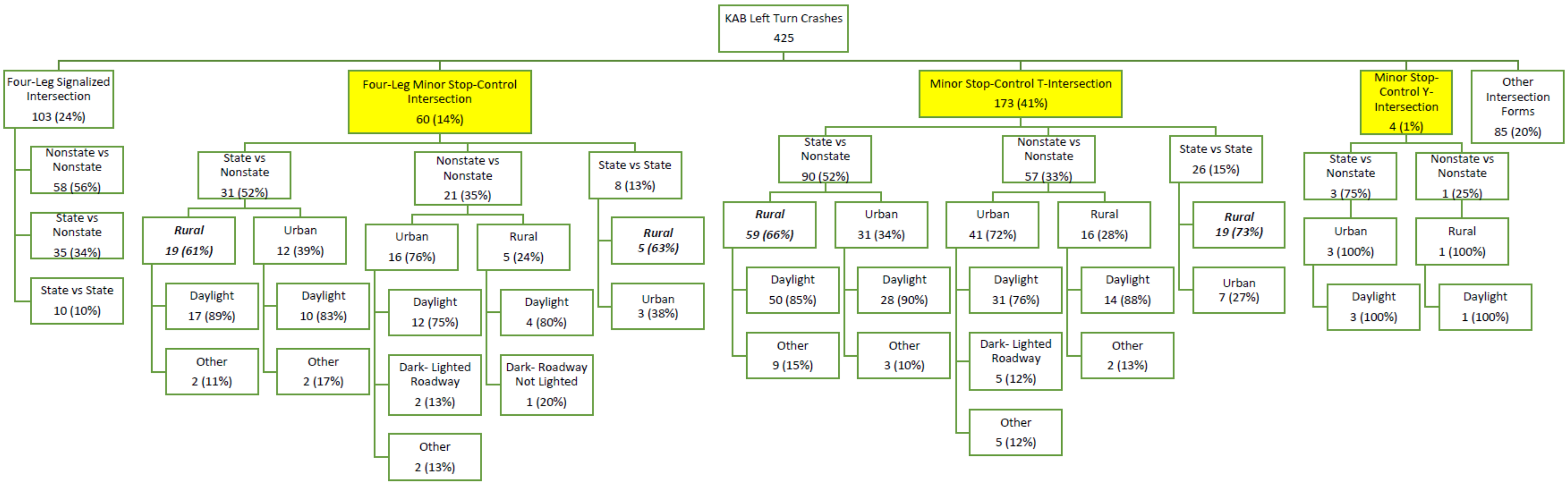
Next Steps

VTrans will review the proposed focus crash and facility types and the revised trees. Once VTrans approves a final list of focus types, VHB will proceed with the risk factor analysis.

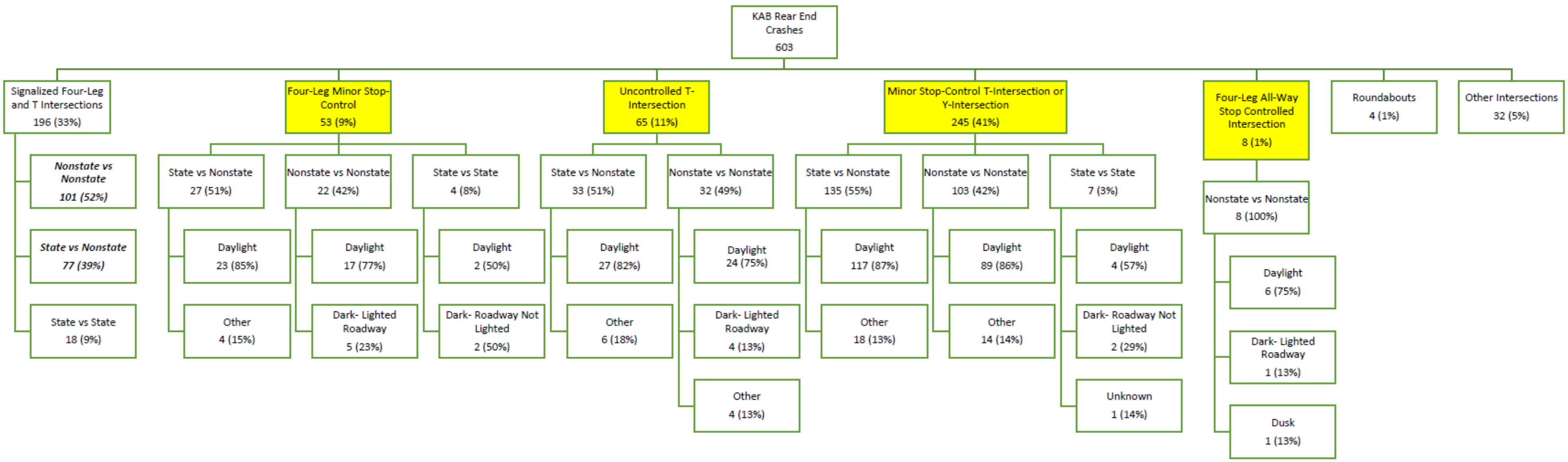
.

