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 roadway departure 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 roadway departure crashes. This assignment also included the preparation of a quantifiable plan with prioritized strategies and locations for reducing roadway departure 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 June 9, 2022.

Background

For this effort, VHB worked with VTrans to collect relevant datasets to identify focus facility types for roadway departure crashes, for all roadway departure crashes and for subsets of roadway departure crashes (for example fixed object crashes). An additional objective of this task was to obtain datasets that can be integrated for risk factor analysis, including traffic volume and roadway inventory data elements. VTrans provided data on geometric and operational features from MIRE data elements, cross-sectional characteristics, alignment characteristics, and operational characteristics.

To support this task, VHB worked with VTrans to identify specific roadway departure crash type definitions. These definitions were based on available data elements that are consistent with the FHWA definition for roadway departure crashes, inclusive of all vehicles leaving the travel lane.

VHB has also been tasked with defining subsets roadway departure crashes such as the following:

- Fatal and injury roadway departure crashes.
- Head-on crashes.
- Run-off-road crashes.
- Fixed object crashes.
- Rollover crashes.

VTrans supplied data elements for all roadways; however, data availability differs by roadway class. VHB worked with VTrans to identify State and local roadway definitions. VHB integrated all data elements available but anticipates analyses will differ for State and local roads by general data availability.

Data Acquisition

For this task, VHB acquired data from VTrans in the form of crash, roadway characteristics, traffic volume, and asset data. VHB compiled attributes from the data obtained from VTrans into an integrated crash database and an integrated roadway segment database. The crash database will support identification of focus facility types while the roadway segment database will support development of risk factors for focus crash types.

Crash Data

VHB obtained crash tables for this analysis for the years 2016 to 2020. This data included crash locations, crash severity, and attributes for defining roadway departure crashes.

Spatial Data

VHB obtained spatial (GIS) data containing area type, roadway attributes, traffic volume, and assets. The following attributes from the spatial data were identified and used:

- Area Type;
    - Urban Area Boundary to define urban/rural areas;
- Roadway Attributes;
    - Cross Sectional;
    - Functional Class and Facility Type;
    - Speed Limit;
    - AADT (for both limited access and non-limited access highways);
    - Curves (horizonal and vertical);
    - Intersections (Nodes and Legs);
    - Line Striping;
    - Tenth of a mile pavement condition;
    - Limited access highways;
        - Long and short structures;
- Asset Data;
    - Guardrails, rumble strips, signs.

Data Processing

For this task, VHB used the data provided by VTrans to generate, classify, or calculate attributes needed for analysis. VHB worked with VTrans to define and reach a common understanding of these attribute classifications. Included in these attributes are definitions for state vs local roads, roadway departure crashes, and subsets of roadway departure crashes such as fatal and serious injury vs. fatal and all injury and head-on vs run-off road left vs run-off road right. These data definitions can be found in the “Data Definitions” section below.

The crash data provided by VTrans were in the form of excel tables and CSV files. To enable spatial analysis, VHB mapped these crashes in GIS and created a point feature class (spatial GIS layer) representing all crashes. This feature class was then used 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 roadway segment database. The attributes were then compiled from their respective sources onto a single spatial LRS/roadway network GIS layer. This was done by spatially overlaying the various input linear roadway data and segmenting the network wherever roadway attributes change (i.e., segmenting when speed limit changes from 45 to 35 mph, or when number of through lanes changes from 3 to 2, etc.). The network was then dissolved to create homogenous segments, with a maximum segment length of 2 miles to avoid having segments of excessive length.

Once the segments were generated, the compiled segment attributes were then transferred over to the crash points to enable future crash tree analysis.

*Note: Specific attributes of asset data such as rumble strips and guardrails will not be used, rather the presence of these assets will be flagged in the segment data in a binary fashion ("1" and "0" or "Yes" and "No").

Attributes Compiled in the Integrated Crash Data

Once VTrans provided VHB with the crash data, the following attributes were integrated in the crash data.

- Road departure flag.
- State vs. local road.
- Crash severity.
- Speed limit.
- Functional class and facility type.
- Vertical curve K value.
- Horizontal curve radius.
- Urban/Rural.
- AADT (both limited access and non-limited access).
- Cross-Sectional
    - Number of through lanes, median type, shoulder type, shoulder width, average lane width).