Intersection Crash Trees

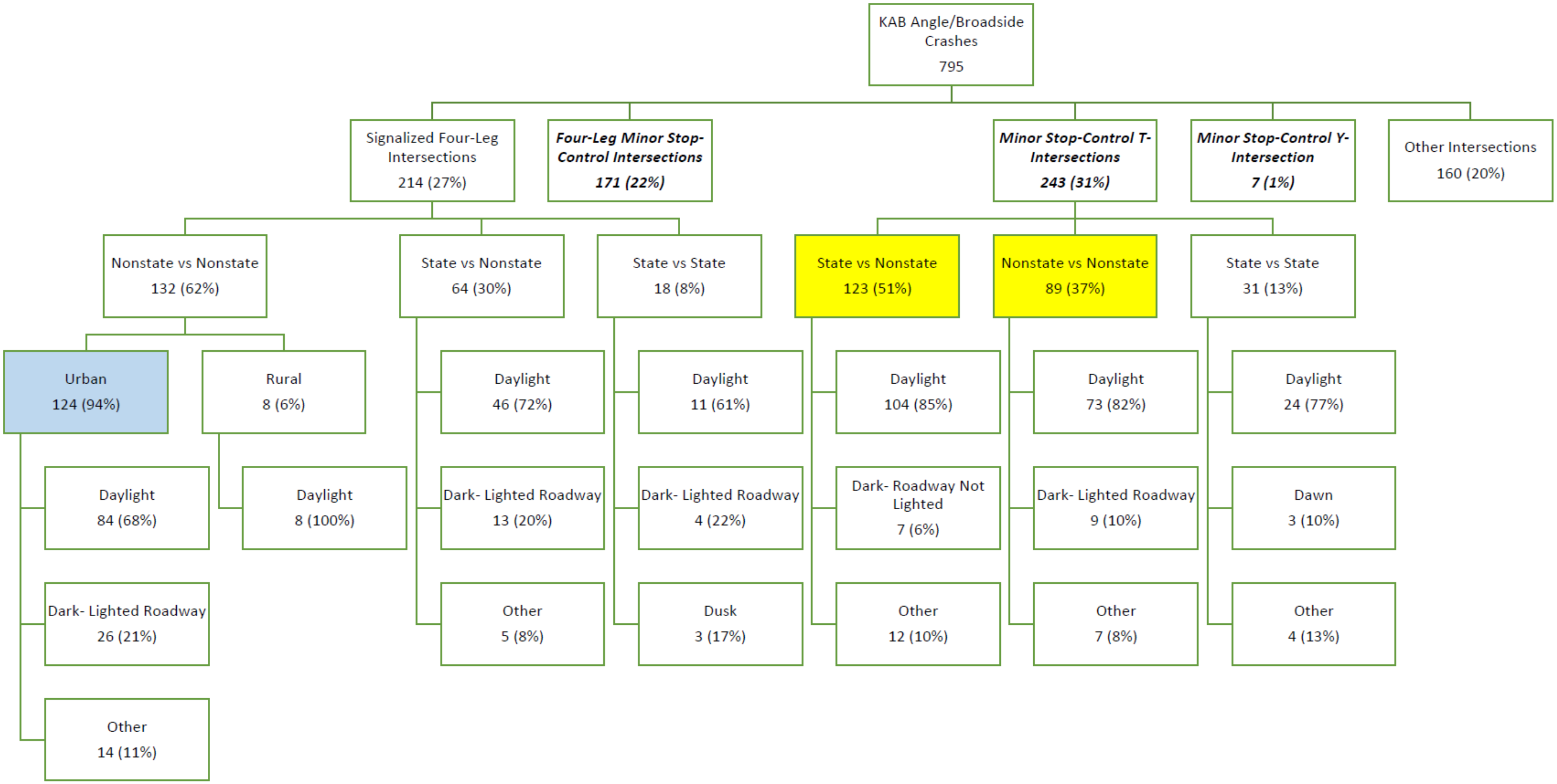
KAB Left Turn Crashes



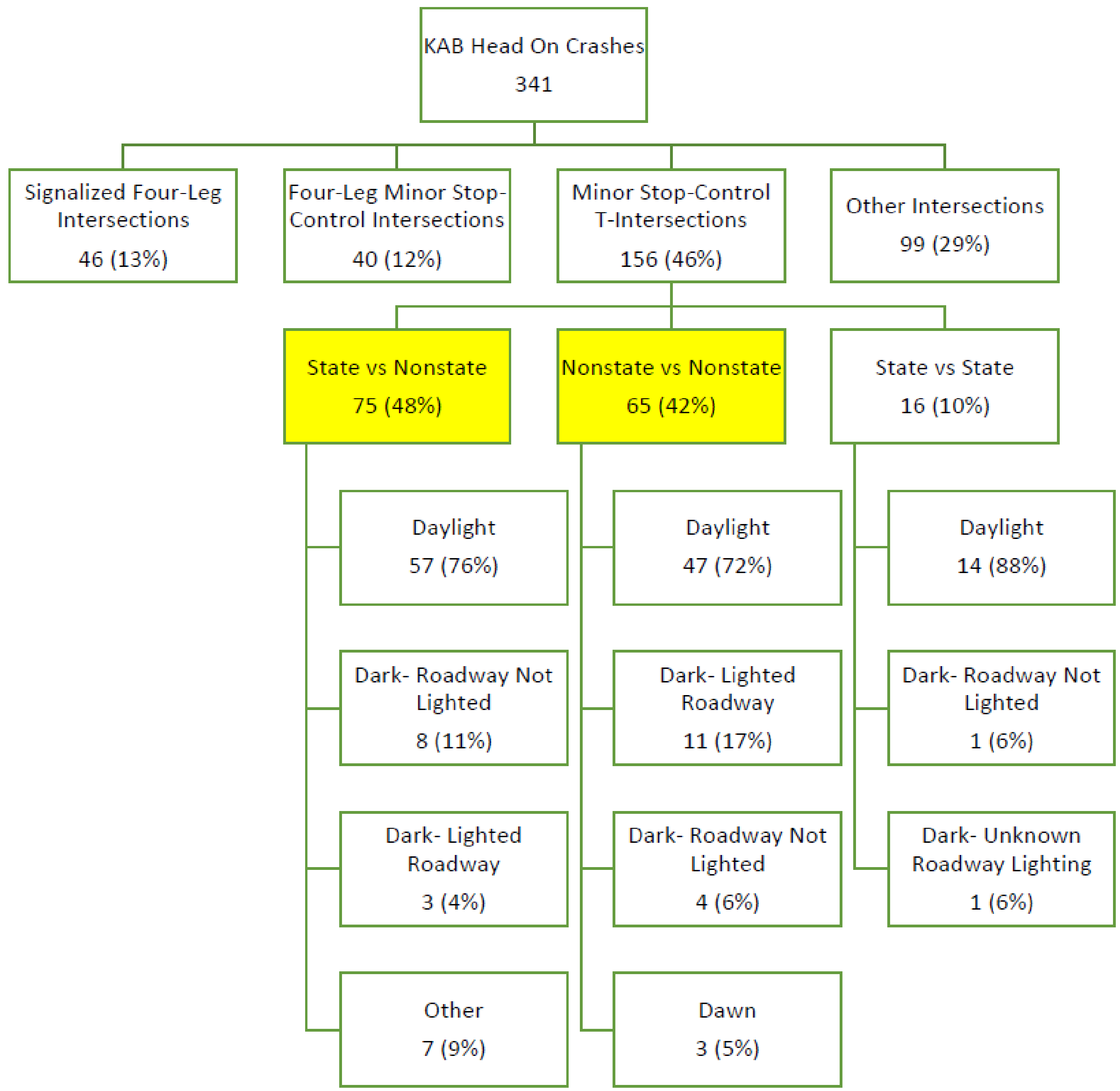
KAB Rear End Crashes



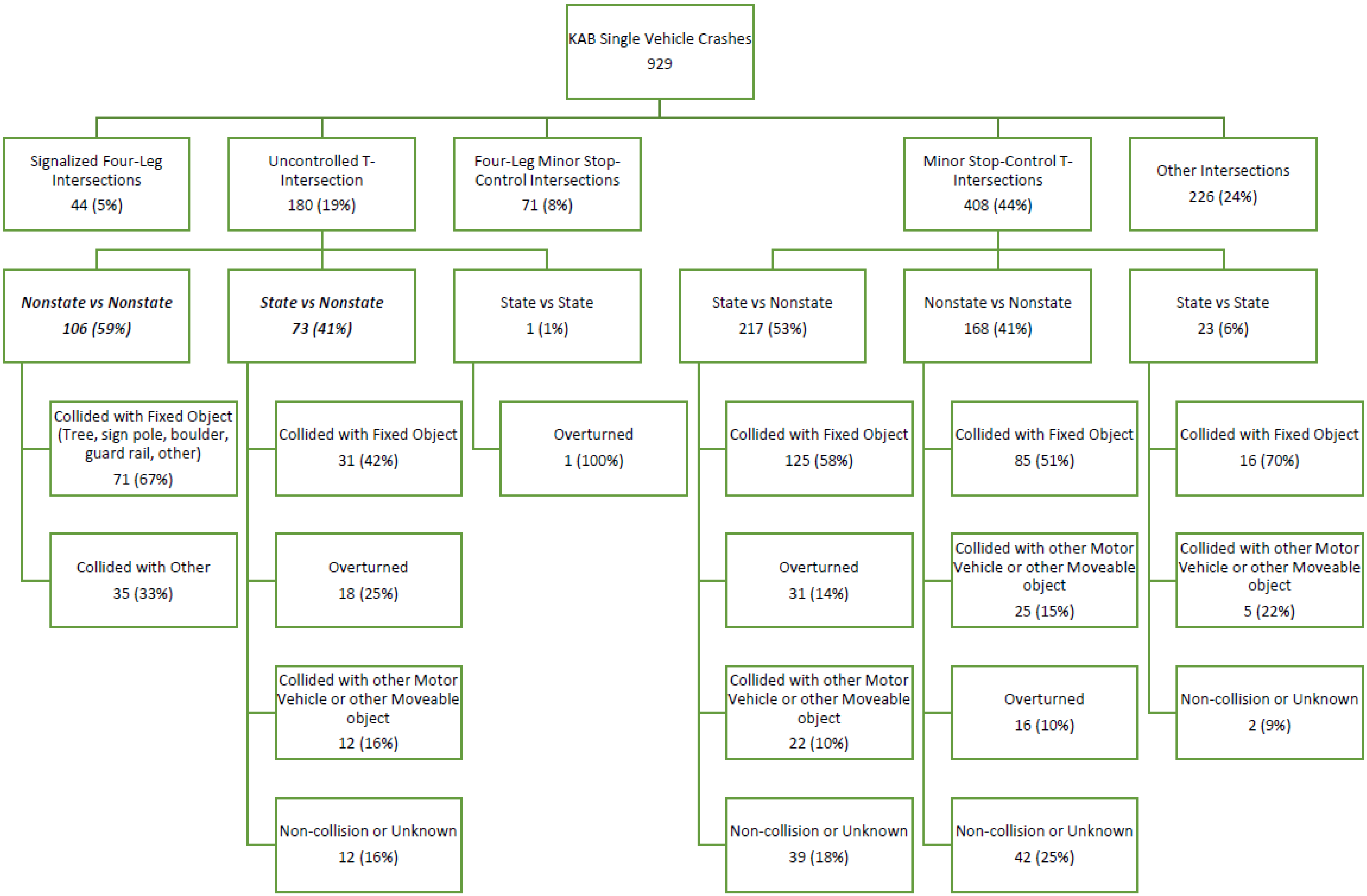
KAB Angle/Broadside Crashes



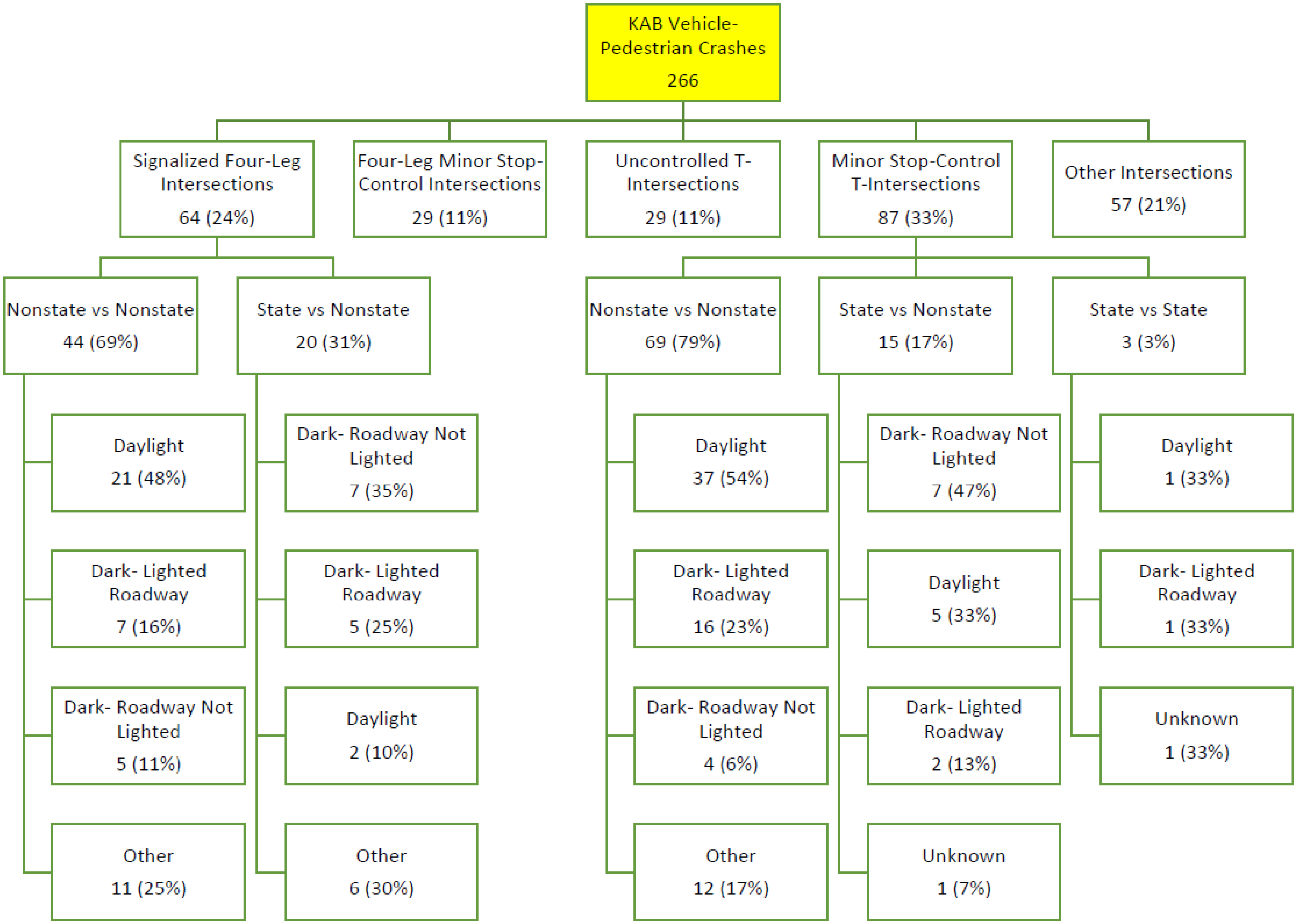
KAB Head On Crashes



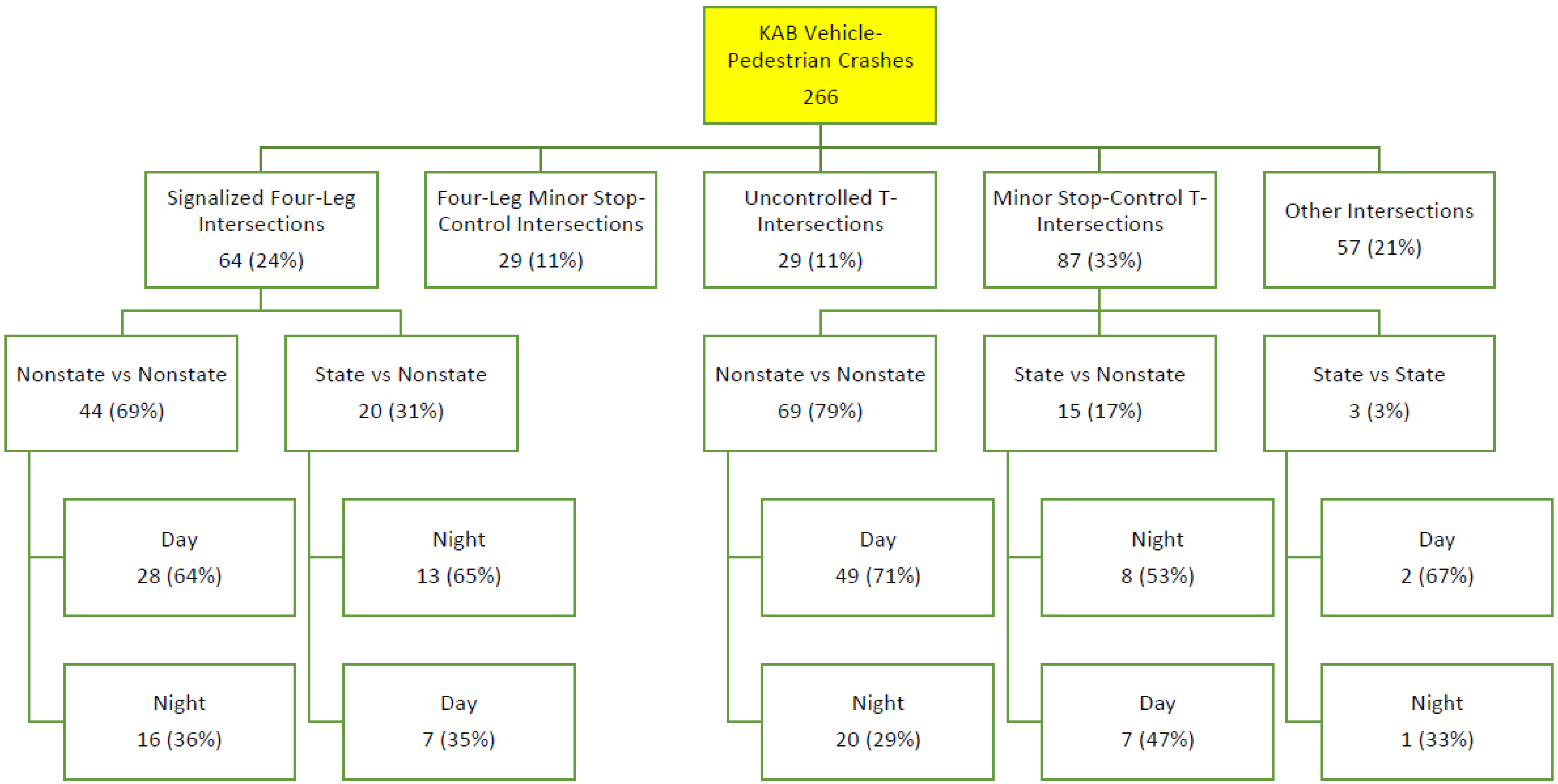
KAB Single Vehicle Crashes



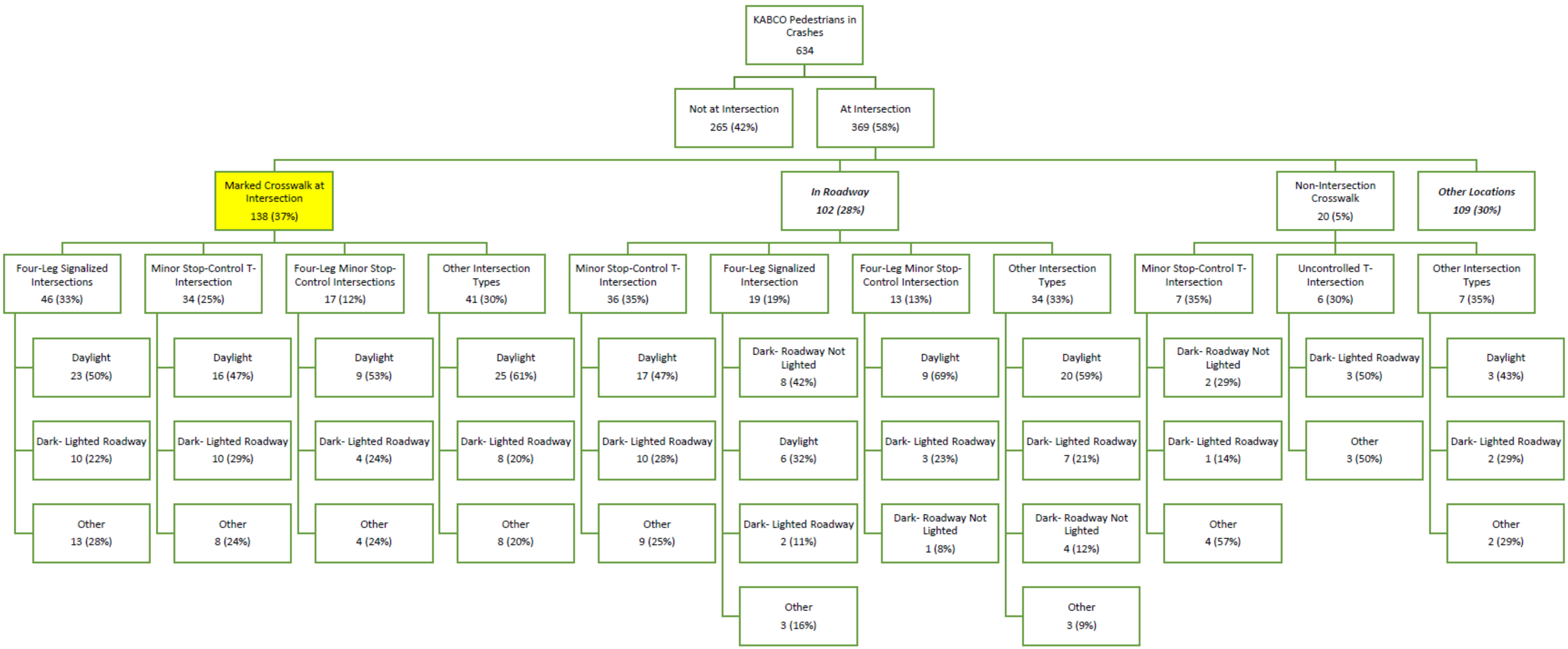
KAB Vehicle-Pedestrian Crashes



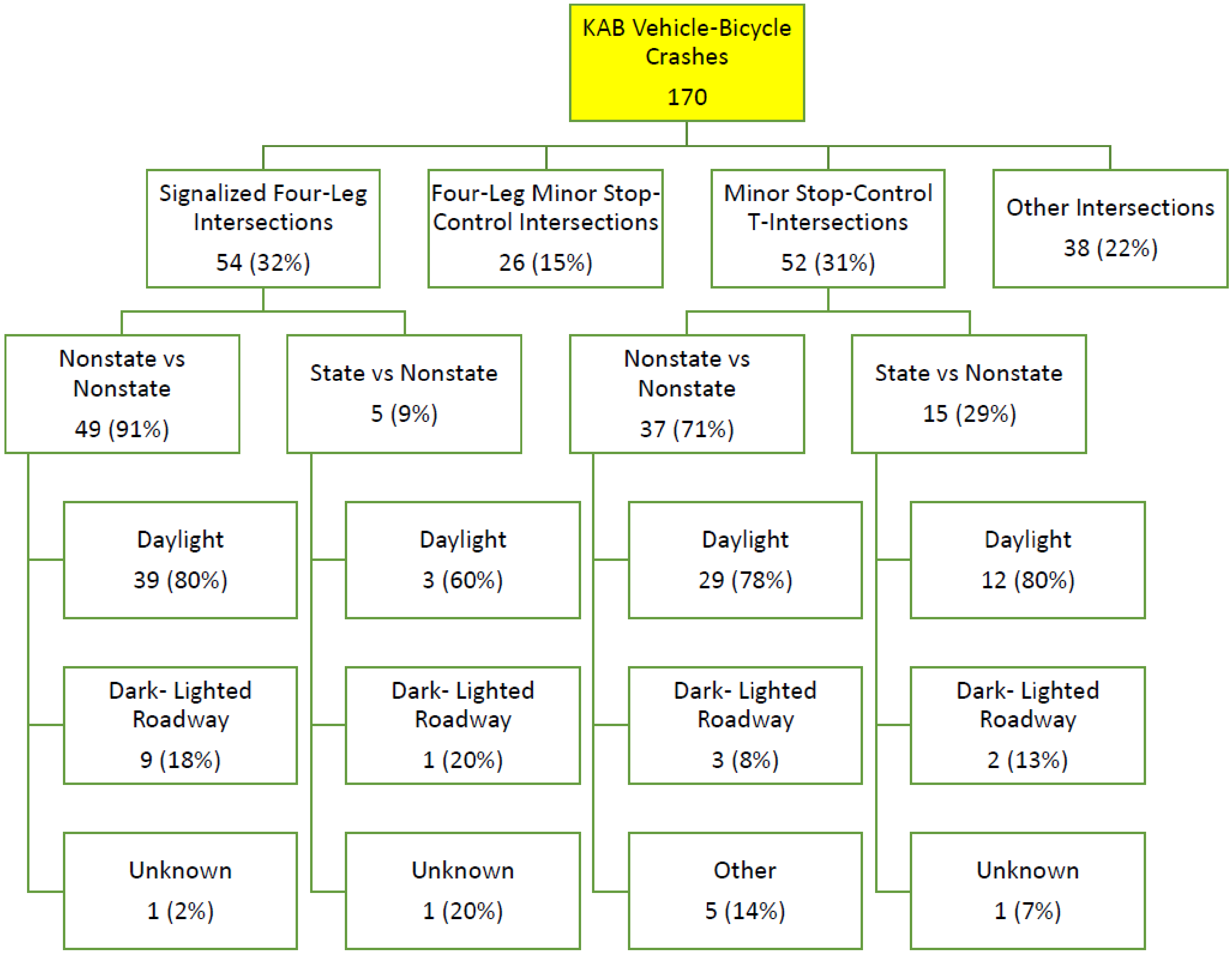
KAB Vehicle-Pedestrian Crashes



All Pedestrians Involved in Crashes



KAB Vehicle-Bicycle Crashes



Memorandum #3-Risk Factor Identification Memo

The purpose of this memo is to describe the crash models created to identify potential risk factors for different crash types. The memo was transmitted by VHB to VTrans on June2, 2023.

Background

In the previous memorandum, VHB described the combinations of focus crash and facility types for risk factor analysis. Ultimately, VTrans agreed to the following combinations:

1. KAB left turn crashes at minor stop-controlled intersections (237 crashes). This includes four-leg minor stop-control intersections, minor stop-control t-intersections, and minor stop-control y-intersections.
2. KAB left turn crashes on rural, minor stop-controlled intersections with at least one state-owned leg (102 crashes). This includes rural four-leg minor stop-control intersections, minor stop-control t-intersections, and minor stop- control y-intersections classified as “State vs State” and “State vs Nonstate”.
3. KAB rear-end crashes at three-leg and four-leg unsignalized intersections (371 crashes). This includes four-leg minor stop-control intersections, uncontrolled t-intersections, minor stop-control t-intersections and y-intersections, and four-leg all-way stop-control intersections.
4. KAB rear-end crashes at signalized intersections with at least one non-state leg (178 crashes). This includes signalized four-leg intersections and signalized t-intersections.
5. KAB angle/broadside crashes at urban four-leg signalized intersections with no state legs (124 crashes).
6. KAB angle/broadside crashes at minor stop-controlled T-intersections with one or more nonstate legs (212 crashes).
7. KAB angle/broadside crashes at three-leg (t-intersections and y-intersections) and four-leg minor stop-controlled intersections (421 crashes).
8. KAB head-on crashes at minor stop-control T-intersections with at least 1 nonstate leg (140 crashes).
9. KAB single vehicle crashes at minor stop-control T-intersections with one or more nonstate legs (385 crashes).
10. KAB single vehicle crashes involving a collision with a fixed object (482 crashes).
11. KAB pedestrian-vehicle crashes at intersections (266 crashes). Given the small sample size, VHB elected not to identify a focus facility type.
12. KABCO pedestrian-vehicle crashes with a pedestrian in marked crosswalk at intersection (138 pedestrians in 131 crashes).
13. KABCO pedestrian-vehicle crashes with a pedestrian not in a marked crosswalk [location not coded “marked crosswalk at intersection” or “non-intersection crosswalk”] (211 pedestrians in 197 crashes).
14. KAB bicycle-vehicle crashes at intersection (170 crashes). Given the small sample size, VHB elected not to identify a focus facility type.
15. KABC pedestrian vehicle-crashes at intersections occurring at night (112 crashes).

Crash Models

One method for identifying risk factors is the use of crash prediction models. These fall into two categories – crash frequency prediction and crash probability prediction. The standard approach for crash frequency prediction is count regression modeling, such as Poisson regression, or the more commonly used Negative Binomial regression, which is more applicable to crash data. Count regression models predict the frequency of events (such as target crashes) on a focus facility element (such as an intersection) as a function of the predictive variables. Crash probability prediction models are typically estimated using binary logistic (logit) regression, which predict the probability of an event (such as a target crash on a focus facility type element) based on the predictive variables.

After selecting the focus facility types, VHB used Stata Version 16, a statistical regression software, to create a binary logit regression model for each of the 15 recommended analyses. The binary logit models predict the probability of a focus crash type occurring at an intersection for a focus facility type. Note that this is different from the approach of using a negative binomial framework to predict the frequency of each focus crash type on the focus facility types. Since sample sizes were small (i.e., crashes were not clustered by location), the binary logit approach provides a more appropriate approach for identifying focus crash risk.

VHB used a forward selection regression approach, adding one factor at a time to identify the individual impact of each factor on crash probability and to evaluate model stability. Given the small sample size, the team considered both the practical and statistical significance of a variable for inclusion in the model; but factors with a P-value exceeding 0.300 were generally considered insignificant and removed. Further, VHB only considered risk factors if they accounted for at least 1 percent of the intersection sample and removed risk factors with cross-correlation higher than 0.70.

Many factors were already binary in nature (for example the presence or absence of a feature). For relevant continuous or categorical factors, VHB tested for thresholds to create binary variables. In some cases, VHB included continuous variables, specifically the natural log of total approach traffic volume. For these analyses, VHB included factors related to intersection geometry, traffic control, adjacent land use, adjacent population, and other intersection and socioeconomic characteristics. Through experimentation and optimization, VHB came to the resulting 15 crash models, from which we can recommend risk factors. Each of the 15 binary logit model outputs are described below.

When considering scoring, VHB considered elevated weighting for risk factors with relatively high Odds Ratios.

Left-Turn Crashes at Minor Stop-Controlled Intersections

This first model is focused on left turn crashes at minor stop-controlled intersections. All risk factors identified in this model were found to have odds ratios greater than 1.0. Table 1 summarizes the binary logistic regression model for these crashes. Generally, the risk factors indicate elevated risk at high-volume intersections in dense, urban areas.

Crash probability increases with total approach AADT, especially when that volume exceeds 10,000 vehicles per day. This is also shown by the lack of locally owned legs predicting higher crash probability, as local legs likely have less volume than state owned legs. The presence of left turn lanes on the major approach also predicts higher crashes, but this correlation is likely due to left turn lanes being implemented in locations that have higher left-turn volumes or problems with left turn crashes to begin with. Intersections with four or more legs are at a higher risk of these crashes compared to other minor stop-controlled intersections with 3 or fewer legs. Higher speeds, represented by minor approach speed limits of over 30 mph predict higher crash probability. Additionally, while these serve as surrogates for denser areas, intersections in areas with bicycle commuters and persons with short commutes are at an elevated risk for these crashes. Low-income areas also experience higher probabilities of these crashes, likely due to these being traditionally underserved communities in terms of infrastructure investments. All recommended risk factor weights are binary (0 and 1), although VHB does recommend a weight of 0 for the continuous natural log of total approach AADT since it serves the purpose of accounting for exposure in the model.

Table 1. Crash Prediction Model for Left-Turn Crashes at Minor Stop-Controlled Intersections

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Intersection has Four or more Legs	1.85	0.31	3.69	0.00	1.34	2.57	1
Natural Log of Total Approach AADT	1.40	0.09	5.51	0.00	1.24	1.58	0
Total Approach AADT > 10,000 veh/day	2.33	0.45	4.39	0.00	1.60	3.39	1
Minor Approach speed limit is over 30 mph	2.92	0.51	6.15	0.00	2.08	4.11	1
Left turn lanes on the Major Approach are present	1.66	0.42	2.01	0.04	1.01	2.71	1
None of the legs are locally owned	2.07	0.40	3.73	0.00	1.41	3.04	1
Over 15% of the persons in the Block Group have incomes less than $25,000	1.36	0.19	2.18	0.03	1.03	1.81	1
Bicycle Commuters are present in the Block Group	1.37	0.23	1.81	0.07	0.97	1.91	1
Over 30% of persons in the Block Group have a commute of 15 minutes or less	1.26	0.19	1.60	0.11	0.95	1.68	1
Constant	0.00073	0.00037	-14.35	0.00	0.00027	0.00197	N/A

Note: Number of observations = 9,451; Log likelihood = -899.69138; Pseudo R2 = 0.1326; LR chi2(9) = 275.00; Prob > chi2 = <0.0001. N/A is not applicable.

Left-Turn Crashes on Rural, Minor Stop-Controlled Intersections with at least one State-Owned Leg

This second model is focused on left turn crashes at rural, minor stop-controlled intersections with at least one State-owned leg. All risk factors identified in this model were found to have odds ratios greater than 1.0. Table 2 summarizes the binary logistic regression model for these crashes. Generally, the risk factors indicate elevated risk at high-volume, denser, underprivileged area intersections. Crash probability increases with total approach AADT. This is also shown by the lack of locally owned legs or privately owned legs predicting higher crash probability, as local legs and private legs likely have less volume than state owned legs. Intersections with four or more legs are at a higher risk of these crashes compared to other minor stop-controlled intersections with 3 or less legs. Higher speeds, represented by minor approach speed limits of over 30 mph predict higher crash probability. Additionally, while these serve as surrogates for denser areas, intersections in areas with bicycle commuters, persons with short commutes, and no seasonal buildings are at an elevated risk for these crashes. Low income and being in an "Opportunity Zone" as designated by the U.S. Secretary of the Treasury also predict higher probabilities of these crashes. Most recommended risk factor weights are binary (0 and 1), although VHB does recommend a weight of 0 for the continuous natural log of total approach AADT since it serves the purpose of accounting for exposure in the model.

Table 2. Crash Prediction Model for Left-Turn Crashes at Rural, Minor Stop-Controlled Intersections with at least one State-Owned Leg

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Intersection has Four or more Legs	2.02	0.51	2.78	0.01	1.23	3.31	1
Natural Log of Total Approach AADT	2.31	0.35	5.46	0.00	1.71	3.11	0
No Seasonal Buildings within a quarter mile of the Intersection	1.77	0.39	2.61	0.01	1.15	2.73	1
Minor Approach speed limit is over 30 mph	2.36	0.56	3.62	0.00	1.48	3.75	1
There are no Local Legs present	2.25	0.61	3.00	<0.01	1.32	3.81	1
There are no Private legs present	2.39	1.15	1.81	0.07	0.93	6.13	1
The area is identified as an Opportunity Zone	1.62	0.60	1.31	0.19	0.79	3.33	1
Over 15% of the persons in the Block Group have incomes less than $25,000	1.39	0.30	1.53	0.13	0.91	2.11	1
Over 30% of persons in the Block Group have a commute of 15 minutes or less	1.52	0.32	1.98	0.05	1.00	2.31	1
Bicycle Commuters are present in the Block Group	1.50	0.41	1.50	0.13	0.88	2.55	1
Constant	<0.00001	<0.00001	-9.00	<0.001	<0.00001	0.00006	N/A

Note: Number of observations = 3,500; Log likelihood = -390.95465; Pseudo R2 = 0.1254; LR chi2(10) = 112.13; Prob > chi2 = <0.0001. N/A is not applicable.

Rear-End Crashes at Three-Leg and Four-Leg Unsignalized Intersections

This third model is focused on rear-end crashes at three and four legged unsignalized intersections. All risk factors identified in this model were found to have odds ratios greater than 1.0. Table 3 summarizes the binary logistic regression model for these crashes.

Table 3. Crash Prediction Model for Rear-End Crashes at Three-Leg and Four-Leg Unsignalized Intersections

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Area is Urban	1.46	0.21	2.64	0.01	1.10	1.92	1
Lighting is present	1.42	0.20	2.50	0.01	1.08	1.86	1
Natural Log of Total Approach AADT	1.42	0.07	6.77	0.00	1.28	1.57	0
Total Approach AADT > 6,000 veh/day	4.04	0.63	9.02	0.00	2.99	5.48	2
The area is an Opportunity Zone	1.60	0.24	3.21	<0.01	1.20	2.14	1
The percentage of the population in the Block Group that speak limited English is over 50%	1.28	0.15	2.10	0.04	1.02	1.62	1
There are no Seasonal Buildings within a quarter mile of the intersection	1.32	0.18	2.00	0.05	1.01	1.73	1
Major Approach Speed limit is over 35 mph	2.22	0.31	5.80	0.00	1.70	2.91	1
None of the legs are privately owned	1.53	0.23	2.85	<0.01	1.14	2.04	1
The total population of the Block Group is over 1500 (based on number of individuals that reported their race in the census)	1.35	0.16	2.48	0.01	1.06	1.70	1
Constant	0.00021	0.00009	-19.27	0.00	0.00009	0.0005	N/A

Note: Number of observations = 17,401; Log likelihood = -1327.7833; Pseudo R2 = 0.2163; LR chi2(10) = 732.86; Prob > chi2 = <0.0001. N/A is not applicable.

Generally, the risk factors indicate elevated risk at high-volume, denser urban area intersections. Crash probability increases with total approach AADT, especially over 6,000 vehicles per day. This is also shown by the lack of privately owned legs predicting higher crash probability, as private legs likely have less volume than state owned legs. Higher speeds, represented by major approach speed limits of over 35 mph predict higher crash probability. Additionally, while these serve as surrogates for denser areas, urban intersections with lighting in an area with no seasonal buildings and total population over 1500 people per block group are at an elevated risk for these crashes. Limited English and being in an "Opportunity Zone" as designated by the U.S. Secretary of the Treasury also predict higher probabilities of these crashes. Most recommended risk factor weights are binary (0 and 1, 0 and 2), although VHB does recommend a weight of 0 for the continuous natural log of total approach AADT since it serves the purpose of accounting for exposure in the model.

Rear-End Crashes at Signalized Intersections with at least One Non-State Leg

This model is focused on rear-end crashes at signalized intersections with one or more non-state-owned leg. All risk factors identified in this model were found to have odds ratios greater than 1.0. Table 4 summarizes the binary logistic regression model for these crashes.

Table 4. Crash Prediction Model for Rear-End Crashes at Signalized Intersections with at least One Non-State Leg

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Intersection has four or more legs	2.54	0.86	2.77	0.01	1.31	4.92	1
Intersection skew angle is over 25 degrees	1.87	0.68	1.73	0.08	0.92	3.80	1
Natural Log of Total Approach AADT	2.59	1.00	2.47	0.01	1.22	5.50	0
Total Approach AADT > 15,000 veh/day	1.76	0.71	1.42	0.16	0.80	3.86	1
The percentage of the population in the Block Group that are minorities is over 50%	2.40	0.88	2.38	0.02	1.17	4.94	1
Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile	1.67	0.49	1.72	0.09	0.93	2.98	1
Major Median is divided	1.67	0.47	1.83	0.07	0.96	2.89	1

Constant	<0.00001	0.00002	-3.43	<0.01	<0.00001	0.00550	N/A

Note: Number of observations = 371; Log likelihood = -180.21186; Pseudo R2 = 0.2154; LR chi2(7) = 98.93; Prob > chi2 = <0.0001. N/A is not applicable.

Generally, the risk factors indicate elevated risk at high-volume intersections. Crash probability increases with total approach AADT, especially over 15,000 vehicles per day. This is also shown through the correlation between the major approach being divided and higher likelihood of these crashes, as higher volume roads are more likely to be divided. Intersections with four or more legs are at a higher risk of these crashes compared to intersections with 3 or fewer legs. An intersection skew angle of 25 degrees or more also predicts higher crash probability. As a surrogate for dense areas, an average density of 33 primary civic buildings per square mile within a quarter mile of the intersection increases crash probability. High minority populations in the block group predict higher probabilities of these crashes. Most recommended risk factor weights are binary (0 and 1), although VHB does recommend a weight of 0 for the continuous natural log of total approach AADT since it serves the purpose of accounting for exposure in the model.

Angle/Broadside Crashes at Urban Four-Leg Signalized Intersections with No State Legs

This model is focused on angle/broadside crashes at urban four-legged intersections with no state-owned legs. All risk factors identified in this model were found to have odds ratios greater than 1.0, in this case significantly greater than 1.0. Table 5 summarizes the binary logistic regression model for these crashes. Since this is a small subset of the network, only a few variables were found to be significant compared to the other models. Generally, the risk factors indicate elevated risk at high-volume, dense area intersections. A total approach AADT over 13,000 vehicles per day increases crash probability. No right turn lanes on the major approach also predicts a higher likelihood of angle/broadside crashes. Additionally, while these serve as surrogates for dense areas, the presence of an alcohol vendor and the lack of an industrial building within a quarter mile increases crash probability. High minority populations in the block group predict higher probabilities of these crashes as well. The recommended risk factor weights are binary with some given elevated weight (0 and 1, 0 and 2).

Table 5. Crash Prediction Model for Angle/Broadside Crashes at Urban Four-Leg Signalized Intersections with No State Legs

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Alcohol is sold within a quarter mile	4.81	2.79	2.70	0.01	1.54	15.02	2
Total Approach AADT > 13,000 veh/day	2.57	1.14	2.13	0.03	1.08	6.14	1
The percentage of the population in the Block Group that are minorities is over 50%	3.58	2.56	1.78	0.08	0.88	14.55	2

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
No industrial buildings present within a quarter mile of the intersection	3.48	1.52	2.87	<0.01	1.48	8.18	2
No right turn lanes present on the Major approach	4.52	2.23	3.06	<0.01	1.72	11.89	2
Constant	0.00739	0.00818	-4.44	0.00	0.00084	0.06463	N/A

Note: Number of observations = 140; Log likelihood = -80.091003; Pseudo R2 = 0.1716; LR chi2(5) = 33.18; Prob > chi2 = <0.0001. N/A is not applicable.

Angle/Broadside Crashes at Minor Stop-Controlled T-Intersections with at least One Non-State Leg

This model is focused on angle/broadside crashes at minor stop-controlled T-intersections with at least one non-state-owned leg. All risk factors identified in this model were found to have odds ratios greater than 1.0. Table 6 summarizes the binary logistic regression model for these crashes. Generally, the risk factors indicate elevated risk at high-volume, denser urban intersections. Crash probability increases with total approach AADT, especially over 4,000 vehicles per day. This is also shown through the correlation between the presence of state-owned legs and higher crash probability, as state-owned legs are more likely to have higher volumes. Higher speeds increase crash probability as represented by intersections with speed limits over 30 mph on their minor legs. Additionally, while these serve as surrogates for denser areas, urban intersections with an alcohol vendor present in areas with shorter average commutes have higher crash probability. Low income also predicts higher probabilities of these crashes. Contrastingly, intersections with no K12 school nearby are also at elevated risk of a severe angle crash. Most recommended risk factor weights are binary (0 and 1, 0 and 2), although VHB does recommend a weight of 0 for the continuous natural log of total approach AADT since it serves the purpose of accounting for exposure in the model.

Table 6. Crash Prediction Model for Angle/Broadside Crashes at Minor Stop-Controlled T-Intersections with at least One Non-State Leg

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Area is Urban	1.85	0.34	3.38	<0.01	1.30	2.65	1
Alcohol is sold within a quarter mile	2.13	0.38	4.26	0.00	1.50	3.01	1
Natural Log of Total Approach AADT	1.21	0.07	3.22	<0.01	1.08	1.35	0

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Total Approach AADT > 8,000 veh/day	2.53	0.50	4.70	0.00	1.72	3.73	1
Minor approach speed limit is over 30 mph	3.41	0.69	6.09	0.00	2.30	5.07	2
There are no K-12 schools in a quarter mile	1.65	0.41	2.02	0.04	1.01	2.69	1
There are state-owned legs present	1.90	0.34	3.55	0.00	1.33	2.70	1
Over 15% of the persons in the Block Group have incomes less than $25,000	1.34	0.21	1.87	0.06	0.99	1.82	1
Over 30% of persons in the Block Group have a commute of 15 minutes or less	1.79	0.30	3.43	<0.01	1.28	2.50	1
Constant	0.00072	0.00037	-14.06	0.00	0.00026	0.00262	N/A

Note: Number of observations = 7,716; Log likelihood = -750.37158; Pseudo R2 = 0.1512; LR chi2(9) = 267.33; Prob > chi2 = <0.0001. N/A is not applicable.

Angle/Broadside Crashes at Three-Leg and Four-Leg Minor Stop-Controlled Intersections

This model is focused on angle/broadside crashes at three-leg and four-leg minor stop-controlled intersections. All risk factors identified in this model were found to have odds ratios greater than 1.0. Table 7 summarizes the binary logistic regression model for these crashes. Generally, the risk factors indicate elevated risk at high-volume, denser urban intersections. Crash probability increases with total approach AADT, especially over 12,000 vehicles per day. This is also shown through the correlation between the presence of state-owned legs and one-way roads and higher crash probability, as state-owned legs and one-way roads are more likely to have higher volumes. Higher speeds increase crash probability as represented by intersections with speed limits over 30 mph on their minor legs. Additionally, while these serve as surrogates for denser areas, urban intersections with an alcohol vendor present within a quarter mile in areas with shorter average commutes have higher crash probability. Low income also predicts higher probabilities of these crashes. Most recommended risk factor weights are binary (0 and 1, 0 and 2), although VHB does recommend a weight of 0 for the continuous natural log of total approach AADT since it serves the purpose of accounting for exposure in the model.

Table 7. Crash Prediction Model for Angle/Broadside Crashes at Three-Leg and Four-Leg Minor Stop-Controlled Intersections

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Area is Urban	1.79	0.25	4.21	0.00	1.37	2.36	1
Alcohol is sold within a quarter mile	1.76	0.23	4.33	0.00	1.36	2.27	1
One-way legs are present	1.98	0.41	3.27	<0.01	1.32	2.99	1
Minor Approach posted speed limit is over 30 mph	3.15	0.46	7.78	0.00	2.36	4.21	2
State owned legs are present	1.83	0.25	4.43	0.00	1.40	2.39	1
Natural Log of Total Approach AADT	1.21	0.05	4.83	0.00	1.12	1.30	0
Total Approach AADT > 12,000 veh/day	2.49	0.42	5.41	0.00	1.79	3.46	1
Over 15% of the persons in the Block Group have incomes less than $25,000	1.27	0.15	2.07	0.04	1.01	1.59	1
Over 30% of persons in the Block Group have a commute of 15 minutes or less	1.59	0.20	3.76	0.00	1.25	2.03	1
Constant	0.00232	0.00071	-19.89	0.00	0.00128	0.00421	N/A

Note: Number of observations = 9,435; Log likelihood = -1291.004; Pseudo R2 = 0.1316; LR chi2(9) = 391.25; Prob > chi2 = <0.0001. N/A is not applicable.

Head-On Crashes at Minor Stop-Control T-Intersections with at least One Nonstate Leg

This model is focused on head-on crashes at minor stop-controlled T-intersections with at least one non-state-owned leg. All risk factors identified in this model were found to have odds ratios greater than 1.0. Table 8 summarizes the binary logistic regression model for these crashes. Generally, the risk factors indicate elevated risk at high-volume, denser urban intersections. Crash probability increases with total approach AADT, especially over 9,000 vehicles per day. This is also shown through the correlation between the lack of private-owned legs and higher crash probability, as private-owned legs are more likely to have lower volumes. An intersection skew angle over 25 degrees increases the probability of head-on crashes. Higher speeds increase crash probability as represented by intersections with speed limits over 30 mph on their minor legs. Additionally, while these serve as surrogates for denser areas, intersections in an area with no seasonal buildings within a quarter mile, high income, bicycle commuters, and over 1500 people per block group have higher crash probability. Being in an "Opportunity Zone" as designated by the U.S. Secretary of the Treasury also predicts higher probabilities of these crashes. Most recommended risk factor weights are binary (0 and 1), although VHB does recommend a weight of 0 for the continuous natural log of total approach AADT since it serves the purpose of accounting for exposure in the model.

Table 8. Crash Prediction Model for Head-On Crashes at Minor Stop-Control T-Intersections with at least One Nonstate Leg

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Intersection skew angle is over 25 degrees	1.34	0.32	1.22	0.22	0.84	2.16	1
Natural Log of Total Approach AADT	1.21	0.06	3.74	0.00	1.09	1.33	0
Total Approach AADT > 9,000 veh/day	2.93	0.65	4.82	0.00	1.89	4.54	1
Area is identified as an Opportunity Zone	1.86	0.44	2.64	0.01	1.17	2.95	1
No seasonal buildings within a quarter mile of the intersection	1.28	0.26	1.20	0.22	0.86	1.90	1
Minor Approach Speed Limit is over 30 mph	1.81	0.46	2.33	0.02	1.10	2.99	1
The percentage ranking of persons with an income more than $200,000 is over 10%	1.47	0.30	1.87	0.06	0.98	2.20	1
Bicycle Commuters are present in the Block Group	1.56	0.33	2.06	0.04	1.02	2.37	1
There are no privately-owned legs	1.69	0.67	1.33	0.18	0.78	3.69	1

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
The total population of the block group is over 1500 (based on number of individuals that reported their race in the census)	1.26	0.24	1.19	0.23	0.86	1.84	1
Constant	0.00116	0.00066	-11.87	0.00	0.00038	0.00355	N/A

Note: Number of observations = 7,716; Log likelihood = -611.44105; Pseudo R2 = 0.0900; LR chi2(10) = 120.96; Prob > chi2 = <0.0001. N/A is not applicable.

Single-Vehicle Crashes at Minor Stop-Control T-Intersections with at least One Nonstate Leg

This model is focused on single vehicle crashes at minor stop-control T-intersections with at least one non-state-owned leg. All risk factors identified in this model were found to have odds ratios greater than 1.0. Table 9 summarizes the binary logistic regression model for these crashes. Generally, the risk factors indicate elevated risk at high-volume, less urban intersections. Crash probability increases with total approach AADT, especially over 15,000 vehicles per day. This is also shown through the correlation between the major approach being divided and higher crash probability, as higher volume roads are often divided. An intersection skew angle over 25 degrees increases the probability of single-vehicle crashes. Higher speeds increase crash probability as represented by intersections with speed limits over 30 mph on their minor legs. Additionally, while these serve as surrogates for more rural areas where single vehicle crashes are more common, intersections in an area with no primary civic buildings, libraries, or transit within a quarter mile have higher crash probability. Low income also predicts higher probabilities of these crashes. Most recommended risk factor weights are binary (0 and 1), although VHB does recommend a weight of 0 for the continuous natural log of total approach AADT since it serves the purpose of accounting for exposure in the model.

Table 9. Crash Prediction Model for Single-Vehicle Crashes at Minor Stop-Control T-Intersections with at least One Nonstate Leg

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Natural Log of Total Approach AADT	1.21	0.03	6.86	0.00	1.14	1.27	0
Total Approach AADT > 15,000 veh/day	2.41	0.66	3.21	<0.01	1.41	4.13	1
The percentage of the population in the Block Group that are low income is above 50%	1.35	0.15	2.70	0.01	1.09	1.68	1

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
No Primary Civic Buildings are within a quarter mile of the intersection	1.34	0.17	2.38	0.02	1.05	1.71	1
Minor Approach Speed Limit is over 30 mph	1.42	0.23	2.13	0.03	1.03	1.96	1
No transit is present within a quarter mile of the intersection	1.35	0.20	2.03	0.04	1.01	1.80	1
Intersection Skew Angle is over 25 degrees	1.23	0.18	1.44	0.15	0.93	1.63	1
Major Median is Divided	1.76	0.52	1.91	0.06	0.99	3.14	1
No libraries are within a quarter mile of the intersection	1.65	0.41	2.00	0.05	1.01	2.68	1
Constant	0.00455	0.00152	-16.09	0.00	0.00236	0.00877	N/A

Note: Number of observations = 7,716; Log likelihood = -1376.9197; Pseudo R2 = 0.0456; LR chi2(9) = 131.67; Prob > chi2 = <0.0001. N/A is not applicable.

Single-Vehicle Crashes Involving a Collision with a Fixed Object

This model is focused on single vehicle crashes involving a collision with a fixed object. All risk factors identified in this model were found to have odds ratios greater than 1.0. Table 10 summarizes the binary logistic regression model for these crashes. Generally, the risk factors indicate elevated risk at high-volume, less urban intersections. Crash probability increases with total approach AADT, especially over 14,000 vehicles per day. This is also shown through the correlation between the presence of three or more state-owned legs divided and higher crash probability, as state- owned roads are often higher volume. An intersection skew angle over 25 degrees increases the probability of single- vehicle crashes. Intersections that are stop-controlled and not interchange related have higher crash probability. Additionally, while these serve as surrogates for more rural areas where single vehicle crashes are more common, intersections in an area with no secondary civic buildings or transit within a quarter mile have higher crash probability. Low income also predicts higher probabilities of these crashes. Most recommended risk factor weights are binary (0 and 1), although VHB does recommend a weight of 0 for the continuous natural log of total approach AADT since it serves the purpose of accounting for exposure in the model.

Table 10. Crash Prediction Model for Single-Vehicle Crashes Involving a Collision with a Fixed Object

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Intersection is roadway/roadway and not interchange related.	1.62	0.27	2.83	0.01	1.16	2.26	1
No transit in a quarter mile of the intersection	1.65	0.22	3.70	0.00	1.27	2.15	1
Intersection Skew angle over 25 degrees	1.22	0.16	1.50	0.13	0.94	1.58	1
Intersection is stop controlled	1.37	0.15	2.95	<0.01	1.11	1.69	1
Natural Log of Total Approach AADT	1.15	0.02	7.86	0.00	1.11	1.19	0
Total Approach AADT > 14,000 veh/day	2.35	0.49	4.06	0.00	1.55	3.55	1
The percentage of the population in the Block Group that are low income is above 25%	1.24	0.14	1.98	0.05	1.00	1.54	1
No Secondary Civic Buildings within a quarter mile of the intersection	1.33	0.15	2.59	0.01	1.07	1.66	1
No libraries within a quarter mile of the intersection	1.61	0.37	2.06	0.04	1.02	2.54	1
Three or more legs are state-owned	2.09	0.39	3.96	0.00	1.45	3.02	1
Constant	0.00140	0.00041	-22.36	0.00	0.00079	0.00249	N/A

Note: Number of observations = 29,909; Log likelihood = -2310.2369; Pseudo R2 = 0.0638; LR chi2(10) = 315.08; Prob > chi2 = <0.0001. N/A is not applicable.

Pedestrian-Vehicle Crashes at Intersections

This model is focused on pedestrian-vehicle crashes at intersections. All risk factors identified in this model were found to have odds ratios greater than 1.0. Table 11 summarizes the binary logistic regression model for these crashes. Generally, the risk factors indicate elevated risk at more complex dense urban intersections. Crash probability increases with total approach AADT, especially over 4,000 vehicles per day. However, more variables show correlations between bigger, less predictable intersections and higher crash probability. Intersections that have four or more legs, have traffic control that is not stop, signal, or uncontrolled (i.e., two-way and all-way flashers, yield control, roundabouts, and unknown), and have left turn lanes on the major approach predict higher crash probability. Speed limits under 35 mph and more than three locally owned legs also correlate high higher crash probability and are likely related to intersections with unconventional traffic control types and higher pedestrian demand. Additional, while these serve as surrogates for higher pedestrian demand, intersections in areas with an average density of 33 primary civic buildings per square mile within a quarter mile, transit within a quarter mile, people who commute by public transportation in the block group, and shorter commutes have higher crash probability. Low income also predicts higher probabilities of these crashes. Most recommended risk factor weights are binary (0 and 1, 0 and 2), although VHB does recommend a weight of 0 for the continuous natural log of total approach AADT since it serves the purpose of accounting for exposure in the model.

Table 11. Crash Prediction Model for Pedestrian-Vehicle Crashes at Intersections

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Intersection has four or more legs	1.90	0.29	4.21	0.00	1.41	2.57	1
Traffic control is not signalized, stop-control, or uncontrolled	1.97	0.63	2.11	0.04	1.05	3.70	1
Natural Log of Total Approach AADT	1.17	0.05	3.82	0.00	1.08	1.27	0
Total Approach AADT > 4,000 veh/day	3.62	0.94	4.94	0.00	2.17	6.04	2
The percentage of the population in the Block Group that are low income is above 50%	1.27	0.20	1.53	0.13	0.93	1.73	1
Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile	2.62	0.43	5.79	0.00	1.89	3.62	1
Major Approach posted speed limit is under 35	2.20	0.60	2.88	<0.01	1.29	3.77	1

Variable	**Odds Ratio**	**Standard Error**	**z-value**	**P>|z|**	**95% Confidence Interval**		**Recommended Weight**
Left turn lanes are present on the Major Approach	2.88	0.51	5.97	0.00	2.04	4.08	1
Transit is present in a quarter mile of the intersection	3.15	0.71	5.09	0.00	2.02	4.90	2
Three or more legs are locally owned	1.61	0.29	2.61	0.01	1.13	2.29	1
Public transit commuters are present in the Block Group	1.32	0.19	1.92	0.06	0.99	1.75	1
Over 30% of persons in the Block Group have a commute of 15 minutes or less	1.59	0.30	2.44	0.02	1.10	2.32	1
Constant	0.00014	0.00005	-24.84	0.00	0.00007	0.00028	N/A

Note: Number of observations = 29,909; Log likelihood = -912.28112; Pseudo R2 = 0.3402; LR chi2(12) = 940.70; Prob > chi2 = <0.0001. N/A is not applicable.

Pedestrian-Vehicle Crashes with a Pedestrian in a Marked Crosswalk at an Intersection

While the previous model focused on all pedestrian crashes at intersections, this model was refined to focus on vehicle-pedestrian crashes in which the pedestrian was reported to have been in the crosswalk. This is an important distinction for future countermeasure planning, as VTrans can focus on ways to increase the potential visibility of pedestrians in a crosswalk, while making drivers more aware of the crosswalk.

All risk factors identified in this model were found to have odds ratios greater than 1.0. Table 12 summarizes the binary logistic regression model for these crashes. Generally, the risk factors indicate elevated risk at high-volume intersections in dense, urban areas. Crash probability increases with total approach AADT, especially when that volume exceeds 11,000 veh/day. Four or more leg signalized intersections are at a higher risk of these crashes compared to other geometric and traffic control configurations. There is also a higher crash probability associated with a lack of state-owned legs. Additionally, while some of these serve as surrogates for areas with increased pedestrian demand, intersections with higher primary civic and commercial building density, transit stops, libraries within a quarter mile, and persons with short commute are at an elevated risk for these crashes. Most recommended risk factor weights are binary (0 and 1 or 0 and 2), although VHB does recommend a weight of 0 for the continuous natural log of total approach AADT since it serves the purpose of accounting for exposure in the model.

Table 12. Crash Prediction Model for Vehicle-Pedestrian Crashes in a Marked Crosswalk

Variable	Odds Ratio	Standard Error	z-value	$P>\lvert z\rvert$	95% Confidence Interval		Recommended Weight
Natural Log of Total Approach AADT	1.27	0.07	4.25	0.00	1.14	1.42	0
Intersection has four or more legs	2.10	0.45	3.48	<0.01	1.38	3.18	1
Total Approach AADT > 11,000 veh/day	3.13	0.78	4.59	0.00	1.92	5.09	2
Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile	3.74	0.80	6.14	0.00	2.46	5.70	2
Over 30% of persons in the Block Group have a commute of 15 minutes or less	2.27	0.77	2.43	0.02	1.17	4.40	1
Intersection traffic control is signalized.	2.02	0.53	2.69	0.01	1.21	3.38	1
Commercial buildings density within a quarter mile of the intersection is over 25 buildings per square mile	2.43	1.01	2.14	0.03	1.08	5.47	1
There is transit present within a quarter mile of the intersection	5.71	3.04	3.27	<0.01	2.01	16.22	2
There is a library within a quarter mile of the intersection	1.55	0.33	2.02	0.04	1.01	2.36	1
None of the legs are state-owned	3.53	1.28	3.50	0.00	1.74	7.17	2
Constant	0.00001	<0.00001	-16.66	0.00	<0.00001	0.00005	N/A

Note: Number of observations = 29,909; Log likelihood = -466.69933; Pseudo R2 = 0.4458; LR chi2(10) = 750.87; Prob > chi2 = <0.0001. N/A is not applicable.

Pedestrian-Vehicle Crashes with a Pedestrian not in a Marked Crosswalk at an Intersections

This model focused on predicting the probability of a vehicle-pedestrian crash at an intersection where a pedestrian is not reported to have been in a crosswalk. This could be true for two reasons: no crosswalk was present for the desired crossing movement, or the pedestrian chose not to use the provided crosswalk. As such, attempts by VTrans to address intersections at high risk of these crashes should determine which of the two cases are relevant and identify countermeasures targeting that case. Again, there is significant correlation between variables related to dense urbanization and the elevated risk of a pedestrian crash when not in a crosswalk. Crash probability increases with total approach AADT, especially when that volume exceeds 6,000 vehicles per day. Intersections with four or more legs which are signalized have elevated risk. The presence of lighting suggests a higher-volume intersection, not that lighting is inherently unsafe. It is a similar situation for the presence of left turn lanes on the major approach. Primary civic building density, shorter commute times, transit presence within a quarter mile, and libraries within a quarter mile point towards the correlation between pedestrian demand and pedestrian crash risk. The lack of state-owned legs also indicates a higher probability of crashes.

Table 13. Crash Prediction Model for Vehicle-Pedestrian Crashes not in a Marked Crosswalk

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Natural log of total road AADT	1.14	0.07	2.03	0.04	1.00	1.29	0
Intersection traffic control is signalized	1.67	0.46	1.86	0.06	0.97	2.88	1
Lighting is present at the intersection	1.76	0.65	1.54	0.12	0.86	3.61	1
Intersection has four or more legs	2.05	0.45	3.32	<0.01	1.34	3.14	1
Total road AADT is over 6,000 veh/day	4.95	1.64	4.83	0.00	2.59	9.47	2
Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile	3.69	0.80	6.03	0.00	2.41	5.63	2
Left turn lane is present on a major approach	2.05	0.52	2.80	0.01	1.24	3.38	1
Over 30% of persons in the Block Group have a commute of 15 minutes or less	2.56	0.85	2.82	0.01	1.33	4.92	1
There is transit present within a quarter mile of the intersection	6.61	3.36	3.71	0.00	2.44	17.90	2
There is a library within a quarter mile of the intersection	1.60	0.35	2.18	0.03	1.05	2.45	1
None of the legs are state-owned	4.01	1.44	3.86	0.00	1.98	8.13	2
Constant	0.00001	<0.00001	-16.96	0.00	<0.00001	0.0005	N/A

Note: Number of observations = 29,909; Log likelihood = -458.21474; Pseudo R2 = 0.4559; LR chi2(11) = 767.84; Prob > chi2 = <0.0001. N/A is not applicable.

Vehicle-Bicycle Crashes at Intersections

This model is focused on vehicle-bicycle crashes at intersections. All risk factors identified in this model were found to have odds ratios greater than 1.0. Table 14 summarizes the binary logistic regression model for these crashes. Generally, the risk factors indicate elevated risk at high-volume intersections in dense, urban areas. Crash probability increases with total approach AADT, especially when that volume exceeds 11,000 veh/day. Four or more leg intersections are at a higher risk of these crashes compared to other geometric configurations. There is also a higher probability associated with a lack of state-owned legs. Additionally, while some of these serve as surrogates for increased density and cyclist demand, urban intersections with higher primary civic and industrial building density and transit stops within a quarter mile are at an elevated risk for these crashes. Industrial buildings may be correlated because roads designed for industrial use are less suitable for cyclists. Limited English also predicts higher probabilities of these crashes. Most recommended risk factor weights are binary (0 and 1 or 0 and 2), although VHB does recommend a weight of 0 for the continuous natural log of total approach AADT since it serves the purpose of accounting for exposure in the model.

Table 14. Crash Prediction Model for Vehicle-Bicycle Crashes at Intersections

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Intersection has four or more legs	2.23	0.40	4.43	0.00	1.56	3.18	1
Area Type is Urban	1.62	0.41	1.88	0.06	0.98	2.67	1
Natural Log of Total Approach AADT	1.25	0.06	5.09	0.00	1.15	1.37	0
Total Approach AADT > 11,000 veh/day	3.79	0.82	6.13	0.00	2.48	5.81	2
The percentage of the population in the Block Group that are limited English speakers is over 50%	1.70	0.33	2.71	0.01	1.16	2.50	1
Industrial building density within a quarter mile of the intersection exceeds 5 buildings per square mile	3.39	1.45	2.86	<0.01	1.47	7.83	2

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile	1.96	0.40	3.27	<0.01	1.31	2.94	1
Transit is present within a quarter mile of the intersection	1.98	0.56	2.40	0.02	1.13	3.44	1
None of the legs are state-owned	1.65	0.37	2.22	0.03	1.06	2.56	1
Constant	0.00008	0.00004	-19.79	0.00	0.00003	0.0002	N/A

Note: Number of observations = 29,909; Log likelihood = -639.90443; Pseudo R2 = 0.3183; LR chi2(9) = 597.43; Prob > chi2 = <0.0001. N/A is not applicable.

Vehicle-Pedestrian Crashes at Intersections at Night

Finally, VHB developed models which predict the likelihood of a pedestrian crash at an intersection at night. This analysis aligns with FHWA's Every Day Counts (EDC) 7 initiative for nighttime visibility. Note the presence of lighting was included in the model but was found to be statistically insignificant. As with other pedestrian models, significant correlations exist between density of the area around the intersection, the presence of pedestrian trip generators, and increased pedestrian crash risk. Crash probability increases with total approach AADT, especially when that volume exceeds 9,000 veh/day. Four or more leg signalized intersections are at a higher risk of these crashes compared to other geometric and traffic control configurations. Additionally, while some of these serve as surrogates for increased pedestrian demand, intersections with higher primary civic and commercial building density, transit stops within a quarter mile, and K-12 schools within a quarter mile are at an elevated risk for these crashes. Finally, intersections in low-income communities were found to be at an elevated crash risk for nighttime pedestrian crashes – likely correlated with historical underinvestment in those communities. Most recommended risk factor weights are binary (0 and 1 or 0 and 2), although VHB does recommend a weight of 0 for the continuous natural log of total approach AADT since it serves the purpose of accounting for exposure in the model.