Attributes Compiled in the Integrated Roadway Segment Data:

Once VTrans provided VHB with the roadway data, the following attributes were integrated in the roadway segment data. Two roadway segment datasets are included – curves and tangents:

- Cross sectional.
    - Number of through lanes, median type/presence, median width, shoulder type, shoulder width, divided/undivided, total lanes.
- Speed limit.
- Functional class and facility type.
- AADT (for both limited access and non-limited access highways) and year.
- Access control (full vs partial).
- Horizontal curve radius, class, type, and angle.
- Vertical curve type, K value, and length.

- Pavement condition category, comp index, IRI, RUT, STRC, TRAN
- Urban/rural.
- Asset data indicating presence of rumble strips, guardrails, signs, intersections, long + short structures

Data Definitions

State vs Local roads:

- State vs Local roads were defined using the AOT Roadway Group field (AOTROADWAYGROUPid) in the crash data. The values from this field that define a state vs local road are listed below.
    - State
        - 7 – Ramp or spur
        - 10 – State Highway numbered route, State owned
    - Local
        - 1 – State System (State Highways and Class I TH links); The crash records having this category were all Class I town highways
        - 2 – Federal Aid Urban System (Class 2 TH's and 3 TH's only)
        - 3 – Federal Aid Secondary System (Class 2 TH)
        - 4 – Minor Collector (Non Fed Aid Rural TH)
        - 5 – Street or Town Highways in FA Urban Area
        - 6 – City, Village, or Urban Compact Street not in FA Urban Area (Class 2 and 3 Non-Federal Aid)
        - 8 – Private Property (Driveways)
        - 9 – Other Public Roadway (Rest Areas, Shopping Center – anything open to the public)
        - 11 – State Highway numbered route, Class 1 TH
    - Crash by crash basis:
        - 0 – Unknown
        - 7 – Ramp or spur (a select few were not state maintained)
        - 12 – State Highway numbered route, unknown ownership

Roadway departure crashes:

- Roadway departure crashes were defined using the Direction of Collision field (DirOfCollision), Vehicle 1 Collided With fields (Veh1CollidedWith_1 and Veh1CollidedWith_2), and Sequence of Events fields (SequenceOfEvent1, SequenceOfEvent2, SequenceOfEvent3, and SequenceOfEvent4) from the crash data. The values from these fields that define roadway departure crashes are listed below.
    - From the Direction of Collision field
        - Head On
    - From the Vehicle 1 Collided With fields
        - 12 – Overturned

        - 13 – Non-collision
        - 14 – Guardrail, curb
        - 15 – Tree
        - 16 – Pole, sign
        - 17 – Ledge, boulder
        - 18 – Fixed object not listed
    - From the Sequence of Events fields
        - 1 – Ran off road
        - 3 – Overturn (rollover)
        - 10 – Collision involving parked motor vehicle
        - 14 – Collision involving fixed object
        - 16 – Non-collision: Cross median/centerline
        - 23 – Cross centerline
        - 24 – Cross median

Head On crashes:

- These are a subset of roadway departure crashes. The values from these fields that define head on crashes are listed below.
    - From the Direction of Collision field
        - Head On

Overturn or Rollover crashes:

- These are a subset of roadway departure crashes. The values from these fields that define overturn crashes are listed below.
    - From the Vehicle 1 Collided With fields
        - 12 – Overturned
    - From the Sequence of Events fields
        - 3 – Overturn (rollover)

Fixed Object crashes:

- These are a subset of roadway departure crashes. The values from these fields that define fixed object crashes are listed below.
    - From the Vehicle 1 Collided With fields
        - 14 – Guardrail, curb
        - 15 – Tree
        - 16 – Pole, sign
        - 17 – Ledge, boulder

        - 18 – Fixed object not listed
    - From the Sequence of Events fields
        - 14 – Collision involving fixed object

Run Off Road crashes:

- These are a subset of roadway departure crashes. These include all roadway departure crashes minus head on collisions.

Horizontal curves and tangents:

- Horizontal curves and tangents were determined using the DIRECTION field in the MIRE curve dataset, where values "right" or "left" indicated a curve, and value "straight" indicated a tangent.

Summary Statistics

The following provides an overview of the crash sample sizes by type and severity (2016 to 2020 total):

- Number of crashes: 59,145.
- Number of roadway departure crashes: 20,188.
- Number of head on crashes: 2,127.
- Number of fixed object crashes: 11,702.
- Number of overturn/rollover crashes: 2,960.
- Number of run off road crashes: 19,251.
- Number of K severity crashes: 286.
- Number of A severity crashes: 1,091.
- Number of K severity roadway departure crashes: 235.
- Number of A severity roadway departure crashes: 782.
- Urban crashes: 24,672.
- Rural crashes: 26,723.
- State road crashes: 27,421.
- Local road crashes: 31,670.
- Number of roadway departure crashes on horizontal curve: 7,454.
- Number of roadway departure crashes within 150 feet of horizontal curve: 12,697.