Table 15. Crash Prediction Model for Vehicle-Pedestrian Crashes at Intersections at Night

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Natural log of Total Approach AADT	1.35	0.09	4.35	0.00	1.18	1.54	0
Intersection traffic control is signalized	1.98	0.54	2.47	0.01	1.15	3.39	1
Intersection has four or more legs	1.94	0.47	2.77	0.01	1.22	3.11	1
Total road AADT is over 9,000 veh/day	3.24	0.95	4.02	0.00	1.83	5.74	2
Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile	2.21	0.54	3.28	<0.01	1.38	3.56	1
The percentage of the population in the Block Group that are low income is above 50%	1.76	0.41	2.44	0.02	1.12	2.78	1
Transit is present within a quarter mile of the intersection	1.96	0.67	1.97	0.05	1.00	3.84	1
A K-12 school is present within a quarter mile of the intersection	1.67	0.37	2.29	0.02	1.08	2.59	1
Commercial building density within a quarter mile of the intersection is higher than 50 buildings per square mile	1.87	0.52	2.25	0.02	1.08	3.23	1
Constant	0.00009	0.00005	-16.93	0.00	0.00003	0.00025	N/A

Note: Number of observations = 29,909; Log likelihood = -463.9428; Pseudo R2 = 0.3246; LR chi2(9) = 446.02; Prob > chi2 = <0.0001. N/A is not applicable.

Next Steps

Once VTrans confirms the final risk factors in this memorandum, VHB will proceed with assigning risk scores to each intersection and developing prioritization maps.

.

Memorandum #4-Risk Maps

The purpose of this memo is to present the risk maps created according to the revised risk factors in the previous memo. Sites are grouped for easy identification of the highest risk roads for each focus crash and facility type. The memo was transmitted by VHB to VTrans on August 3, 2023.

Background

The risk maps are based on 15 models described in the Risk Factors memorandum. VHB acquired crash, intersection characteristics, traffic volume, and asset data from VTrans and created integrated crash and intersection databases. From these data, VHB identified focus crash types and created crash trees to select focus facility types. VHB recommended 15 focus crash and facility type combinations, which were approved by VTrans. VHB created crash models for each focus and applied statistical methods to identify the risk factors shown below (crash severity, crash sample size, count, and risk factor weight are shown):

1. Left turn crashes at minor stop-controlled intersections[7] – (KAB[8]) 237 crashes over 9435 intersections. (Maximum score of 8)
    a. Intersection has four or more legs (weight of 1)
    b. Total approach AADT>10,000 veh/day (weight of 1)
    c. Minor approach speed limit is over 30 mph (weight of 1)
    d. Left turn lanes are present on the major approach (weight of 1)
    e. None of the legs are locally owned (weight of 1)
    f. Over 15% of the persons in the Block Group have incomes less than $25,000 (weight of 1)
    g. Bicycle commuters are present in the Block Group (weight of 1)
    h. Over 30% of persons in the Block Group have a commute of 15 minutes or less (weight of 1)
2. Left turn crashes on rural, minor stop-controlled intersections with at least one state-owned leg[9] – (KAB) 102 crashes over 3494 intersections. (Maximum score of 9)
    a. Intersection has four or more legs (weight of 1)
    b. No seasonal buildings are present within a quarter mile of the intersection (weight of 1)
    c. Minor approach speed limit is over 30 mph (weight of 1)

[7] This includes four-leg minor stop-control intersections, minor stop-control t-intersections, and minor stop-control y-intersections.
[8] KAB represents the KABCO injury severity scale, where K is a fatal crash, A is a suspected serious injury crash, and B is a suspected minor injury crash.
[9] This includes rural four-leg minor stop-control intersections, minor stop-control t-intersections, and minor stop-control y-intersections classified as “State vs State” and “State vs Nonstate”.

d. No locally owned legs are present (weight of 1)
e. No privately owned legs are present (weight of 1)
f. The area is identified as an Opportunity Zone (weight of 1)
g. Over 15% of the persons in the Block Group have incomes less than $25,000 (weight of 1)
h. Over 30% of persons in the Block Group have a commute of 15 minutes or less (weight of 1)
i. Bicycle commuters are present in the Block Group (weight of 1)

3. Rear-end crashes at certain three-leg and four-leg unsignalized intersections[10] – (KAB) 371 crashes over 16488 intersections. (Maximum score of 10)
    a. Area is urban (weight of 1)
    b. Lighting is present (weight of 1)
    c. Total approach AADT is over 6,000 vehicles per day (weight is 2)
    d. The area is an Opportunity Zone (weight of 1)
    e. Percentage of the population in the Block Group that speak limited English is over 50% (weight of 1)
    f. No seasonal buildings are present within a quarter mile of the intersection (weight of 1)
    g. Major Approach speed limit is over 35 mph (weight of 1)
    h. None of the legs are privately owned (weight of 1)
    i. Total population of the Block Group is over 1500[11] (weight of 1)
4. Rear-end crashes at signalized intersections with at least one non-state leg[12] – (KAB) 178 crashes over 330 intersections. (Maximum score of 6)
    a. Intersection has four or more legs (weight of 1)
    b. Intersection skew angle is over 25 degrees (weight of 1)
    c. Total approach AADT is more than 15,000 vehicles per day (weight of 1)
    d. Percentage of the population in the Block Group that are minorities is over 50% (weight of 1)
    e. Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile (weight of 1)
    f. Major median is divided (weight of 1)

[10] This includes four-leg minor stop-control intersections, uncontrolled t-intersections, minor stop-control t-intersections and y-intersections, and four-leg all-way stop-control intersections.
[11] Based on the number of individuals that reported their race in the census.
[12] This includes signalized four-leg intersections and signalized t-intersections.

5. Angle/Broadside crashes at urban four-leg signalized intersections with no state legs – (KAB) 124 crashes over 137 intersections. (Maximum score of 9)
    a. Alcohol is sold within a quarter mile (weight of 2)
    b. Total approach AADT is over 13,000 vehicles per day (weight of 1)
    c. Percentage of the population in the Block Group that are minorities is over 50% (weight of 2)
    d. No industrial buildings present within a quarter mile of the intersection (weight of 2)
    e. No right turn lanes present on the major approach (weight of 2)
6. Angle/Broadside crashes at minor stop-controlled T-intersections with one or more nonstate legs– (KAB) 212 crashes over 7716 intersections. (Maximum score of 9)
    a. Area is urban (weight of 1)
    b. Alcohol is sold within a quarter mile (weight of 1)
    c. Total approach AADT is over 8,000 vehicles per day (weight of 1)
    d. Minor approach speed limit is over 30 mph (weight of 2)
    e. No K-12 schools in a quarter mile (weight of 1)
    f. There are state-owned legs present (weight of 1)
    g. Over 15% of the persons in the Block Group have incomes less than $25,000 (weight of 1)
    h. Over 30% of persons in the Block Group have a commute of 15 minutes or less (weight of 1)
7. Angle/Broadside crashes at three-leg (t-intersections and y-intersections) and four-leg minor stop-controlled intersections– (KAB) 421 crashes over 9435 intersections. (Maximum score of 9)
    a. Area is urban (weight of 1)
    b. Alcohol is sold within a quarter mile (weight of 1)
    c. One-way legs are present (weight is 1)
    d. Minor approach posted speed limit is over 30 mph (weight is 2)
    e. State owned legs are present (weight of 1)
    f. Total approach AADT is over 12,000 vehicles per day (weight of 1)
    g. Over 15% of the persons in the Block Group have incomes less than $25,000 (weight 1)
    h. Over 30% of persons in the Block Group have a commute of 15 minutes or less (weight of 1)
8. Head-on crashes at minor stop-control T-intersections with at least 1 nonstate leg– (KAB) 140 crashes over 7716 intersections. (Maximum score of 9)
    a. Intersection skew angle is over 25 degrees (weight of 1)

b. Total approach AADT is over 9,000 vehicles per day (weight of 1)
c. Area is identified as an Opportunity Zone (weight of 1)
d. No seasonal buildings within a quarter mile of the intersection (weight of 1)
e. Minor approach speed limit is over 30 mph (weight of 1)
f. Percentage ranking of persons with an income more than $200,000 is over 10% (weight of 1)
g. Bicycle commuters are present in the Block Group (weight of 1)
h. No privately-owned legs (weight of 1)
i. Total population of the block group is over 1500[13] (weight of 1)

9. Single vehicle crashes at minor stop-control T-intersections with one or more nonstate legs – (KAB) 385 crashes over 7716 intersections. (Maximum score of 8)
    a. Total approach AADT is more than 15,000 vehicles per day (weight of 1)
    b. Percentage of the population in the Block Group that are low income is above 50% (weight of 1)
    c. No primary civic buildings are within a quarter mile of the intersection (weight of 1)
    d. Minor approach speed limit is over 30 mph (weight of 1)
    e. No transit is present within a quarter mile of the intersection (weight of 1)
    f. Intersection skew angle is over 25 degrees (weight of 1)
    g. Major median is divided (weight of 1)
    h. No libraries are within a quarter mile of the intersection (weight of 1)
10. Single vehicle crashes involving a collision with a fixed object– (KAB) 482 crashes over 29909 intersections. (Maximum score of 9)
    a. Intersection is roadway/roadway and not interchange related (weight of 1)
    b. No transit in a quarter mile of the intersection (weight of 1)
    c. Intersection skew angle over 25 degrees (weight of 1)
    d. Intersection is stop controlled (weight of 1)
    e. Total approach AADT is more than 14,000 vehicles per day (weight of 1)
    f. Percentage of the population in the Block Group that are low income is above 25% (weight of 1)
    g. No secondary civic buildings within a quarter mile of the intersection (weight of 1)
    h. No libraries within a quarter mile of the intersection (weight of 1)

[13] Based on the number of individuals that reported their race in the census.

   i. Three or more legs are state-owned (weight of 1)

11. Pedestrian-vehicle crashes at intersections– (KAB) 266 crashes over 29909 intersections. (Maximum score of 13)
    a. Intersection has four or more legs (weight of 1)
    b. Traffic control is not signalized, stop-control, or uncontrolled (weight of 1)
    c. Total approach AADT is more than 4,000 vehicles per day (weight of 2)
    d. Percentage of the population in the Block Group that are low income is above 50% (weight of 1)
    e. Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile (weight of 1)
    f. Major approach posted speed limit is under 35 (weight of 1)
    g. Left turn lanes are present in the major approach (weight of 1)
    h. Transit is present in a quarter mile of the intersection (weight of 2)
    i. Three or more legs are locally owned (weight of 1)
    j. Public transit commuters are present in the Block Group (weight of 1)
    k. Over 30% of persons in the Block Group have a commute of 15 minutes or less (weight of 1)
12. Pedestrian-vehicle crashes with a pedestrian in marked crosswalk– (KABCO[14]) 150 crashes over 29909 intersections. (Maximum score of 13)
    a. Intersection has four of more legs (weight of 1)
    b. Total approach AADT is more than 11,000 vehicles per day (weight of 2)
    c. Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile (weight of 2)
    d. Over 30% of persons in the Block Group have a commute of 15 minutes or less (weight of 1)
    e. Intersection traffic control is signalized (weight of 1)
    f. Commercial buildings density within a quarter mile of the intersection is over 25 buildings per square mile (weight of 1)
    g. Transit is present within a quarter mile of the intersection (weight of 2)
    h. A library is present within a quarter mile of the intersection (weight of 1)
    i. None of the legs are state-owned (weight of 2)

[14] KABCO represents the KABCO injury severity scale, where K is a fatal crash, A is a suspected serious injury crash, B is a suspected minor injury crash, C is a possible injury crash, and O is a non-injury crash.

13. Pedestrian-vehicle crashes with a pedestrian not in a marked crosswalk[15] – (KABCO) 211 crashes over 29909 intersections. (Maximum score of 14)
    a. Intersection traffic control is signalized (weight of 1)
    b. Lighting is present at the intersection (weight of 1)
    c. Intersection has four or more legs (weight of 1)
    d. Total road AADT is over 6,000 vehicles per day (weight of 2)
    e. Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile (weight of 2)
    f. Left turn lane is present on a major approach (weight of 1)
    g. Over 30% of persons in the Block Group have a commute of 15 minutes or less (weight of 1)
    h. Transit is present within a quarter mile of the intersection (weight of 2)
    i. A library within a quarter mile of the intersection (weight of 1)
    j. None of the legs are state-owned (weight of 2)
14. Bicycle-vehicle crashes at intersection[16]– (KAB) 170 crashes over 29909 intersections. (Maximum score of 10)
    a. Intersection has four or more legs (weight of 1)
    b. Area type is urban (weight of 1)
    c. Total approach AADT is more than 11,000 vehicles per day (weight of 2)
    d. Percentage of the population in the Block Group that are limited English speakers is over 50% (weight of 1)
    e. Industrial building density within a quarter mile of the intersection exceeds 5 buildings per square mile (weight of 2)
    f. Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile (weight of 1)
    g. Transit is present within a quarter mile of the intersection (weight of 1)
    h. None of the legs are state-owned (weight of 1)
15. Pedestrian-vehicle crashes at intersections occurring at night– (KABC[17]) 112 crashes over 29909 intersections. (Maximum score of 9)

[15] location not coded "marked crosswalk at intersection" or "non-intersection crosswalk".
[16] Given the small sample size, VHB elected not to identify a focus facility type.
[17]KABC represents the KABCO injury severity scale, where K is a fatal crash, A is a suspected serious injury crash, B is a suspected minor injury crash, and C is a possible injury crash.

a. Intersection traffic control is signalized (weight of 1)
b. Intersection has four or more legs (weight of 1)
c. Total road AADT is over 9,000 vehicles per day (weight of 2)
d. Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile (weight of 1)
e. Percentage of the population in the Block Group that are low income is above 50% (weight of 1)
f. Transit is present within a quarter mile of the intersection (weight of 1)
g. A K-12 school is present within a quarter mile of the intersection (weight of 1)
h. Commercial building density within a quarter mile of the intersection is higher than 50 buildings per square mile (weight of 1)

VTrans reviewed and approved VHB's proposed risk factors. VHB proceeded to create risk maps using the weighted scoring method.

Risk Maps

VHB calculated intersection risk scores for each of the focus crash and facility types using the scoring system described above. Intersections are scored separately for each focus. An intersection's risk score under each model is the cumulative weights of each factor present at the intersection.

After scoring, intersections were categorized into Primary, High, Medium, Low, and Minimal risk. Scores were converted to a percentile (i.e., ranked from lowest to highest) and banded according to Table 1. For example, the top 5% of scores is considered "Primary Risk". VHB correlated these with the risk categories used by the International Roadway Assessment Programme (iRAP).

Table 1 Risk Categories Based on Percentile Score Range

Risk Category	Percentile Score Range	Color
Primary Risk	95-100	Black
High Risk	85-94	Red
Medium Risk	60-84	Orange
Low Risk	30-60	Yellow
Minimal Risk	0-30	Green
Not a Focus Facility	N/A	Gray

VHB then overlaid each of the 15 focus crash and facility types on a GIS map, coloring the intersections by their risk score. Sample maps of each of the 15 risk maps are shown below along with tables representing the distribution of risk scores. Scores were binned as closely as possible to iRAP ranges in Table 1. Since many sites will typically have the same score, there are sometimes more sites at a risk level than the percentile indicates (i.e., if 10 percent of sites share the maximum score, the 95th percentile score [primary risk, colored black] will include 10% of sites.) In a limited number of cases, concentration of sites at a single score led to consolidation to fewer categories (i.e., if more than 15% of sites have the top score, the 95th and 85th percentile scores are therefore equal and so "primary risk" and "high risk" would be merged.)

FFT 1: Left Turn Crashes At Minor Stop-Controlled Intersections[18]

Figure 1 shows a representative section of the risk map for KAB left turn crashes at minor stop-controlled intersections.

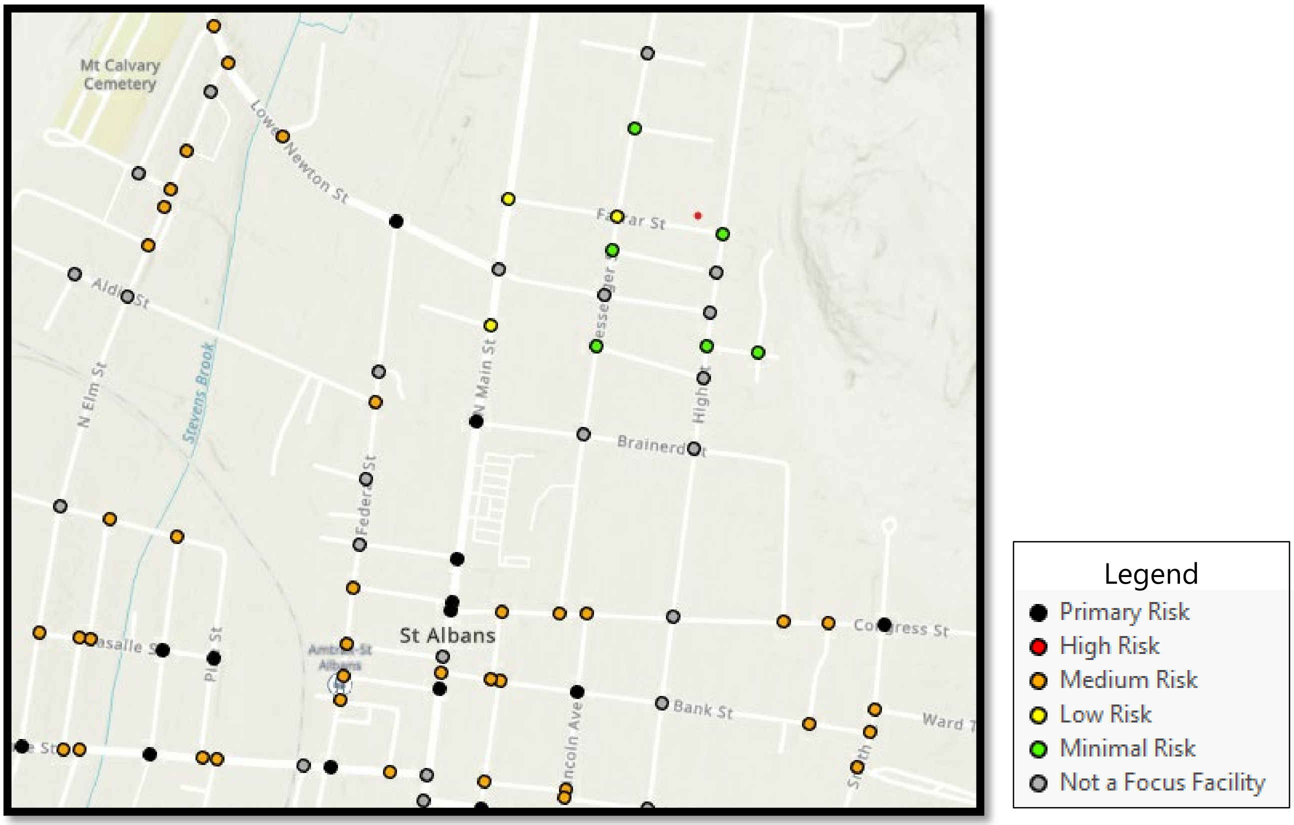


Figure 2. Section of Risk Map for Left Turn Crashes at Minor Stop-Controlled Intersections

Table 2 shows the distribution of risk scores by percentage of intersections and focus crash type. For left turn crashes at minor stop-controlled intersections, the predominant risk category is medium and low risk.

Table 2 Percentage of Intersections and Left Turn KAB Crashes by Risk Score at Minor Stop-Controlled Intersections

Risk Category	Intersection (Percent)	KAB Crashes (Percent)
Primary Risk	1484 (16%)	116 (49%)
High Risk	0 (0%)	0 (0%)
Medium Risk	2884 (31%)	69 (29%)
Low Risk	3377 (36%)	40 (17%)
Minimal Risk	1690 (18%)	12 (5%)

[18] This includes four-leg minor stop-control intersections, minor stop-control t-intersections, and minor stop-control y-intersections.

FFT 2: Left Turn Crashes on Rural, Minor Stop-Controlled Intersections with at Least One State-Owned Leg[19]

Figure 2 shows a representative section of the risk map for KAB left turn crashes on rural, minor stop-controlled intersections with at least one state-owned leg.

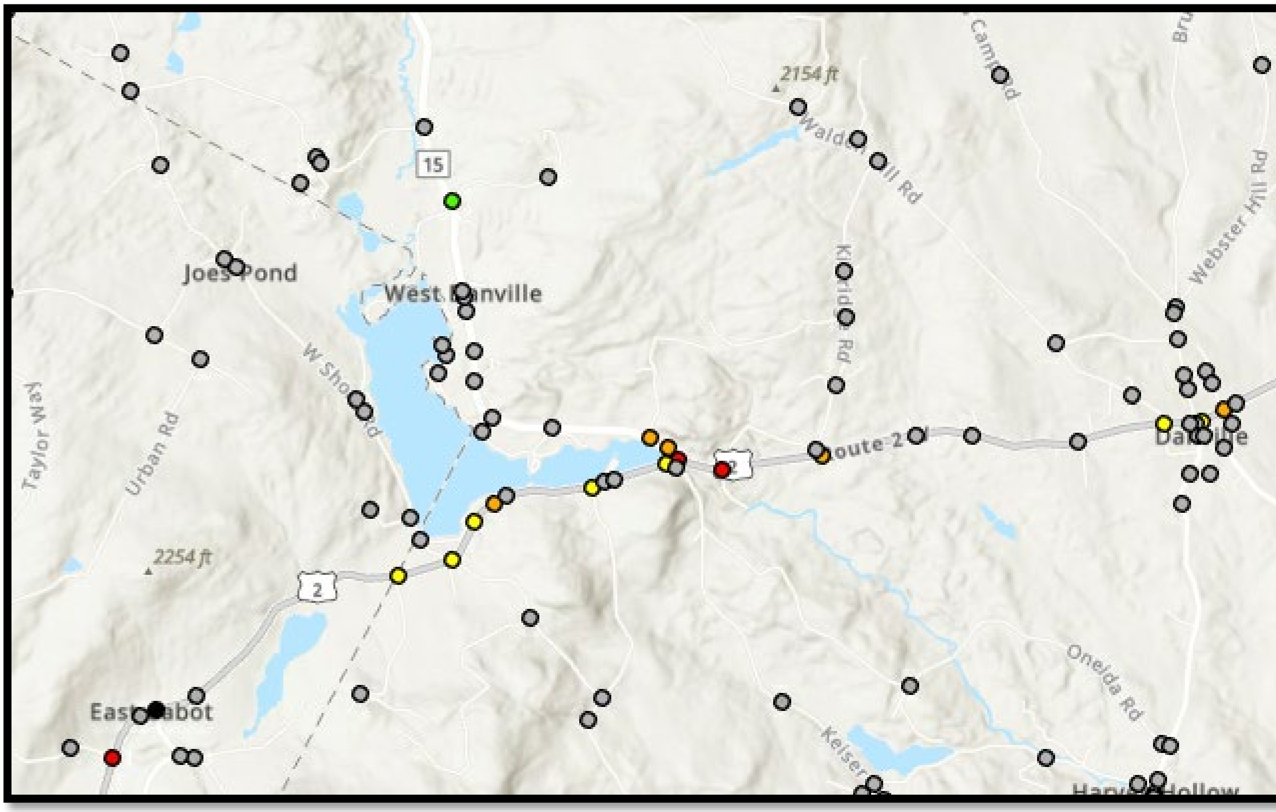


Figure 3. Section of Risk Map for Left Turn Crashes on Rural, Minor Stop-Controlled Intersections with at Least One State-Owned Leg

Table 3 shows the distribution of risk scores by percentage of intersection and focus crash type. For left turn crashes on rural minor stop-controlled intersections with at least one state-owned leg, the predominant risk category is "Medium".

[19] This includes rural four-leg minor stop-control intersections, minor stop-control t-intersections, and minor stop-control y-intersections classified as "State vs State" and "State vs Nonstate".

Table 3 Percentage of Intersections and Left Turn KAB Crashes by Risk Score on Minor Stop-Controlled Intersections with at Least One State-Owned Leg

Risk Category	Intersections (Percent[20])	KAB Crashes (Percent)
Primary Risk	250 (7%)	27 (26%)
High Risk	602 (17%)	33 (32%)
Medium Risk	1183 (34%)	22 (22%)
Low Risk	1110 (32%)	18 (18%)
Minimal Risk	349 (10%)	2 (2%)

FFT 3: Rear-End Crashes at Three-Leg and Four-Leg Unsignalized Intersections[21]

Figure 3 shows a representative section of the risk map for KAB rear-end crashes at three-leg and four-leg unsignalized intersections. Table 4 shows the distribution of risk scores by percentage of intersections and focus crash

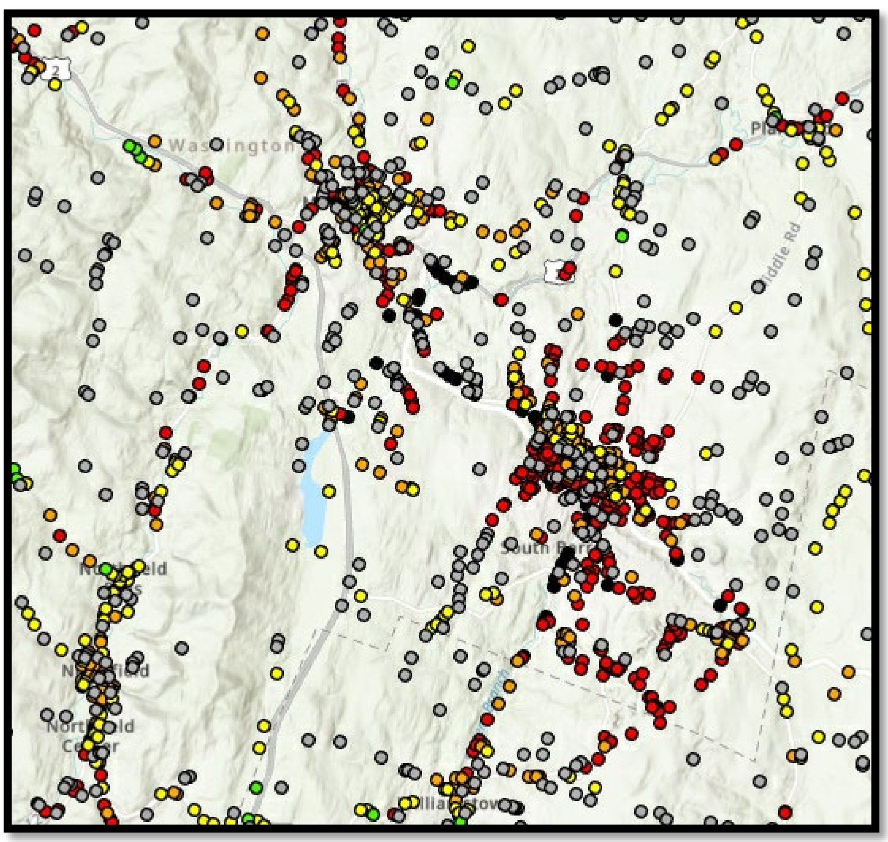
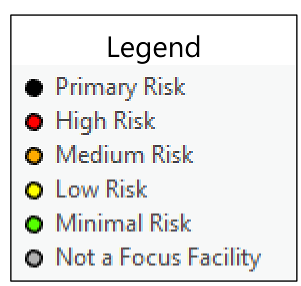


Figure 4. Section of Risk Map for Rear-End crashes (KAB) at Three-Leg and Four-Leg Unsignalized Intersections



[20] Intersections percentages shown do not add to 100% due to rounding.
[21] This includes four-leg minor stop-control intersections, uncontrolled t-intersections, minor stop-control t-intersections and y-intersections, and four-leg all-way stop-control intersections.

type. For rear-end crashes at three-leg and four-leg unsignalized intersections, the predominant risk category is “Low”.

Table 4 Percentage of Intersections and Rear-End KAB Crashes by Risk Score at Three-Leg and Four-Leg Unsignalized Intersections

Risk Category	Intersections (Percent)	KA Crashes (Percent)
Primary Risk	988 (6%)	145 (39%)
High Risk	3059 (19%)	126 (34%)
Medium Risk	2788 (17%)	50 (13%)
Low Risk	7093 (43%)	45 (12%)
Minimal Risk	2560 (16%)	5 (1%)

FFT 4: Rear-End Crashes at Signalized Intersections with at Least One Non-State Leg

Figure 4 shows a representative section of the risk map for KAB rear-end crashes at signalized intersections with at least one non-state leg.

Table 5 shows the distribution of risk scores by percentage of intersections and focus crash type. For rear-end crashes at signalized intersections with at least one non-state leg, the predominant risk category is “Medium”.

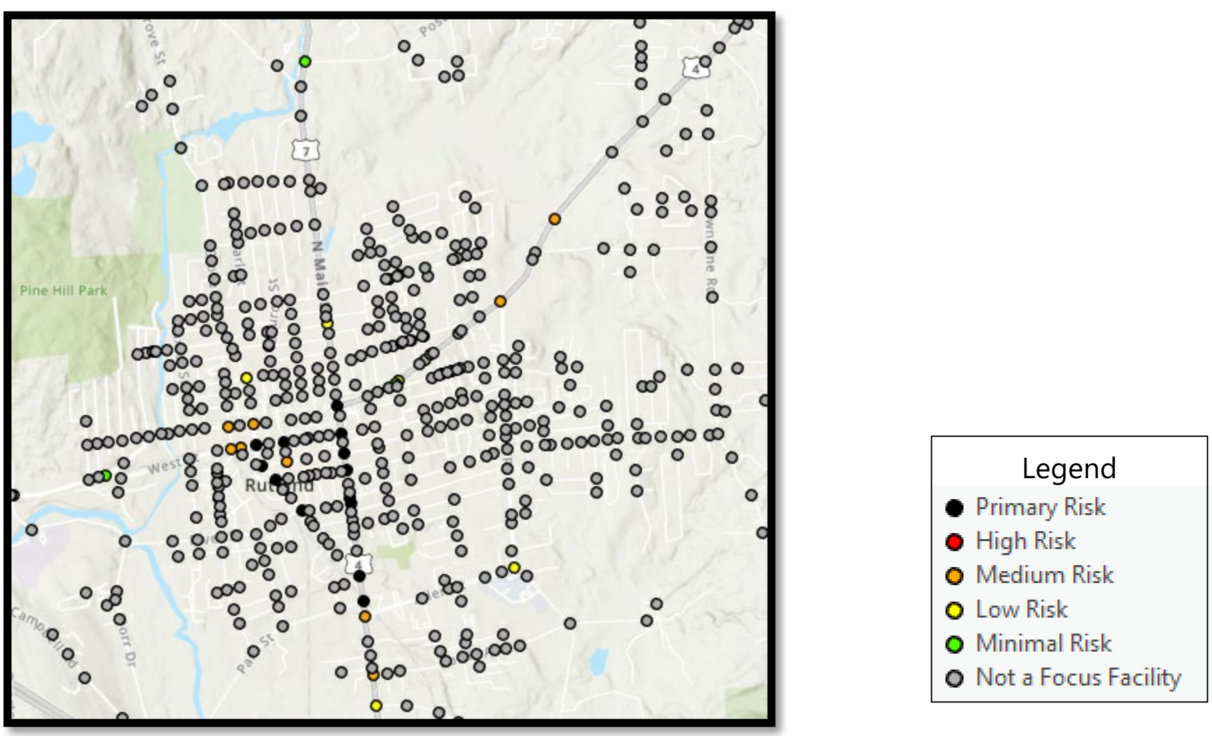


Figure 5. Section of Risk Map for Rear-End Crashes (KAB) at Signalized Intersections with at Least One Non-State Leg

Table 5 Percentage of Intersections and Rear-End KAB Crashes by Risk Score at Signalized Intersections with at Least One Non-State Leg

Risk Category	Intersections (Percent)	KAB Crashes (Percent)
Primary Risk	93 (28%)	99 (56%)
High Risk	0 (0%)	0 (0%)
Medium Risk	126 (38%)	58 (33%)
Low Risk	66 (20%)	13 (7%)
Minimal Risk	45 (14%)	8 (4%)

FFT 5: Angle/Broadside Crashes at Urban Four-Leg Signalized Intersections with No State Legs

Figure 5 shows a representative section of the risk map for KAB angle/broadside crashes at urban four-leg signalized intersections with no state legs. Table 6 shows the distribution of risk scores by percentage of intersections and focus crash type. For angle/broadside crashes at urban four-leg signalized intersections with no state legs, the predominant risk category is "Low".

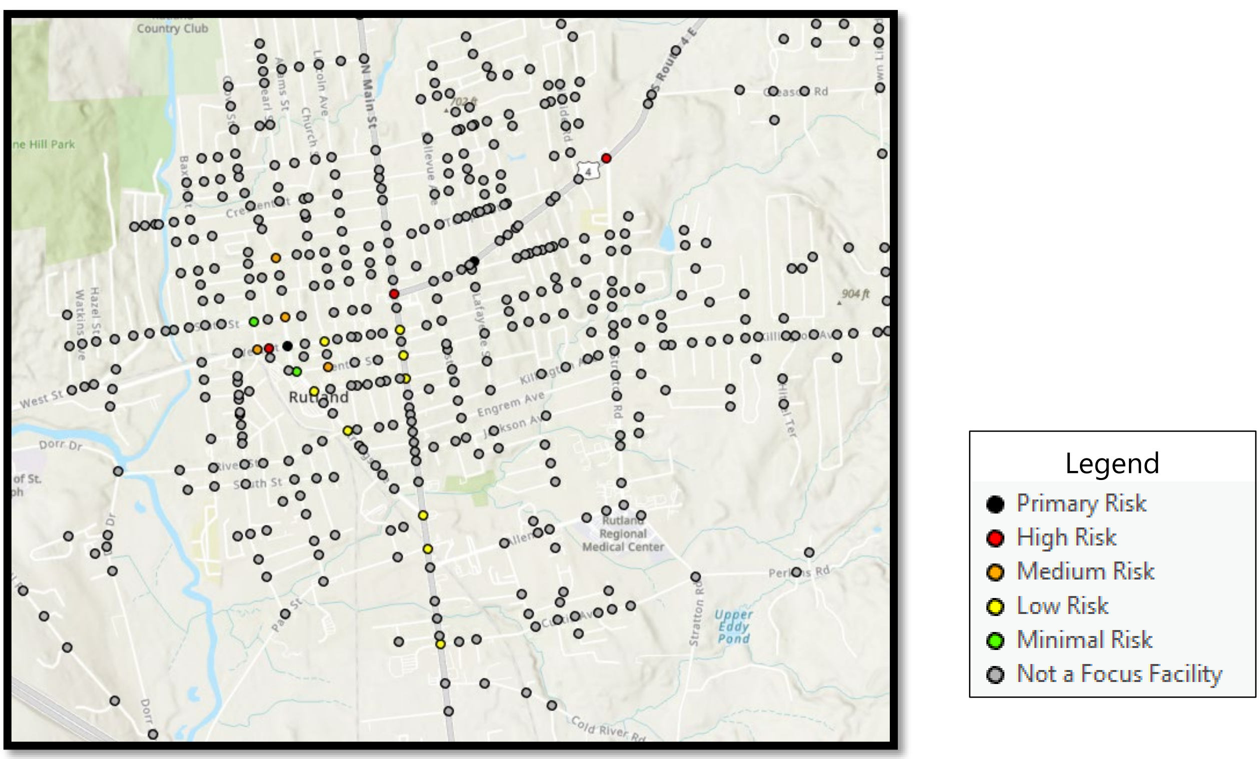


Figure 6. Section of Risk Map for Angle/Broadside Crashes (KAB) at Urban Four-Leg Signalized Intersections with No State Legs

Table 6 Percentage of Intersections and Angle/Broadside Crashes by Risk Score at Urban Four-Leg Signalized Intersections with No State Legs

Risk Category	Intersections (Percent)	KAB Crashes (Percent)
Primary Risk	11 (8%)	26 (21%)
High Risk	35 (26%)	44 (36%)
Medium Risk	19 (14%)	11 (9%)
Low Risk	49 (36%)	36 (30%)
Minimal Risk	23 (17%)	5 (4%)

FFT 6: Angle/Broadside Crashes at Minor Stop-Controlled T-Intersections with One or More Non-State Legs

Figure 6 shows a representative section of the risk map for KAB angle/broadside crashes at minor stop-controlled T-intersections with one or more non-state legs. Table 7 shows the distribution of risk scores by percentage of intersections and focus crash type. The most predominant risk category is "Medium".

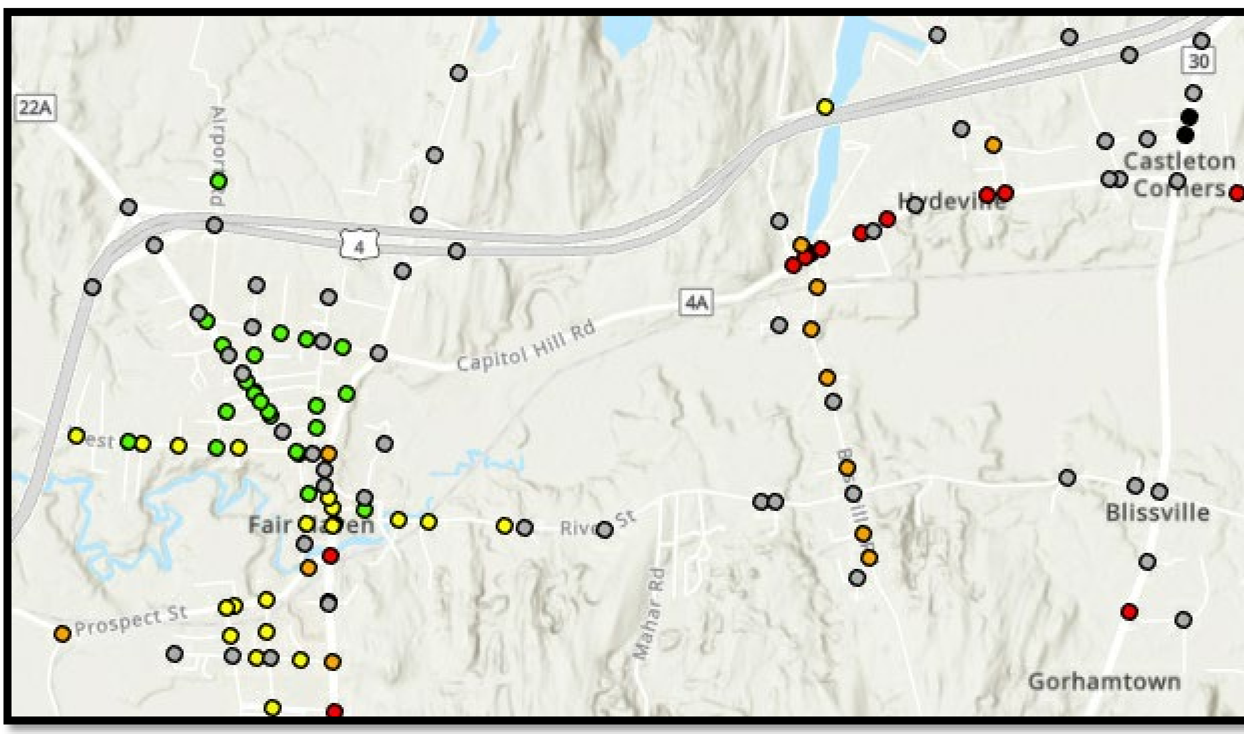


Figure 7. Section of Risk Map for Angle/Broadside crashes (KAB) at Minor Stop-Controlled T-Intersections with One or More Non-State Legs

Table 7 Percentage of Intersections and Angle/Broadside KAB Crashes by Risk Score at Minor Stop-Controlled T-Intersections with One or More Non-State Legs

Risk Category	Intersections (Percent)	KAB Crashes (Percent)
Primary Risk	1027 (13%)	117 (55%)
High Risk	1445 (19%)	37 (17%)
Medium Risk	2272 (29%)	36 (17%)
Low Risk	2087 (27%)	17 (8%)
Minimal Risk	885 (11%)	5 (2%)

FFT 7: Angle/Broadside Crashes at Three-Leg[22] and Four-Leg Minor Stop-Controlled Intersections

Figure 7 shows a representative section of the risk map for KAB angle/broadside crashes at three-leg and four-leg minor stop-controlled intersections. Table 8 shows the distribution of risk scores by percentage of intersections and focus crash type. The most predominant risk category is "Medium".

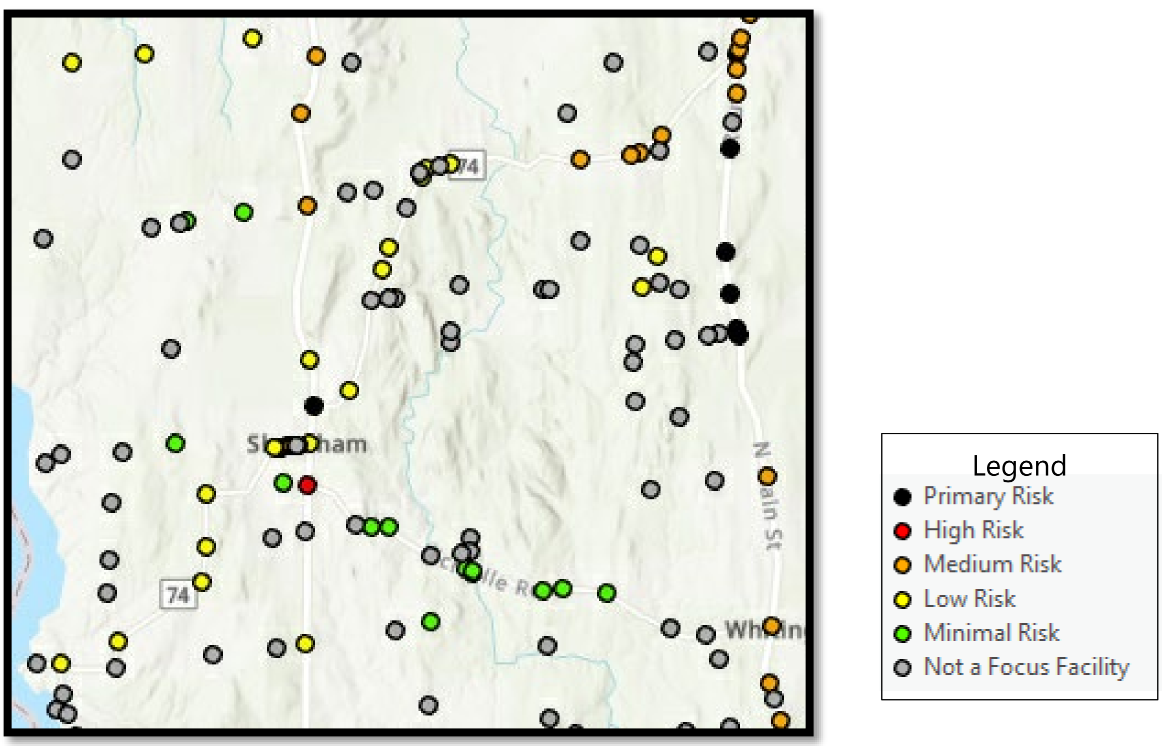


Figure 8. Section of Risk Map for Angle/Broadside crashes (KAB) at Three-Leg and Four-Leg Minor Stop-Controlled Intersections

[22] T-Intersections and Y-Intersections

Table 8 Percentage of Intersections and Angle/Broadside KAB Crashes by Risk Score at Three-Leg and Four-Leg Minor Stop-Controlled Intersections

Risk Category	Intersections (Percent)	KAB Crashes (Percent)
Primary Risk	1409 (15%)	220 (52%)
High Risk	1954 (21%)	91 (22%)
Medium Risk	2808 (30%)	69 (16%)
Low Risk	2426 (26%)	32 (8%)
Minimal Risk	838 (9%)	9 (2%)

FFT 8: Head-On Crashes at Minor Stop-Control T-Intersections with at Least One Non-State Leg

Figure 8 shows a representative section of the risk map for KAB head-on crashes at minor stop-control T-intersections with at least one non-state leg. Table 9 shows the distribution of risk scores by percentage of intersections and focus crash type. The most predominant risk category is "Low".

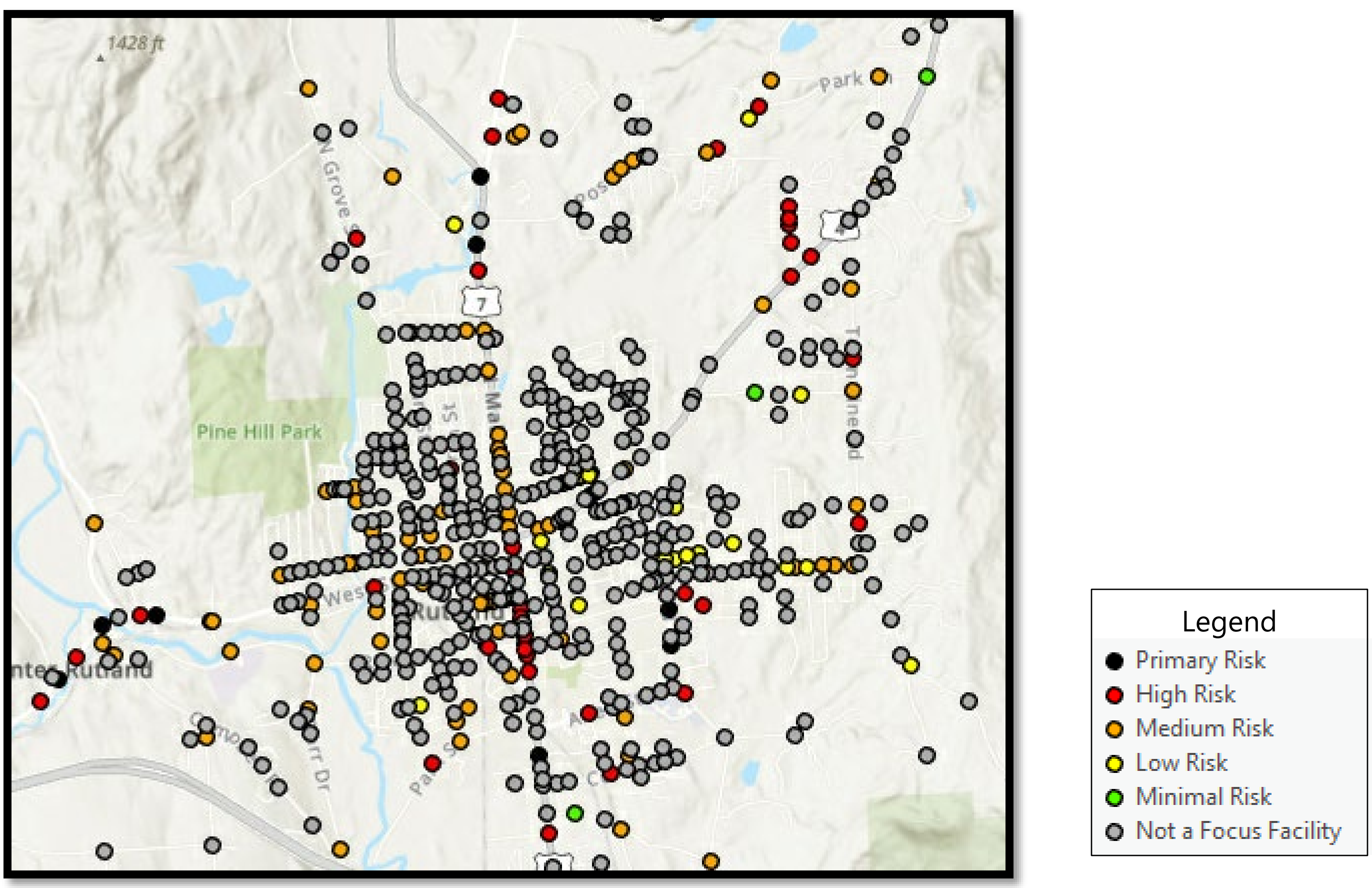


Figure 9. Section of Risk Map for Head-On crashes (KAB) at Minor Stop-Control T-Intersections with at Least One Non-State Leg

Table 9 Percentage of Intersections and Head-On KAB Crashes by Risk Score at Minor Stop-Control T-Intersections with at Least One Non-State Leg

Risk Category	Intersections (Percent)	KA Crashes (Percent)
Primary Risk	536 (7%)	31 (22%)
High Risk	1159 (15%)	31 (22%)
Medium Risk	2154 (28%)	44 (31%)
Low Risk	2397 (31%)	21 (15%)
Minimal Risk	1470 (19%)	13 (9%)

FFT 9: Single Vehicle Crashes at Minor Stop-Control T-Intersections with One or More Non-State Legs

Figure 9 shows a representative section of the risk map for KAB single vehicle crashes at minor stop-control T-intersections with one or more non-state legs. Table 10 shows the distribution of risk scores by percentage of intersections and focus crash type. The plurality of intersections is in the "Medium" risk category.