The following provides an overview of the integrated roadway segment curves:

- Total number of segments: 327,927 segments
- Mean segment length: 32.4 meters
- Minimum segment length: 0.00305 meters
- Maximum segment length: 714.4 meters
- Median segment length: 25.9 meters
- Mean number of through lanes: 1.97 lanes
- Mode through lanes: 2 lanes
- Mean average lane width: 11.3 feet
- Mode average lane width: 11 feet
- Number of segments with median present: 1,815 segments
- Mode speed limit: 50 MPH

The following provides an overview of the integrated roadway segment tangents:

- Total number of segments: 129,895 segments
- Mean segment length: 95.6 meters
- Minimum segment length: 0.0032 meters[1]
- Maximum segment length: 3,218.7 meters
- Median segment length: 53.4 meters
- Mean number of through lanes: 2.0 lanes
- Mode through lanes: 2 lanes
- Mean average lane width: 11.3 feet
- Mode average lane width: 11 feet
- Number of segments with median present: 1,580 segments
- Mode speed limit: 50 MPH

[1] VHB found that short segments appeared in two cases-
(1) Two curves are so close together that the tangent is essentially null (but ArcGIS picks up a <1 inch segment) or
(2) When a roadway characteristic (like speed limit, number of lanes, median type, etc.) changes at the end of a curve or tangent, but does not precisely overlap, so there are two breaks (one for the curve/tangent and one for the roadway characteristic) less than an inch apart.
Since this does not represent an issue with the underlying segmentation algorithm, VHB elected to let these segments stand, but to ignore them in the risk model (i.e., by set a minimum length of ~0.05 miles).

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 August 1, 2022.

Background

In the previous memorandum, VHB described working with VTrans to identify focus crash types. VHB acquired crash, roadway characteristics, traffic volume, and asset data from VTrans and integrated them in a crash database and a roadway segment database. The roadway segment database supported the identification of risk factors for focus crash types. Using GIS, VHB joined the roadway segment 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:

- All roadway departures.
- Head-on crashes.
- Fixed object crashes.
- Overturn or rollover crashes.
- Run-off-road crashes.

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 Selection Tool*[2]*,* the data are typically split by urban and rural, ownership (state or local), segment and 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 the focus facility types, VHB created crash trees for each focus crash type. VHB preferred to use fatal and suspected serious injury (KA) crashes only, but suspected minor injury (B) crashes were added for crash trees that had too few KA crashes (i.e., fewer than 100 crashes).

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 urban vs rural, state ownership, curve vs tangent, presence at an intersection, fixed object struck (if any) and lighting -primarily in that order. There are some minor differences between the crash trees, like the nighttime run-off road crash trees splitting by lighting first, and the head-on crash tree dividing by curve vs tangent before the rest of the elements. VHB identified facility types that accounted for a plurality of crashes in their branch and had more than roughly 100 crashes (deemed the minimum value to allow for accurate modeling) as focus facility types. Based on the crash trees, VHB recommends the following analyses for VTrans, along with the number of crashes observed and roadway mileage covered:

1. Head-on crashes on rural local road curves – (KAB) 100 crashes over 4,989 miles.

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

2. Overturn crashes on rural local road curves – (KAB) 195 crashes over 4,989 miles.
3. Run-off road crashes on rural local road curves – (KA) 151 crashes over 4,989 miles.
4. Fixed object crashes on rural local road curves – (KA) 120 crashes over 4,989 miles.
5. Night-time run-off road crashes on rural local road curves – (KAB) 280 crashes over 4989 miles.
6. Head-on crashes on rural state curves of minor arterials and major collectors – (KAB) 113 crashes over 717miles.
7. Overturn crashes on rural state curves of minor arterials, major collectors, and principal arterials - other – (KAB) 189 crashes over 831 miles.
8. Run-off road crashes on rural state curves of minor arterials and major collectors – (KA) 161 crashes over 717 miles.
9. Fixed object crashes on rural state curves of minor arterials and major collectors – (KA) 105 crashes over 717 miles.
10. Night-time run-off road crashes on rural state curves of minor arterials and major collectors – (KAB) 202 crashes over 717 miles.
11. Overturn crashes on Interstates – (KA) 54 crashes over 716 miles.
12. Head on crashes on rural state tangents of minor arterials, major collectors, and principal arterials – other – (KAB) 137 crashes over 1,234 miles.
13. Overturn crashes on rural state tangents of minor arterials, major collectors, and principal arterials – other – (KAB) 211 crashes over 1,234 miles.
14. Run-off road crashes on rural state tangents of minor arterials and major collectors. – (KA) 116 crashes over 1,020 miles.