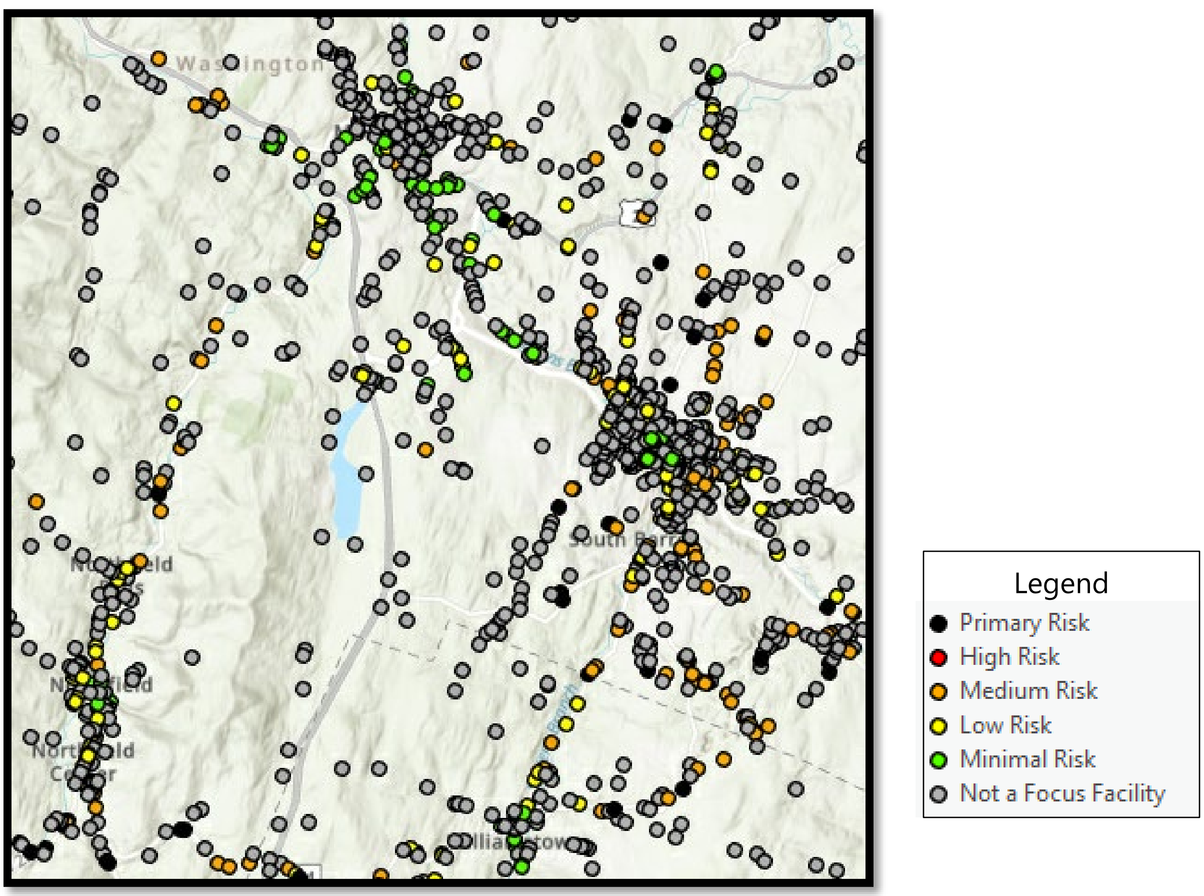


Figure 10. Section of Risk Map for Single Vehicle crashes (KAB) at Minor Stop-Control T-Intersections with One of More Non-State Legs

Table 10 Percentage of Intersections and Single Vehicle KAB Crashes by Risk Score at Minor Stop-Control T-Intersections with One or More Non-State Legs

Risk Category	Intersections (Percent)	KA Crashes (Percent)
Primary Risk	1785 (23%)	128 (33%)
High Risk	0 (0%)	0 (0%)
Medium Risk	2569 (33%)	158 (41%)
Low Risk	2204 (29%)	64 (17%)
Minimal Risk	1158 (15%)	33 (9%)

FFT 10: Single Vehicle Crashes Involving a Collision with a Fixed Object

Figure 10 shows a representative section of the risk map for KAB single vehicle crashes involving a collision with a fixed object. Table 11 shows the distribution of risk scores by percentage of intersections and focus crash type. The plurality of intersections falls in the "Low" risk category.

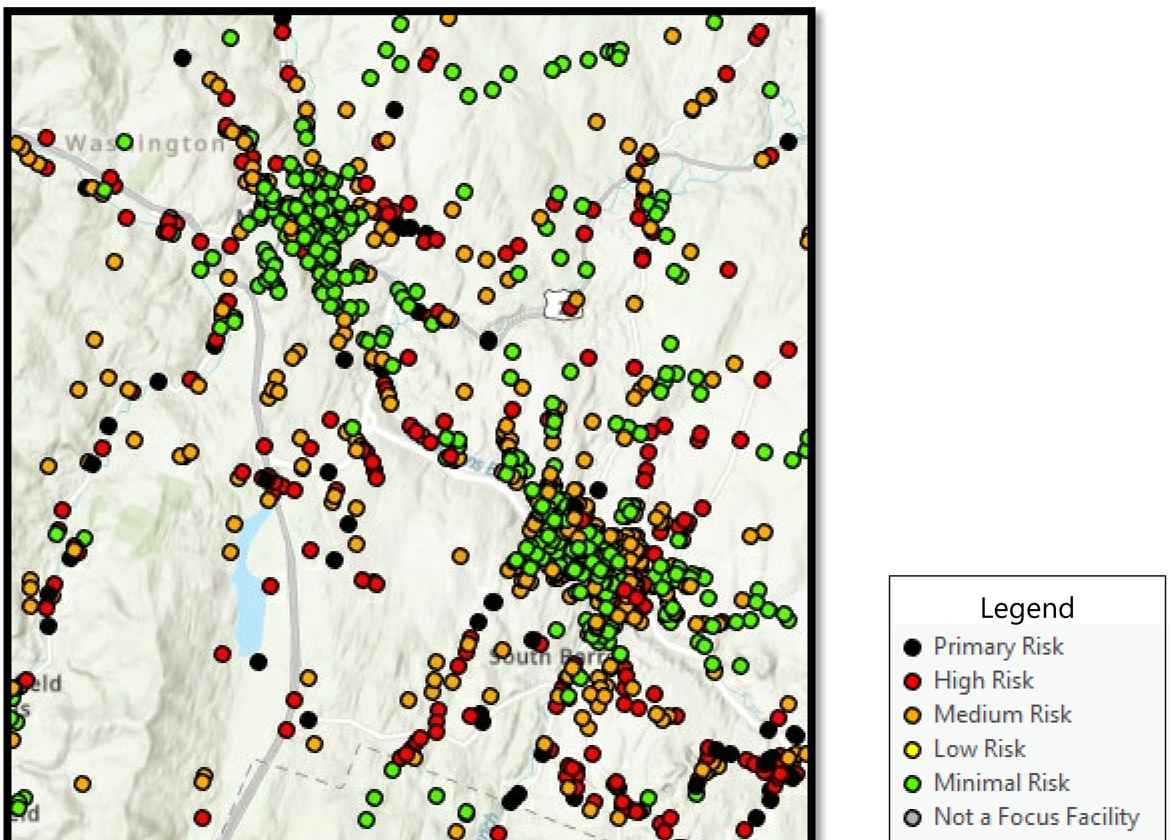


Figure 11. Section of Risk Map for Single Vehicle Crashes (KAB) Involving a Collision with a Fixed Object

Table 11 Percentage of Intersections and Single Vehicle KAB Crashes Involving a Collision with a Fixed Object by Risk Score

Risk Category	Intersections (Percent)	KAB Crashes (Percent)
Primary Risk	4274 (14%)	154 (32%)
High Risk	7077 (24%)	165 (34%)
Medium Risk	12002 (40%)	118 (24%)
Low Risk	0 (0%)	0 (0%)
Minimal Risk	6556 (22%)	45 (9%)

FFT 11: Pedestrian-Vehicle Crashes at Intersections

Figure 11 shows a representative section of the risk map for KAB pedestrian-vehicle crashes at intersections.

Table 12 shows the distribution of risk scores by percentage of intersections and focus crash type. The plurality of intersections is in the "Medium" risk category.

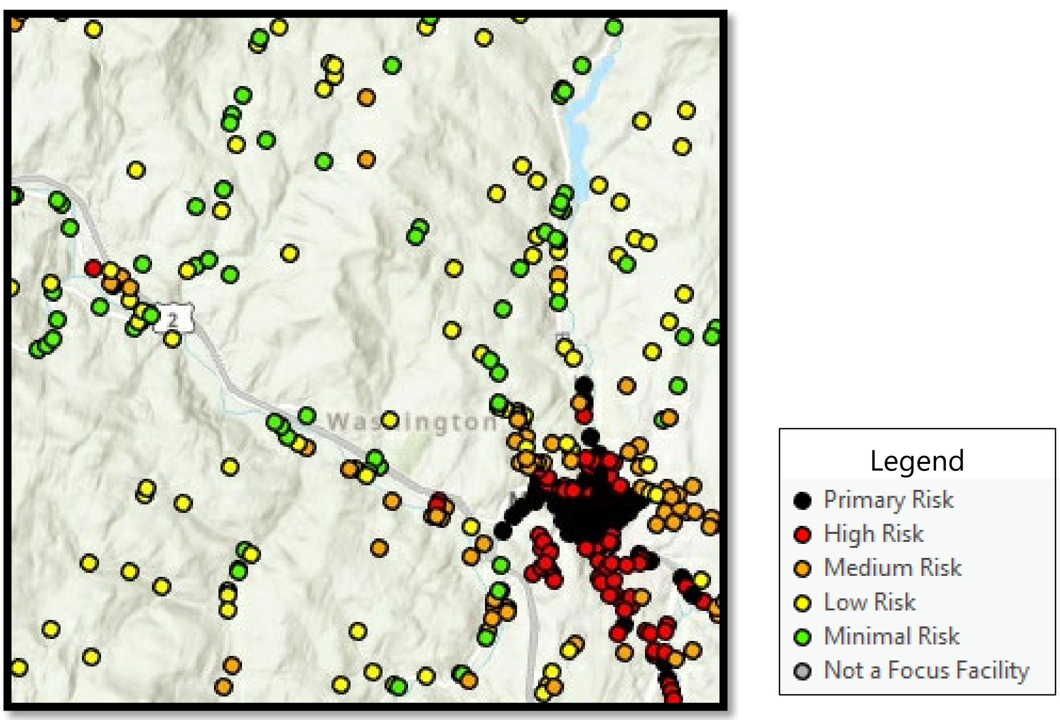


Figure 12. Section of Risk Map for Pedestrian-Vehicle Crashes (KAB) at Intersections

Table 12 Percentage of Intersections and Pedestrian-Vehicle KAB Crashes by Risk Score at Intersections

Risk Category	Intersections (Percent)	KAB Crashes (Percent)
Primary Risk	2341 (8%)	204 (77%)
High Risk	3968 (13%)	36 (14%)
Medium Risk	11513 (38%)	15 (6%)
Low Risk	6926 (23%)	7 (3%)
Minimal Risk	5161 (17%)	3 (1%)

FFT 12: Pedestrian-Vehicle Crashes with a Pedestrian in Marked Crosswalk at Intersections

Figure 12 shows a representative section of the risk map. Ideally, the focus facility type would be restricted to intersections with a marked crosswalk. However, the intersection inventory does not include this information and so the model used all intersections. When using these results, engineers and planners should verify crosswalk presence before advancing a site for countermeasures.

Table 13 shows the distribution of risk scores by percentage of intersections and focus crash type. The plurality of intersections is in the "Medium" risk category.

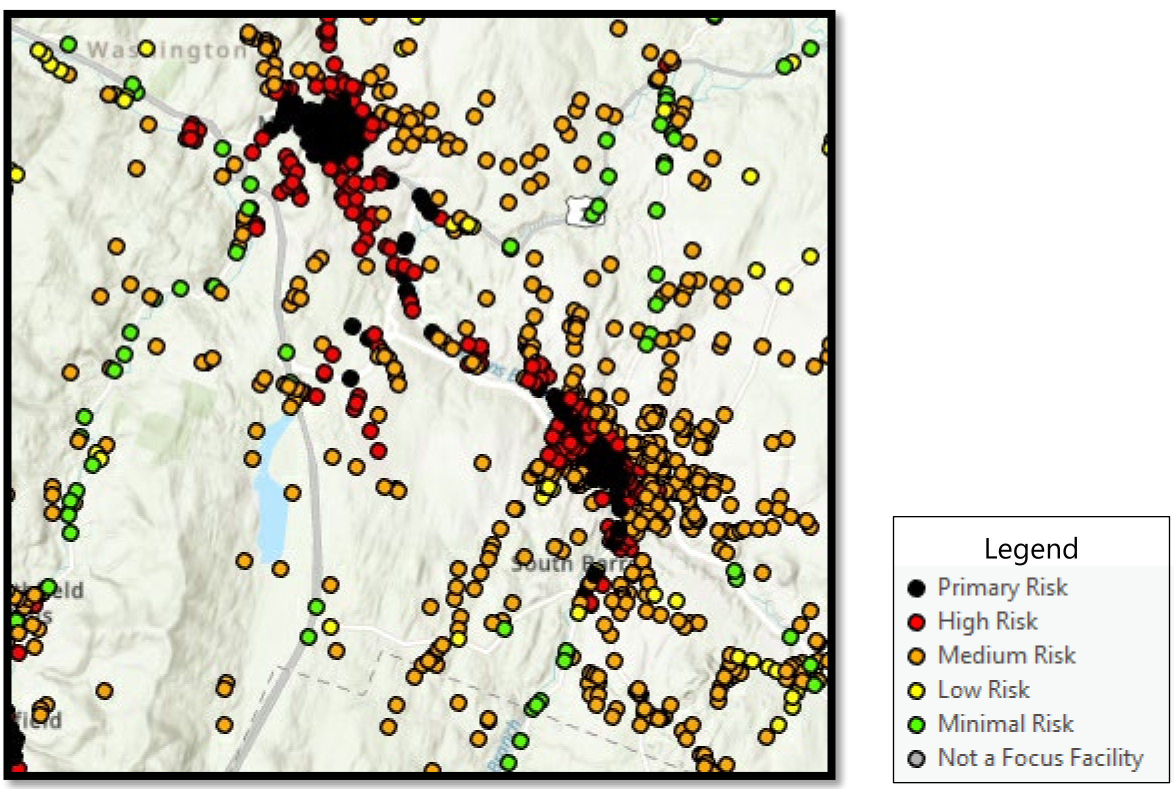


Figure 13. Section of Risk Map for Pedestrian-Vehicle crashes (KABCO) with a Pedestrian in Marked Crosswalk at Intersections

Table 13 Percentage of Intersections and Pedestrian-Vehicle KABCO Crashes with a Pedestrian in Marked Crosswalk by Risk Score at Intersections

Risk Category	Intersections (Percent)	KABCO Crashes (Percent)
Primary Risk	1874 (6%)	136 (91%)
High Risk	3031 (10%)	10 (7%)
Medium Risk	9074 (30%)	3 (2%)
Low Risk	11357 (38%)	0 (0%)
Minimal Risk	4573 (15%)	1 (1%)

FFT 13: Pedestrian-Vehicle Crashes with a Pedestrian Not in a Marked Crosswalk[23]

Figure 13 shows a representative section of the risk map for KABCO pedestrian-vehicle crashes with a pedestrian not in a marked crosswalk.

Table 14 shows the distribution of risk scores by percentage of intersections and focus crash type. The plurality of intersections is classified as “Low” risk.

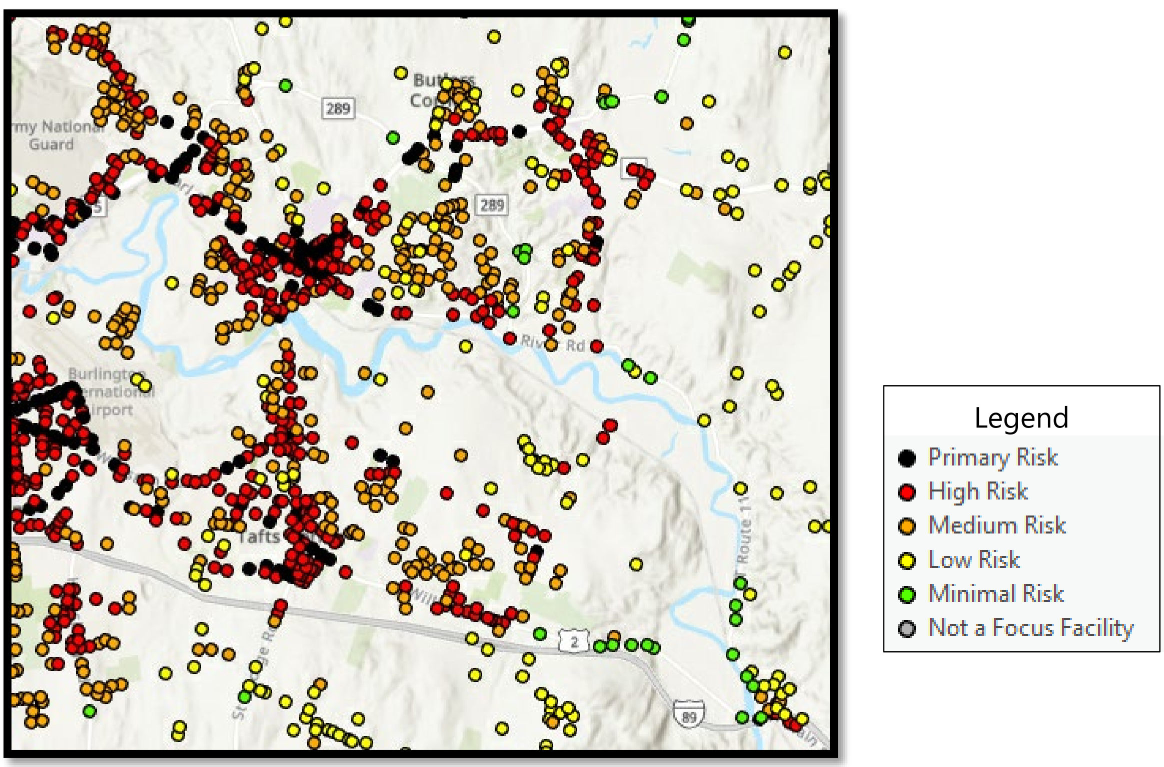


Figure 14. Section of Risk Map for Pedestrian-Vehicle crashes (KABCO) with a Pedestrian Not in a Marked Crosswalk

[23] [location not coded “marked crosswalk at intersection” or “non-intersection crosswalk”]

Table 14 Percentage of Intersections and Pedestrian-Vehicle KABCO Crashes with a Pedestrian Not in a Marked Crosswalk by Risk Score

Risk Category	Intersections (Percent)	KAB Crashes (Percent)
Primary Risk	1518 (5%)	114 (58%)
High Risk	3881 (13%)	42 (21%)
Medium Risk	9350 (31%)	25 (13%)
Low Risk	11292 (38%)	7 (4%)
Minimal Risk	3868 (13%)	9 (5%)

FFT 14: Bicycle-Vehicle Crashes at Intersections

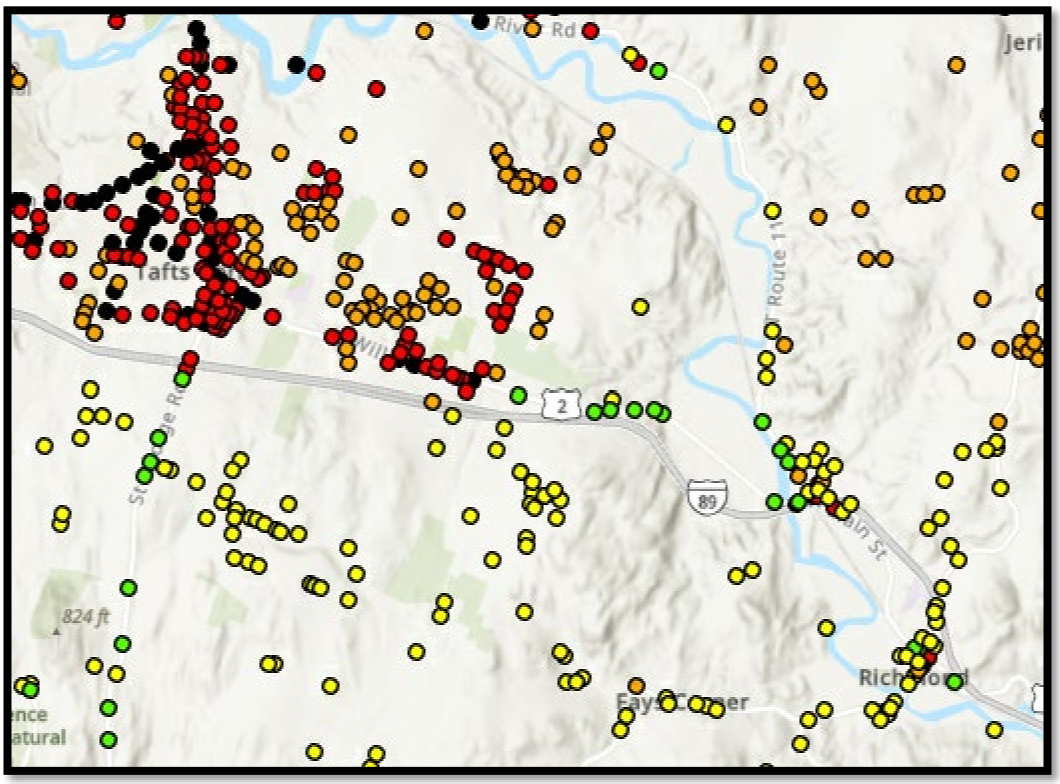


Figure 15. Section of Risk Map for Bicycle-Vehicle crashes (KAB) at Intersections

Figure 14 shows a representative section of the risk map for KAB bicycle-vehicle crashes at intersections.

Table 15 shows the distribution of risk scores by percentage of intersections and focus crash type. Most of the intersections is classified as “Low” risk.

Table 15 Percentage of Intersections and Bicycle-Vehicle AB Crashes by Risk Score at Intersections

Risk Category	Intersections (Percent)	KAB Crashes (Percent)
Primary Risk	1896 (6%)	121 (71%)
High Risk	4494 (15%)	24 (14%)
Medium Risk	9383 (31%)	11 (6%)
Low Risk	11686 (39%)	8 (5%)
Minimal Risk	2450 (8%)	6 (4%)

FFT 15: Pedestrian-Vehicle Crashes at Intersections Occurring at Night

Figure 15 shows a representative section of the risk map for KABC pedestrian-vehicle crashes at intersections occurring at night. Table 16 shows the distribution of risk scores by percentage of intersections and focus crash type. Most of the intersections is classified as "Medium" or "Low" risk.

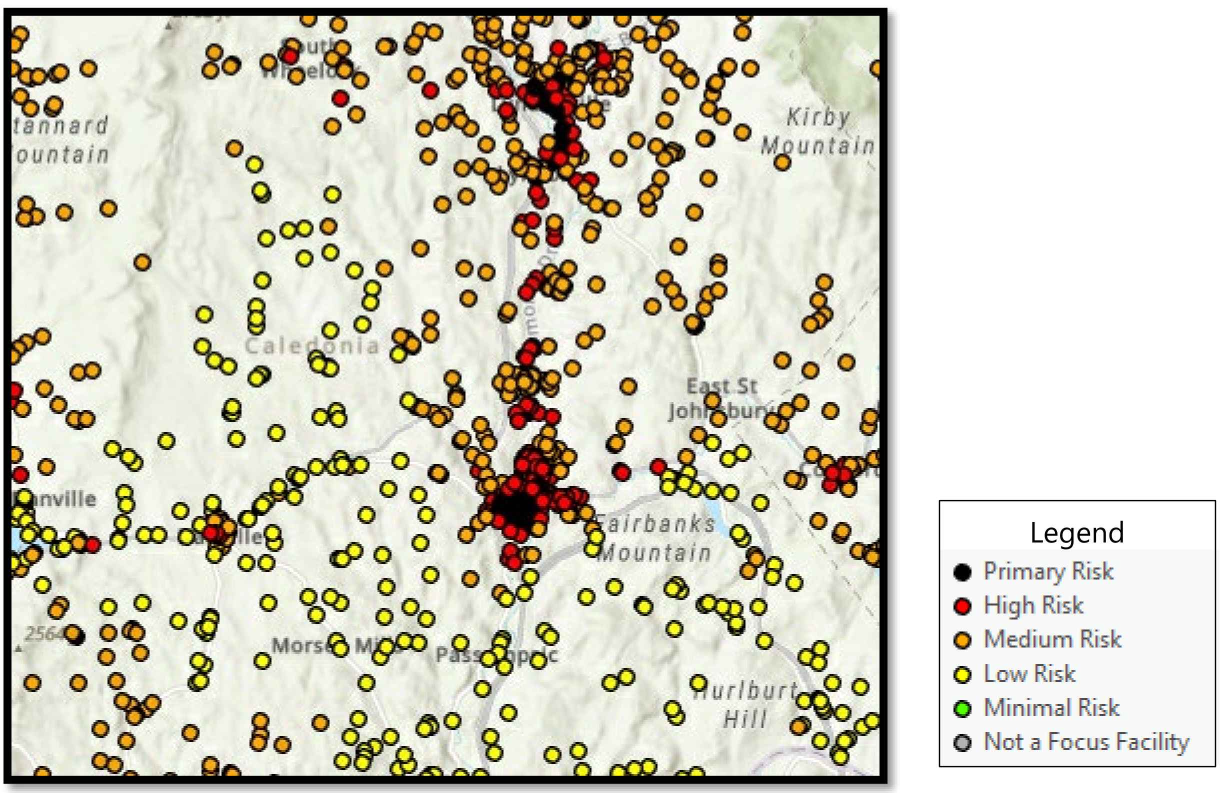


Figure 16. Section of Risk Map for Pedestrian-Vehicle crashes (KABC) at Intersections Occurring at Night

Table 16 Percentage of Intersections and Pedestrian-Vehicle KABC Crashes by Risk Score at Intersections Occurring at Night

Risk Category	Intersections (Percent)	KABC Crashes (Percent)
Primary Risk	2120 (7%)	87 (78%)
High Risk	4432 (15%)	15 (13%)
Medium Risk	11508 (38%)	5 (4%)
Low Risk	11849 (40%)	5 (5%)
Minimal Risk	0 (0%)	0 (0%)

Next Steps

VHB is submitting the risk maps as an attachment to this memo. These maps will also include tables specific to each focus crash and facility type combination containing the fields needed for risk score calculation. They can be joined to the maps as needed.

After VTrans' review, VHB will revise risk maps as needed. VHB will then develop draft countermeasure packages for each focus type and risk level. The countermeasure packages will be context-sensitive and consider the focus crash type.

.

Memorandum #5-Countermeasures & Implementation Plan

The purpose of this memo is to describe the identified countermeasure packages associated with each risk level, to propose lists of prioritized sites matched to potential countermeasures and to suggest targeted strategies to deliver these projects through multiple channels. The memo was transmitted by VHB to VTrans on October 9, 2023.

Background

"Intersection crashes" are a critical emphasis area in Vermont's current Strategic Highway Safety Plan (SHSP) and include all crashes within 250 feet of the center of an intersection. These were divided along crash and road attributes into several focus crash types to analyze individually. The intent with this approach is for risk scores to be as specific as possible so that intersections in a single category are comparable and recommendations are tightly focused. Ultimately, VHB and VTrans selected 15 combinations of focus crash types and facility types for risk factor identification:

1. Left turn crashes at minor stop-controlled intersections[24].
2. Left turn crashes on rural, minor stop-controlled intersections with at least one state-owned leg[25].
3. Rear-end crashes at certain three-leg and four-leg unsignalized intersections[26].
4. Rear-end crashes at signalized intersections with at least one non-state leg[27].
5. Angle/Broadside crashes at urban four-leg signalized intersections with no state legs.
6. Angle/Broadside crashes at minor stop-controlled T-intersections with one or more nonstate legs.
7. Angle/Broadside crashes at three-leg (t-intersections and y-intersections) and four-leg minor stop-controlled intersections.
8. Head-on crashes at minor stop-controlled T-intersections with at least one nonstate leg.
9. Single vehicle crashes at minor stop-controlled T-intersections with one or more nonstate legs.
10. Single vehicle crashes involving a collision with a fixed object.
11. Pedestrian-vehicle crashes at intersections.
12. Pedestrian-vehicle crashes with a pedestrian in marked crosswalk.
13. Pedestrian-vehicle crashes with a pedestrian not in a marked crosswalk[28].

---

[24] This includes four-leg minor stop-controlled intersections, minor stop-controlled t-intersections, and minor stop-controlled y-intersections.
[25] This includes rural four-leg minor stop-controlled intersections, minor stop-controlled t-intersections, and minor stop-controlled y-intersections classified as "State vs State" and "State vs Nonstate".
[26] This includes four-leg minor stop-controlled intersections, uncontrolled t-intersections, minor stop-controlled t-intersections and y-intersections, and four-leg all-way stop-controlled intersections.
[27] This includes signalized four-leg intersections and signalized t-intersections.
[28] "Location" in crash data not coded "marked crosswalk at intersection" or "non-intersection crosswalk".

14. Bicycle-vehicle crashes at intersection[29].
15. Pedestrian-vehicle crashes at intersections occurring at night.

After a statistical analysis incorporating crash, roadway, traffic, and socioeconomic factors, sites were scored according to the schema listed in **Appendix B**. The numeric scores were converted to a percentile and then classified using the groupings in **Table 1**. VHB provided the prioritized maps to VTrans as shapefiles and ArcGIS Online links.

Table 17. Risk Categories Based on Percentile Score Range

Risk Category	Percentile Score Range	Color
Primary Risk	95-100	Black
High Risk	85-94	Red
Medium Risk	60-84	Orange
Low Risk	30-59	Yellow
Minimal Risk	0-29	Green
Not a Focus Facility	N/A	Gray

The next section describes the recommended countermeasures at each risk level. Many of these countermeasures have additional criteria (besides the intersection clearing a minimum risk level). The evaluation of those additional criteria was outside the scope of this project. Therefore, these recommendations presume VTrans will complete their due diligence and conduct site-specific diagnostics and evaluation (including compatibility with VTrans' internal design guidelines) before advancing a project.

[29] Given the small sample size, VHB elected not to identify a focus facility type.

Countermeasure Matrix

To implement the systemic safety approach, VTrans will select sites for improvement based on the risk of a severe crash rather than crash experience alone. The countermeasure matrix (see **Appendix A**) is intended to help focus resources for efficiently reducing intersection crash risk. To begin, VHB paired potential countermeasures with each focus crash and facility type. These recommendations are grouped in tiers by risk, with more expensive or complex countermeasures included at higher risk levels. The tiers also include a set of standard treatments which should be considered for all risk sites which are being addressed. Recommendations presume minimum signage is present as recommended in the Manual on Uniform Traffic Control Devices (MUTCD) but include enhanced or supplemental signs under certain conditions.

Note that for focus area 12 (Pedestrian-vehicle crashes with a pedestrian in marked crosswalk), the VTrans intersection inventory does not include a data element to indicate whether a crosswalk is present at the intersection. As such, due diligence for these sites should include verifying presence of a crosswalk before considering countermeasures.

The sites at each risk level are treated as a pool of potential locations for the associated countermeasures. Listing is not an assessment that the countermeasure is "needed" at any one site – professional judgment is essential in selecting sites and countermeasures to implement. Given the planning-level effort of this work, the sites were not reviewed for the appropriateness of the countermeasure or to determine if one or more of the countermeasures are already present; however, additional criteria are listed for some countermeasures to facilitate this check in the future. Conditions must be field verified prior to programming any improvements.

VTrans will need to be selective in the application of countermeasures for the primary risk category due to the higher relative costs. Although the safety program has funded most of the listed improvements before, installing them at all recommended locations would be cost-prohibitive. As discussed later in this plan, it will be critical to Operations and Safety Bureau's (OSB's) success with these projects that it develops processes to control scope and costs. This includes aggressively ruling out sites with Right-of-Way (ROW) or environmental challenges, strictly limiting scope, and enforcing value engineering standards (including consideration of life cycle costs). During site selection, VTrans should employ prioritization criteria to further stratify the primary risk category. Recommended criteria are provided below in **Table 2**.

Table 18. Prioritization Criteria for Primary Risk Countermeasures

Countermeasure	Prioritization Criteria
Roundabout	• *Required: Unsignalized intersection with a history of severe (K, A, or B) angle, left turn, and/or pedestrian crashes.* • One point for every target crash of KAB severity. • One point if four or more legs are present at the intersection. • One point if rural. • One point for every 10 degrees of skew angle.
Mini Roundabout	• *Required: Unsignalized intersection with a history of angle, left turn, and/or pedestrian crashes.* • Intersections with lower daily volumes and less available ROW. • One point for every target crash of KAB severity. • Two points if approach speed limits are 35 MPH or less. • One point for every local approach. • One point if four or more legs are present at the intersection. • One point if urban.
All-Way Stop-Control	• *Required: Minor stop control or uncontrolled intersection with a history of angle, left turn, pedestrian, and/or bicyclist crashes.* • One point for every target crash of KAB severity. • Three points if difference between major and minor road AADT is less than 100, two points if the difference is between 100 and 250, and one point if the difference is between 250 and 500.
Intersection Lighting	• *Required: Intersection with a history of nighttime crashes in unlit conditions, especially involving pedestrians.* • One point for every nighttime crash. • One point for every pedestrian crash. • One point for every 10 degrees of skew angle. • One point if major road AADT exceeds 3,000. • One point if minor road AADT exceeds 1,500. • One point if major road posted speed limit exceeds 45 mph. • One point if minor road posted speed limit exceeds 45 mph.
Dedicated Turn Lane	• *Required: Intersection with a history of crashes related to left or right turns where a dedicated turn lane is not currently present.* • One point for every target crash of KAB severity. • One point if no lighting is present. • One point if major approach speed limit exceeds 35 MPH. • One point if major road AADT exceeds 10,000.

Raised Crosswalk ***(only applicable for local road approaches outside of State ROW)***	• *Required: Intersection with a history of pedestrian crashes and the intersecting roads are local or collector streets with existing sidewalks.* • One point if a pedestrian crash has occurred. • Two points if a pedestrian crash occurred "in a marked crosswalk". • One point if lighting is present. • One point if posted speed limit on minor approach is less than or equal to 30 MPH. • One point if minor road has two through lanes.
High-Friction Surface Treatment (HFST)	• *Required: Intersection or its approaches with a history or evidence of friction issues.* • One point for every target crash of KAB severity. • One point for every wet road crash. • One point if major road speed limit is at least 45 mph.
Protected Bicycle Lanes with Bike Boxes and Bike Signals	• *Required: Intersection or its approaches with existing bicycle lanes and a history of bicycle-related crashes.* • One point for every bicycle crash. • One point if no lighting is present. • One point if transit stop is present within quarter mile. • One point if intersection has 4 or more legs.

The intersection inventory does not have AADT or posted speed limit values for non-Federal-aid approaches to intersections. For the purpose of scoring, VHB replaced the null entries with the following assumed values:

- AADT = 500 vehicles per day at urban intersection approaches.
- AADT = 250 vehicles per day at rural intersection approaches.
- Posted speed limit = 25 MPH.

VHB applied the listed numeric criteria to rank primary risk sites for these countermeasures. This ranked site list is provided as an attachment to this memo. The following are considerations for engineers, planners, and designers implementing certain recommended countermeasures. The key takeaway is that the matrix is just a preliminary screen for potential countermeasures. Before advancing a countermeasure, the designer must compare alternatives, verify the feasibility of the selected countermeasure, and evaluate the cost-benefit ratio. Further, countermeasures should always be implemented in accordance with present VTrans design guidance/policy.

- Roundabout:
    - An unsignalized intersection with a history of severe angle, left turn, and/or pedestrian crashes. Sufficient ROW would be necessary to construct roundabouts. In situations where ROW is not available, mini-roundabouts may be considered. Conversion to roundabout has been found to reduce injury crashes by 42 percent[30]. A full evaluation process should be completed including a comparison of alternative designs and a detailed cost-benefit analysis.
- Compact and Mini-roundabout:

[30] https://www.cmfclearinghouse.org/detail.php?facid=4868

  - An unsignalized intersection with a history of angle, left turn, and/or pedestrian crashes. Mini-roundabout approach speeds should be 35 mph or less. Compact and mini-roundabouts are typically considered at intersections with lower daily volumes and less available ROW. Mini-roundabouts are also more feasible as systemic projects compared to traditional roundabouts; they can also be implemented using a quick-build approach. Mini-roundabouts have been found to reduce crashes by 20 percent[31]. A full evaluation process should be completed to confirm a mini-roundabout is an appropriate geometric design for the intersection. The Washington State DOT (WSDOT) systemically deployed compact roundabouts; this could be a useful model for VTrans[32].
- All-Way Stop-Control:
  - A minor stop control or uncontrolled intersection can be upgraded to an all-way stop control if one or more of the traffic conditions listed in Section 2B.07 of the Manual on Uniform Traffic Control Devices (MUTCD) exist; engineering judgement should be used to confirm viability as a traffic control strategy. The MUTCD provides volume thresholds as criteria for all-way stop-control and considers if the intersection has a history of angle, left turn, pedestrian, and/or bicyclist crashes. North Carolina has had success implementing an all-way stop-control program in rural areas, including a 68 percent reduction in all crashes and a 77 percent reduction in injury crashes[33].
- Intersection Lighting:
  - An intersection with a history of nighttime crashes in unlit conditions, especially involving pedestrians, which are expected to be addressed through lighting. Lighting has been found to reduce nighttime pedestrian crashes at intersections by 42 percent, while reducing injury nighttime crashes at intersections by 33 to 38 percent[34]. Existing lighting may also be improved where poorly designed or ineffective; as such, designers should review even those intersections with lighting present to verify the current lighting is sufficient. The lighting should be used to highlight conflicts, including on approaches to a pedestrian crosswalk. Designers can use VTrans intersection lighting warrants[35] to verify lighting applicability; however, VHB recommends VTrans further refine the warrants and guidance for when and where lighting is applied.
- Dedicated Turn Lane:
  - An intersection with a history of crashes related to left or right turns where a dedicated turn lane is not currently present. Left turn lanes have been found to reduce crashes by 28 to 48 percent, and injury crashes by 36 percent when installed with positive offset[36]. Right turn lanes have been found to

---

31 https://www.cmfclearinghouse.org/detail.php?facid=11240
32 https://trb.secure-platform.com/a/gallery/rounds/52/details/10845
33 https://connect.ncdot.gov/resources/safety/Teppl/TEPPL%20All%20Documents%20Library/RCards.pdf
34 https://highways.dot.gov/safety/proven-safety-countermeasures/lighting
35
https://vtrans.vermont.gov/sites/aot/files/highway/documents/publications/VTRANS%20Lighting%20Guidance%20Document%20%282015%29.pdf
36 https://highways.dot.gov/safety/proven-safety-countermeasures/dedicated-left-and-right-turn-lanes-intersections

reduce crashes by 14 to 26 percent[36]. Analysts should verify turning movement counts against volume warrants[37].

- Raised Crosswalk:
    - An intersection with a history of pedestrian crashes and the intersecting roads are local or collector streets with existing sidewalks. Raised crosswalks are typically installed on roadways with less than 9,000 vehicles per day, 2 or 3 lanes, and speed limits of 30 mph or less. Raised crosswalks have been documented to reduce vehicle-pedestrian crashes by 45 percent[38]. Note that raised crosswalks are not eligible on State highways; designers should review the proposed design to verify the raised crosswalk does not encroach on State ROW. If considered, local agencies should ensure the design does not interfere with drainage or snow removal.
- High-Friction Surface Treatment (HFST):
    - An intersection or its approaches with a history or evidence of friction issues (e.g., polished pavement, wet road crashes, rear end crashes) and sufficient pavement structure to accommodate a successful HFST installation. HFST has been documented to reduce wet road crashes on intersection approaches by 20 percent[39].
- Protected Bicycle Lanes with Bike Boxes and Bike Signals:
    - An intersection or its approaches with existing bicycle lanes and a history of bicycle-related crashes. Bike boxes and/or bike signals are recommended at signalized intersections to provide greater protection for bicyclists. The National Association of City Transportation Officials (NACTO) notes that benefits for bicyclists include increased visibility, reduced signal delay, and fewer opportunities for vehicle-bicycle conflicts due to the prioritization of bicycles at the start of a green phase[40]. The City of Burlington has deployed bike boxes in quick-build applications.[41] VHB recommends VTrans consider bicycle warrants for applications on State roads, as maintaining the pavement markings will be a challenge.
- Targeted Speed Reduction Measures:
    - This general recommendation is meant to encourage designers and planners to review the VTrans Traffic Safety Toolbox to identify appropriate countermeasures for the context of the intersection. Additionally, the countermeasures should be proposed with all users in mind; designers and planners should consider soliciting public input when selecting the countermeasure(s).
- Signage and Pavement Marking Improvements:
    - The countermeasure matrix includes several instances of recommending improvements to intersection warning signage and pavement markings. For "Medium" risk tier sites, the plan

---

[37] https://vtrans.vermont.gov/sites/aot/files/planning/documents/trafficresearch/TIS%20Guidelines%20Revised%20April%202019%20CGC.pdf
[38] https://www.cmfclearinghouse.org/detail.php?facid=136
[39] https://www.cmfclearinghouse.org/detail.php?facid=2259
[40] https://nacto.org/publication/urban-bikeway-design-guide/intersection-treatments/bike-boxes/
[41] https://www.burlingtonvt.gov/DPW/BikeBoxes#:~:text=It's%20a%20painted%20green%20space,and%20predictable%20to%20approaching%20drivers.

recommends implementation of either doubling-up advance warning signage or implementing oversized advance warning signage; both of which use retroreflective sheeting. At "High" or "Primary" risk sites, designers should consider both treatments. Additionally, this should include a review of the intersection signage for compliance with the MUTCD. Finally, as noted in the "Medium" risk tier, designers should consider implementing reflective sheeting on sign posts to increase visibility of the signage, especially at rural intersections. Advance street name signs can also be employed as part of any signing package.

- Brush Trimming and Sight Line Maintenance:
    - Brush trimming and sight line maintenance is included as a standard treatment for all tiered intersections. This calls on maintenance staff responsible for the ROW to regularly remove brush and other potential visible obstructions from the ROW to maintain adequate intersection sight distance. It is important that staff consider seasonal changes in vegetation when reviewing and maintaining sight distance. For mixed ownership intersections, VTrans maintenance staff should work with relevant local agencies to verify the intersection receives adequate clearing.
- Traffic Signal Improvements:
    - Several countermeasures include proposed modifications to traffic signal timing, phasing, or equipment. Any proposed changes of this sort should be done within VTrans traffic signal guidelines (or those of the governing local agency).
- Education and Public Outreach:
    - Many of the countermeasures included in this plan require some level of compliance from road users. This is critical, especially given that many of these countermeasures will be installed in bulk throughout the roadway system. As such, VTrans should consider developing public outreach and education campaigns to support the deployment of these countermeasures. Such campaigns should explain what the countermeasure is, how it works, why it works, and how drivers are expected to respond to the treatment.

Delivery Approaches

The types of treatments contemplated in this plan are not a significant departure from the projects the HSIP has previously funded in Vermont. However, delivering these through a systemic program will require a fundamentally different approach from projects previously delivered. OSB should take on an expanded role including initial project definition and involvement in approving changes through preliminary design, developing the target schedule, directing the use of specific funding sources, and deciding whether to bundle projects for either design or construction. Projects will still be delivered by the Project Delivery Bureau (PDB), with continued coordination on schedule, budget, and design changes after the hand-off. It may take several cycles to develop processes and a division of roles, and systemic efforts should scale up gradually as this process matures.

In the first few years, OSB and their partners should focus on simpler countermeasures from this plan – such as changes to signing, marking, and signal programming. OSB and their partners should also work on guidance and engineering instructions for more complex treatments to encourage consistent application as the program expands.

Starting with lower-stakes projects will make the systemic program sustainable as OSB learns to manage risks including scope and cost overruns, effects on traffic operations, and maintenance impacts.

In the short- to medium-term, VHB recommends three tracks for delivering systemic projects:

1. HSIP-led systemic projects
2. Harmonized projects
3. Local road grant program

These three tracks are discussed in more detail in the following sections.

HSIP-Led Systemic Projects

In most cases, these systemic improvements should be initiated as standalone projects through HSIP and delivered by PDB. These improvements should be at intersections with state-owned approaches, including intersections of state and local roadways. This will improve safety on both the state and local system while streamlining the process by staying within state ROW.

Focusing on one to three countermeasures each year is a realistic goal that should also be sufficient to reach systemic spending targets. If Traffic Engineering Instructions (TEI) do not already exist (or need to be updated), OSB should write new ones documenting selection criteria for the countermeasures to be implemented. The HSIP Engineer should then consult screening results, eligibility criteria, and prioritization factors to generate a preliminary site list. The HSIP Engineer should also perform a feasibility review and strike sites that would require ROW acquisition, be unlikely to receive a National Environmental Protection Act (NEPA) categorical exclusion or have other complicating factors that would require a larger scope (e.g., relocating a culvert). The exact thresholds where a site is ruled out for complexity will need to evolve over time as OSB's project experience grows. While costs will vary from site to site, the point is to avoid outliers costing 50 percent or more than average for a countermeasure.

Some of these projects include a change in traffic control; these should be supported by an engineering study. In the case of proposed changes to traffic control at a ramp terminal, VTrans should verify with the Vermont FHWA Division that the proposed changes will not require an Interstate Access Request[42].

After sites are selected, projects should be assigned a PDB project manager to shepherd them through design and delivery. For simpler treatments, OSB may manage design, either creating plans in-house or through one of its consulting contracts. Even after passing the project to PDB, the HSIP Engineer should retain ultimate authority for scope and design decisions. They should be responsive to concerns from other Bureaus raised up to and through Online Shared Review, while holding firm on scope to the greatest extent practical.