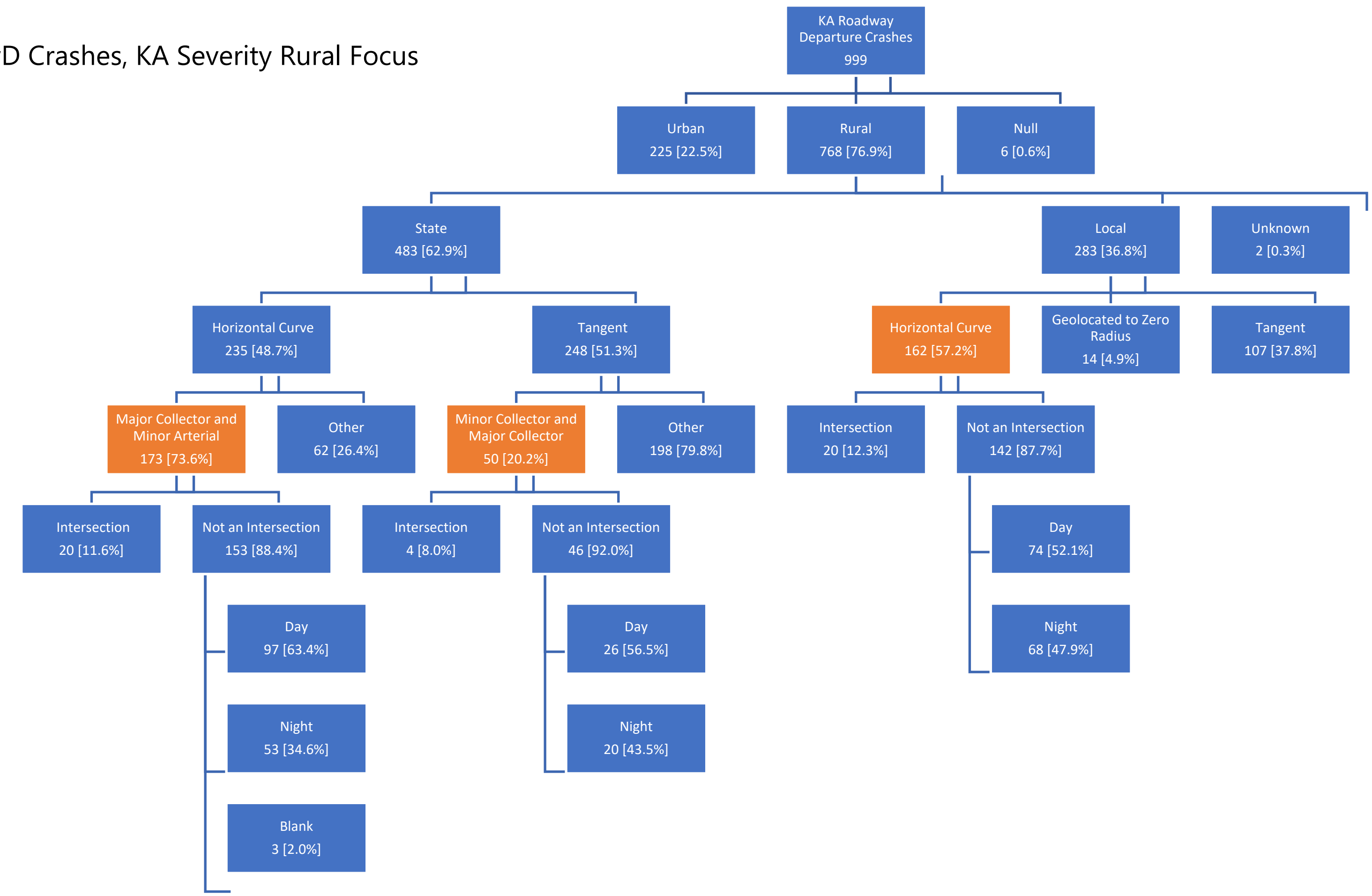
Note, the crash trees were included as an attachment to this memorandum in a PowerPoint file. They are reproduced here at the end of this memo.