Because these types of projects will have downstream effects elsewhere in the agency – such as maintenance needs, traffic impacts, or new assets – the coordination must continue even after countermeasures are in place. OSB should expect to do a shorter-term evaluation considering these non-safety factors and be prepared to adjust course (modifying or removing countermeasures) if a safety effect is not demonstrated and there are adverse impacts on traffic or maintenance.

Harmonized Projects

Another avenue is to incorporate a systemic countermeasure into an existing project (harmonization). This works best when HSIP is involved at the scoping stage and has selected a countermeasure compatible with the type of work. This approach is most appropriate for projects on state highways but could also have applications with Class 1 paving jobs.

OSB should continue to coordinate with the Asset Management Bureau (AMB) to work out the right time and approach for OSB's involvement. In general, scoping exercises such as Drive Throughs or New Project Summaries are good opportunities to add safety input. Because of the additional judgment required, risk maps and the countermeasure matrix should not be considered a self-service tool at this time. OSB should assist with interpreting these results and endorse specific countermeasures based on its review of project-specific conditions.

The scope of work for the subject project will limit the countermeasures that can be incorporated; however, the HSIP Engineer should still evaluate a full complement of countermeasures. If the preferred countermeasure is not compatible, other treatments should not be recommended just to "get something in the ground" unless the value can be justified as an interim measure.

If a countermeasure is recommended within the bounds of the project, OSB should discuss this recommendation with AMB. The two bureaus should then coordinate the specific requirements to be added to the project. HSIP funding can be applied to the portion of engineering and construction attributable to the added treatments. If costs are minimal, AMB may choose not to adjust funding and continue using other funds. Even if HSIP funds are not applied, the HSIP Engineer should track the project as a safety improvement for future evaluation.

Local Road Grant Program

Intersections of town highways (no state-owned approach) should be addressed through the HSIP local road grant program. Currently, towns have the flexibility to select their own sites and choose countermeasures from a predefined list. As the program evolves, it should be modified to incentivize projects in line with the countermeasure matrix.

[42] https://www.fhwa.dot.gov/programadmin/fraccess.cfm

The HSIP Engineer will set requirements for applicants again next year. The cap will likely be similar to the $35,000 per town established this year. The program should offer countermeasures that are readily constructable within that cap. VHB does not recommend offering more expensive countermeasures and requiring a local match to bridge the gap. Rules could also be changed to set one cap for the discretionary types of projects allowed last year and a higher cap for systemic projects on the screening list.

It is critical that screening information provided to towns and Regional Planning Commissions (RPCs) be clear and consistent. Neither the full maps nor the matrix should be provided to avoid the perception that VTrans recommends the countermeasures at any listed location. Instead, selected countermeasures should be offered with clearly defined eligibility criteria in similar detail to a TEI. Any criteria that can be pre-evaluated by VTrans (including crash, traffic, control type, or any other information assembled for this project) should be provided in a GIS web map or other suitable alternative to facilitate eligibility checking for towns.

Once towns apply for a project on the list, the grant program should function as it does now. For small-dollar improvements, the Municipal Assistance Section (MAS) should renew or maintain the Force Account Authorization from FHWA for this grant program. Force account approval allows municipalities to defer to their own contracting procedures and either self-perform or contract the work. If larger projects are contemplated or force account cannot be reauthorized for another reason, the grant program should revert to standard contracting procedures. The HSIP Engineer reviews and approves grant applications, verifying eligibility and balancing awards geographically. A grant agreement is signed between VTrans and the awardee, which includes a commitment to maintain the improvement and provide details to support post-implementation evaluations.

Project Tracking and Evaluation

Project tracking and evaluation are critical to improving the HSIP and the overall safety program in Vermont. Although the standard evaluation process is detailed in the VTrans HSIP Manual, systemic projects have additional record-keeping needs. All HSIP projects should be tracked in the HSIP dashboard. A separate page should track multi-site projects (such as grant programs that all fall under one project number). Projects that include safety countermeasures, even if not using HSIP funds, should be listed to the extent practical. Those must be tagged so that they are excluded from cost-benefit analyses but included in averaging for crash modification factors. Project managers should track installation dates so that before and after periods can be selected for evaluation. Ideally, project locations are also mapped in GIS. Sites should be aggregated by focus type and countermeasure for evaluation as a group. Additional information about project tracking is available in FHWA's *HSIP Evaluation Guide*.

Additionally, OSB and other project managers should coordinate project tracking with AMB to ensure new assets are sufficiently documented to maintain justification for future maintenance efforts and other projects.

Next Steps

VTrans OSB will work with stakeholders to begin implementing the program as described in this plan and the HSIP Manual.

Appendix A – Countermeasure Matrix

Table 3 to Table 6 list recommended countermeasures for each focus type organized by facility type (i.e., minor stop-controlled intersection or signalized intersection) and crash type for primary, high, and medium risk categories. Table 6 includes a baseline set of countermeasures which are recommended as standards for each facility type (this includes some treatments that are already VTrans standards but may be absent on local roads). At higher risk levels, additional countermeasures are added for consideration. Recommendations presume minimum signage is present as recommended in the MUTCD but include supplemental signs at higher-risk intersections which may not already have signage present. Note that countermeasures are not divided between State route and local route sites – the proposed countermeasures can and should be feasibly considered for both.

As discussed elsewhere in the plan, the countermeasures are applicable to all sites at the applicable risk level or above. As such, standard countermeasures are applicable to all risk sites; medium risk level countermeasures are applicable to medium risk, high risk, and primary risk sites; high risk level countermeasures are applicable to high-risk sites and primary risk sites; and primary risk level countermeasures are applicable to primary risk sites. The tables are applicable as follows:

- Primary risk sites - Table 3.
- High risk sites - Table 4.
- Medium risk sites - Table 5.
- Standard countermeasures - Table 6.

Table 19 Countermeasure Matrix for Primary Risk Sites

Risk Level	Countermeasure (Focus Crash and Facility Type)	Target Crash Types and Facilities								
		Left turn & angle crashes, minor stop controlled (1, 2, 6, 7)	Rear-end crashes, unsignalized (3)	Rear-end crashes, signalized (4)	Angle crashes, signalized (5)	Head-on crashes, minor stop controlled (8)	Single vehicle crashes (9, 10)	Pedestrian-vehicle crashes (11, 12, 13)	Bicycle-vehicle crashes (14)	Pedestrian-vehicle crashes at night (15)
Primary	Convert to Roundabout	●				●		●	●	●
	Dedicated Left- or Right-Turn Lane	●	●	●	●	●				
	Convert to Mini-Roundabout	●	●			●		●	●	●
	Convert to All-Way Stop-Control	●				●		●	●	●
	Lighting	●	●	●	●	●	●	●	●	●
	Raised Crosswalk							●		●
	HFST	●	●	●	●	●	●	●	●	●
	Protected Bicycle Lanes with Bike Boxes/Signals								●	

Table 20 Countermeasure Matrix for High-Risk Sites

Risk Level	Countermeasure (Focus Crash and Facility Type)	Target Crash Types and Facilities								
		Left turn & angle crashes, minor stop controlled (1, 2, 6, 7)	Rear-end crashes, unsignalized (3)	Rear-end crashes, signalized (4)	Angle crashes, signalized (5)	Head-on crashes, minor stop controlled (8)	Single vehicle crashes (9, 10)	Pedestrian-vehicle crashes (11, 12, 13)	Bicycle-vehicle crashes (14)	Pedestrian-vehicle crashes at night (15)
High	Reduce Intersection Skew	●	●			●	●	●	●	●
	Double-Up and Oversize Advance Signage, Upgrade to Fluorescent Sheeting[43]	●	●	●	●	●	●	●	●	●
	Curb Extensions							●		●
	Advanced Dilemma Zone Detection			●	●					
	Protected Left-Turn Phasing				●			●		●
	Flashing Yellow Arrow				●					
	Dedicated Bicycle Lanes								●	

[43] At medium risk sites, designers are recommend to choose one. At high risk sites, designers are recommend to deploy both.

Risk Level	Countermeasure (Focus Crash and Facility Type)	Target Crash Types and Facilities								
		Left turn & angle crashes, minor stop controlled (1, 2, 6, 7)	Rear-end crashes, unsignalized (3)	Rear-end crashes, signalized (4)	Angle crashes, signalized (5)	Head-on crashes, minor stop controlled (8)	Single vehicle crashes (9, 10)	Pedestrian-vehicle crashes (11, 12, 13)	Bicycle-vehicle crashes (14)	Pedestrian-vehicle crashes at night (15)
High	High-Visibility Crosswalk[44]							●		●
	Pedestrian Refuge Island							●		●
	Targeted Speed Reduction Measures[45]	●	●	●	●	●	●	●	●	●

[44] Longitudinal crosswalk markings implemented using thermoplastic paint.
[45] Designers can refer to VTrans's Traffic Safety Toolbox for potential speed reduction countermeasures: https://vtrans.vermont.gov/sites/aot/files/documents/20230606%20Toolbox.pdf. Note, this does not include changing the posted speed limit.

Table 21 Countermeasure Matrix for Medium Risk Sites

Risk Level	Countermeasure (Focus Crash and Facility Type)	Target Crash Types and Facilities								
		Left turn & angle crashes, minor stop controlled (1, 2, 6, 7)	Rear-end crashes, unsignalized (3)	Rear-end crashes, signalized (4)	Angle crashes, signalized (5)	Head-on crashes, minor stop controlled (8)	Single vehicle crashes (9, 10)	Pedestrian-vehicle crashes (11, 12, 13)	Bicycle-vehicle crashes (14)	Pedestrian-vehicle crashes at night (15)
Medium	Double-Up or Oversize Advance Signage, Upgrade to Fluorescent Sheeting	●	●	●	●	●	●	●	●	●
	Retroreflective Sheeting on Sign Posts	●	●	●	●	●	●	●	●	●
	Enhanced Pavement Markings that Delineate Intersection[46]	●	●			●	●	●	●	●
	Improve Intersection Sight Distance	●	●	●	●	●	●	●	●	●
	Leading Pedestrian Interval							●		●

[46] Countermeasures can include a painted splitter island if sufficient pavement width is available or a "STOP AHEAD" in pavement markings, edge lines delineating the curb return if not already present.

Risk Level	Countermeasure (Focus Crash and Facility Type)	Target Crash Types and Facilities								
		Left turn & angle crashes, minor stop controlled (1, 2, 6, 7)	Rear-end crashes, unsignalized (3)	Rear-end crashes, signalized (4)	Angle crashes, signalized (5)	Head-on crashes, minor stop controlled (8)	Single vehicle crashes (9, 10)	Pedestrian-vehicle crashes (11, 12, 13)	Bicycle-vehicle crashes (14)	Pedestrian-vehicle crashes at night (15)
Medium	Prohibit Right-Turn on Red				●			●	●	●
	Adjust Yellow Change Intervals to Reduce Dilemma Zone			●	●					
	Install Crosswalks if Not Present[47]							●		●
	R10-15 "Turning Vehicles Yield to Pedestrians"							●		●
	Parking Restriction Near Crossing							●	●	●

[47] Designers should review the VTrans Guidelines for Pedestrian Crossing Treatments to verify site eligibility for a crosswalk: https://vtrans.vermont.gov/sites/aot/files/highway/documents/ltf/VTrans%20Ped%20Crossing%20Guide%20August%202019%20Update.pdf.

Table 22 Countermeasure Matrix for All Sites

Risk Level	Countermeasure (Focus Crash and Facility Type)	Target Crash Types and Facilities								
		Left turn & angle crashes, minor stop controlled (1, 2, 6, 7)	Rear-end crashes, unsignalized (3)	Rear-end crashes, signalized (4)	Angle crashes, signalized (5)	Head-on crashes, minor stop controlled (8)	Single vehicle crashes (9, 10)	Pedestrian-vehicle crashes (11, 12, 13)	Bicycle-vehicle crashes (14)	Pedestrian-vehicle crashes at night (15)
Standard	Properly Placed Stop Bar	●	●	●	●			●	●	●
	Double Arrow Warning Sign at Stem of T-Intersections	●					●			
	Brush Trimming and Sight Line Maintenance	●	●	●	●	●	●	●	●	●
	Backplates with Retroreflective Borders			●	●					
	Pedestrian Countdown Signals							●		●

Appendix B – Scoring Formulas

The following describes the risk factors and risk scoring for each combination of focus crash types and facility types.

1. Left turn crashes at minor stop-controlled intersections[48] – (KAB[49]) 237 crashes over 9,435 intersections. (Maximum score of 8)
    a. Intersection has four or more legs (weight of 1)
    b. Total approach AADT>10,000 veh/day (weight of 1)
    c. Minor approach speed limit is over 30 mph (weight of 1)
    d. Left turn lanes are present on the major approach (weight of 1)
    e. None of the legs are locally owned (weight of 1)
    f. Over 15% of the persons in the Block Group have incomes less than $25,000 (weight of 1)
    g. Bicycle commuters are present in the Block Group (weight of 1)
    h. Over 30% of persons in the Block Group have a commute of 15 minutes or less (weight of 1)
2. Left turn crashes on rural, minor stop-controlled intersections with at least one state-owned leg[50] – (KAB) 102 crashes over 3,494 intersections. (Maximum score of 9)
    a. Intersection has four or more legs (weight of 1)
    b. No seasonal buildings are present within a quarter mile of the intersection (weight of 1)
    c. Minor approach speed limit is over 30 mph (weight of 1)
    d. No locally owned legs are present (weight of 1)
    e. No privately owned legs are present (weight of 1)
    f. The area is identified as an Opportunity Zone (weight of 1)
    g. Over 15% of the persons in the Block Group have incomes less than $25,000 (weight of 1)
    h. Over 30% of persons in the Block Group have a commute of 15 minutes or less (weight of 1)
    i. Bicycle commuters are present in the Block Group (weight of 1)
3. Rear-end crashes at certain three-leg and four-leg unsignalized intersections[51] – (KAB) 371 crashes over 16,488 intersections. (Maximum score of 10)
    a. Area is urban (weight of 1)
    b. Lighting is present (weight of 1)
    c. Total approach AADT is over 6,000 vehicles per day (weight is 2)
    d. The area is an Opportunity Zone (weight of 1)

[48] This includes four-leg minor stop-controlled intersections, minor stop-controlled t-intersections, and minor stop-controlled y-intersections.
[49] KAB represents the KABCO injury severity scale, where K is a fatal crash, A is a suspected serious injury crash, and B is a suspected minor injury crash.
[50] This includes rural four-leg minor stop-controlled intersections, minor stop-controlled t-intersections, and minor stop-controlled y-intersections classified as "State vs State" and "State vs Nonstate".
[51] This includes four-leg minor stop-controlled intersections, uncontrolled t-intersections, minor stop-controlled t-intersections and y-intersections, and four-leg all-way stop-controlled intersections.

e. Percentage of the population in the Block Group that speak limited English is over 50% (weight of 1)

f. No seasonal buildings are present within a quarter mile of the intersection (weight of 1)

g. Major Approach speed limit is over 35 mph (weight of 1)

h. None of the legs are privately owned (weight of 1)

i. Total population of the Block Group is over 1500[52] (weight of 1)

4. Rear-end crashes at signalized intersections with at least one non-state leg[53] – (KAB) 178 crashes over 330 intersections. (Maximum score of 6)

    a. Intersection has four or more legs (weight of 1)

    b. Intersection skew angle is over 25 degrees (weight of 1)

    c. Total approach AADT is more than 15,000 vehicles per day (weight of 1)

    d. Percentage of the population in the Block Group that are minorities is over 50% (weight of 1)

    e. Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile (weight of 1)

    f. Major median is divided (weight of 1)

5. Angle/Broadside crashes at urban four-leg signalized intersections with no state legs – (KAB) 124 crashes over 137 intersections. (Maximum score of 9)

    a. Alcohol is sold within a quarter mile (weight of 2)

    b. Total approach AADT is over 13,000 vehicles per day (weight of 1)

    c. Percentage of the population in the Block Group that are minorities is over 50% (weight of 2)

    d. No industrial buildings present within a quarter mile of the intersection (weight of 2)

    e. No right turn lanes present on the major approach (weight of 2)

6. Angle/Broadside crashes at minor stop-controlled T-intersections with one or more nonstate legs– (KAB) 212 crashes over 7,716 intersections. (Maximum score of 9)

    a. Area is urban (weight of 1)

    b. Alcohol is sold within a quarter mile (weight of 1)

    c. Total approach AADT is over 8,000 vehicles per day (weight of 1)

    d. Minor approach speed limit is over 30 mph (weight of 2)

    e. No K-12 schools in a quarter mile (weight of 1)

    f. There are state-owned legs present (weight of 1)

    g. Over 15% of the persons in the Block Group have incomes less than $25,000 (weight of 1)

    h. Over 30% of persons in the Block Group have a commute of 15 minutes or less (weight of 1)

7. Angle/Broadside crashes at three-leg (t-intersections and y-intersections) and four-leg minor stop-controlled intersections– (KAB) 421 crashes over 9,435 intersections. (Maximum score of 9)

    a. Area is urban (weight of 1)

[52] Based on the number of individuals that reported their race in the census.

[53] This includes signalized four-leg intersections and signalized t-intersections.

b. Alcohol is sold within a quarter mile (weight of 1)

c. One-way legs are present (weight is 1)

d. Minor approach posted speed limit is over 30 mph (weight is 2)

e. State owned legs are present (weight of 1)

f. Total approach AADT is over 12,000 vehicles per day (weight of 1)

g. Over 15% of the persons in the Block Group have incomes less than $25,000 (weight 1)

h. Over 30% of persons in the Block Group have a commute of 15 minutes or less (weight of 1)

8. Head-on crashes at minor stop-controlled T-intersections with at least 1 nonstate leg– (KAB) 140 crashes over 7,716 intersections. (Maximum score of 9)

    a. Intersection skew angle is over 25 degrees (weight of 1)

    b. Total approach AADT is over 9,000 vehicles per day (weight of 1)

    c. Area is identified as an Opportunity Zone (weight of 1)

    d. No seasonal buildings within a quarter mile of the intersection (weight of 1)

    e. Minor approach speed limit is over 30 mph (weight of 1)

    f. Percentage ranking of persons with an income more than $200,000 is over 10% (weight of 1)

    g. Bicycle commuters are present in the Block Group (weight of 1)

    h. No privately-owned legs (weight of 1)

    i. Total population of the block group is over 1500[54] (weight of 1)

9. Single vehicle crashes at minor stop-controlled T-intersections with one or more nonstate legs – (KAB) 385 crashes over 7,716 intersections. (Maximum score of 8)

    a. Total approach AADT is more than 15,000 vehicles per day (weight of 1)

    b. Percentage of the population in the Block Group that are low income is above 50% (weight of 1)

    c. No primary civic buildings are within a quarter mile of the intersection (weight of 1)

    d. Minor approach speed limit is over 30 mph (weight of 1)

    e. No transit is present within a quarter mile of the intersection (weight of 1)

    f. Intersection skew angle is over 25 degrees (weight of 1)

    g. Major median is divided (weight of 1)

    h. No libraries are within a quarter mile of the intersection (weight of 1)

10. Single vehicle crashes involving a collision with a fixed object– (KAB) 482 crashes over 29,909 intersections. (Maximum score of 9)

    a. Intersection is roadway/roadway and not interchange related (weight of 1)

    b. No transit in a quarter mile of the intersection (weight of 1)

    c. Intersection skew angle over 25 degrees (weight of 1)

    d. Intersection is stop controlled (weight of 1)

---

[54] Based on the number of individuals that reported their race in the census.

e. Total approach AADT is more than 14,000 vehicles per day (weight of 1)

f. Percentage of the population in the Block Group that are low income is above 25% (weight of 1)

g. No secondary civic buildings within a quarter mile of the intersection (weight of 1)

h. No libraries within a quarter mile of the intersection (weight of 1)

i. Three or more legs are state-owned (weight of 1)

11. Pedestrian-vehicle crashes at intersections– (KAB) 266 crashes over 29,909 intersections. (Maximum score of 13)

   a. Intersection has four or more legs (weight of 1)

   b. Traffic control is not signalized, stop-controlled, or uncontrolled (weight of 1)

   c. Total approach AADT is more than 4,000 vehicles per day (weight of 2)

   d. Percentage of the population in the Block Group that are low income is above 50% (weight of 1)

   e. Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile (weight of 1)

   f. Major approach posted speed limit is under 35 (weight of 1)

   g. Left turn lanes are present in the major approach (weight of 1)

   h. Transit is present in a quarter mile of the intersection (weight of 2)

   i. Three or more legs are locally owned (weight of 1)

   j. Public transit commuters are present in the Block Group (weight of 1)

   k. Over 30% of persons in the Block Group have a commute of 15 minutes or less (weight of 1)

12. Pedestrian-vehicle crashes with a pedestrian in marked crosswalk– (KABCO[55]) 150 crashes over 29,909 intersections. (Maximum score of 13)

   a. Intersection has four of more legs (weight of 1)

   b. Total approach AADT is more than 11,000 vehicles per day (weight of 2)

   c. Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile (weight of 2)

   d. Over 30% of persons in the Block Group have a commute of 15 minutes or less (weight of 1)

   e. Intersection traffic control is signalized (weight of 1)

   f. Commercial buildings density within a quarter mile of the intersection is over 25 buildings per square mile (weight of 1)

   g. Transit is present within a quarter mile of the intersection (weight of 2)

   h. A library is present within a quarter mile of the intersection (weight of 1)

   i. None of the legs are state-owned (weight of 2)

13. Pedestrian-vehicle crashes with a pedestrian not in a marked crosswalk[56] – (KABCO) 211 crashes over 29,909 intersections. (Maximum score of 14)

---

[55] KABCO represents the KABCO injury severity scale, where K is a fatal crash, A is a suspected serious injury crash, B is a suspected minor injury crash, C is a possible injury crash, and O is a non-injury crash.

[56] location not coded "marked crosswalk at intersection" or "non-intersection crosswalk".

a. Intersection traffic control is signalized (weight of 1)
b. Lighting is present at the intersection (weight of 1)
c. Intersection has four or more legs (weight of 1)
d. Total road AADT is over 6,000 vehicles per day (weight of 2)
e. Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile (weight of 2)
f. Left turn lane is present on a major approach (weight of 1)
g. Over 30% of persons in the Block Group have a commute of 15 minutes or less (weight of 1)
h. Transit is present within a quarter mile of the intersection (weight of 2)
i. A library within a quarter mile of the intersection (weight of 1)
j. None of the legs are state-owned (weight of 2)

14. Bicycle-vehicle crashes at intersection[57]– (KAB) 170 crashes over 29,909 intersections. (Maximum score of 10)
    a. Intersection has four or more legs (weight of 1)
    b. Area type is urban (weight of 1)
    c. Total approach AADT is more than 11,000 vehicles per day (weight of 2)
    d. Percentage of the population in the Block Group that are limited English speakers is over 50% (weight of 1)
    e. Industrial building density within a quarter mile of the intersection exceeds 5 buildings per square mile (weight of 2)
    f. Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile (weight of 1)
    g. Transit is present within a quarter mile of the intersection (weight of 1)
    h. None of the legs are state-owned (weight of 1)
15. Pedestrian-vehicle crashes at intersections occurring at night– (KABC[58]) 112 crashes over 29,909 intersections. (Maximum score of 9)
    a. Intersection traffic control is signalized (weight of 1)
    b. Intersection has four or more legs (weight of 1)
    c. Total road AADT is over 9,000 vehicles per day (weight of 2)
    d. Primary civic building density within a quarter mile of the intersection exceeds 33 buildings per square mile (weight of 1)
    e. Percentage of the population in the Block Group that are low income is above 50% (weight of 1)
    f. Transit is present within a quarter mile of the intersection (weight of 1)
    g. A K-12 school is present within a quarter mile of the intersection (weight of 1)

[57] Given the small sample size, VHB elected not to identify a focus facility type.
[58]KABC represents the KABCO injury severity scale, where K is a fatal crash, A is a suspected serious injury crash, B is a suspected minor injury crash, and C is a possible injury crash.

h. Commercial building density within a quarter mile of the intersection is higher than 50 buildings per square mile (weight of 1)