Next Steps

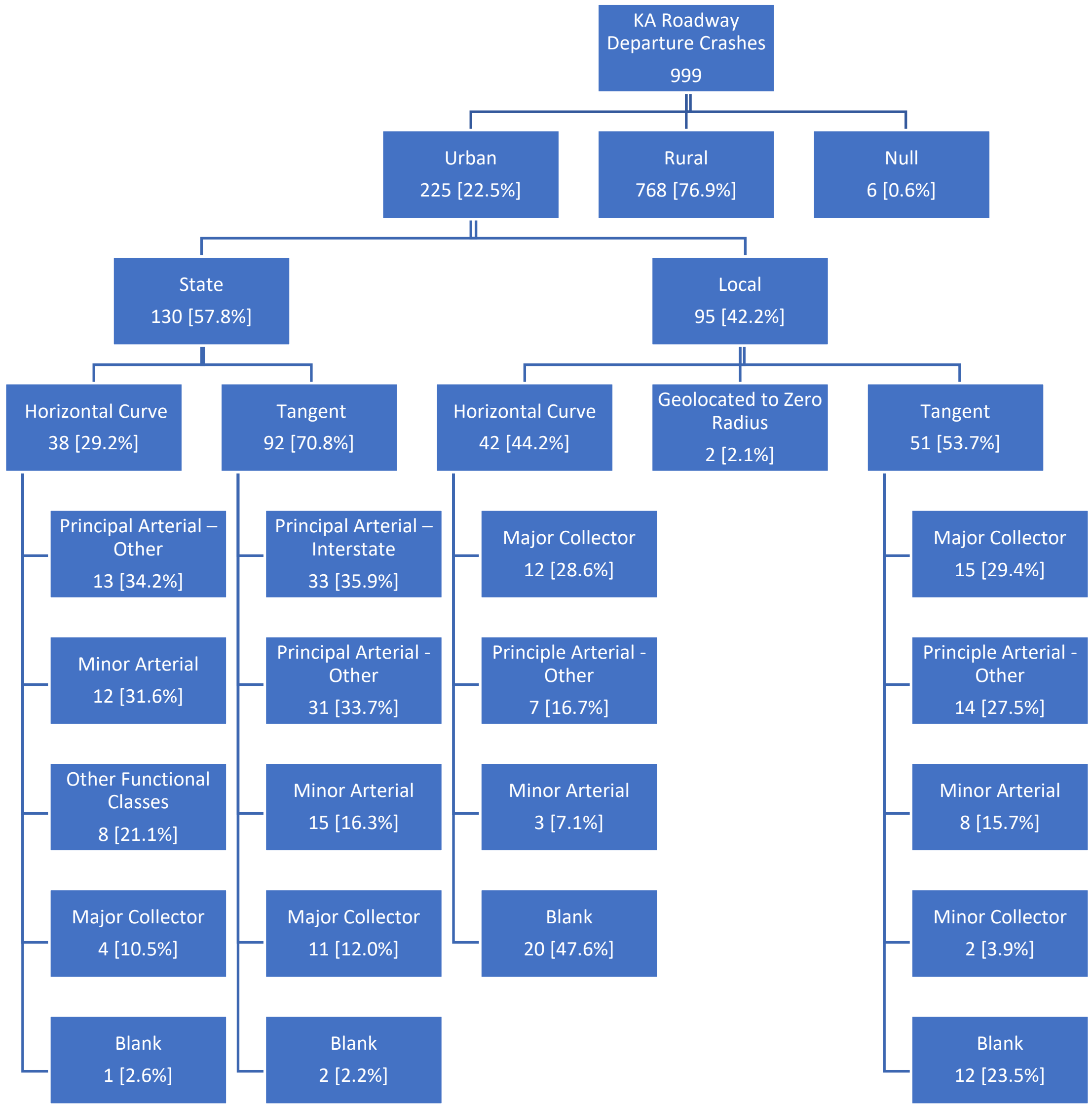
VTrans approved VHB proceeding with the recommended analyses. VHB will finalize the integrated modeling dataset and begin developing crash prediction or probability models to select risk factors. VHB will provide VTrans with summary results and recommended risk factors in a draft memorandum. After receiving feedback from VTrans, VHB will submit a final memorandum.

Roadway Departure Crash Trees

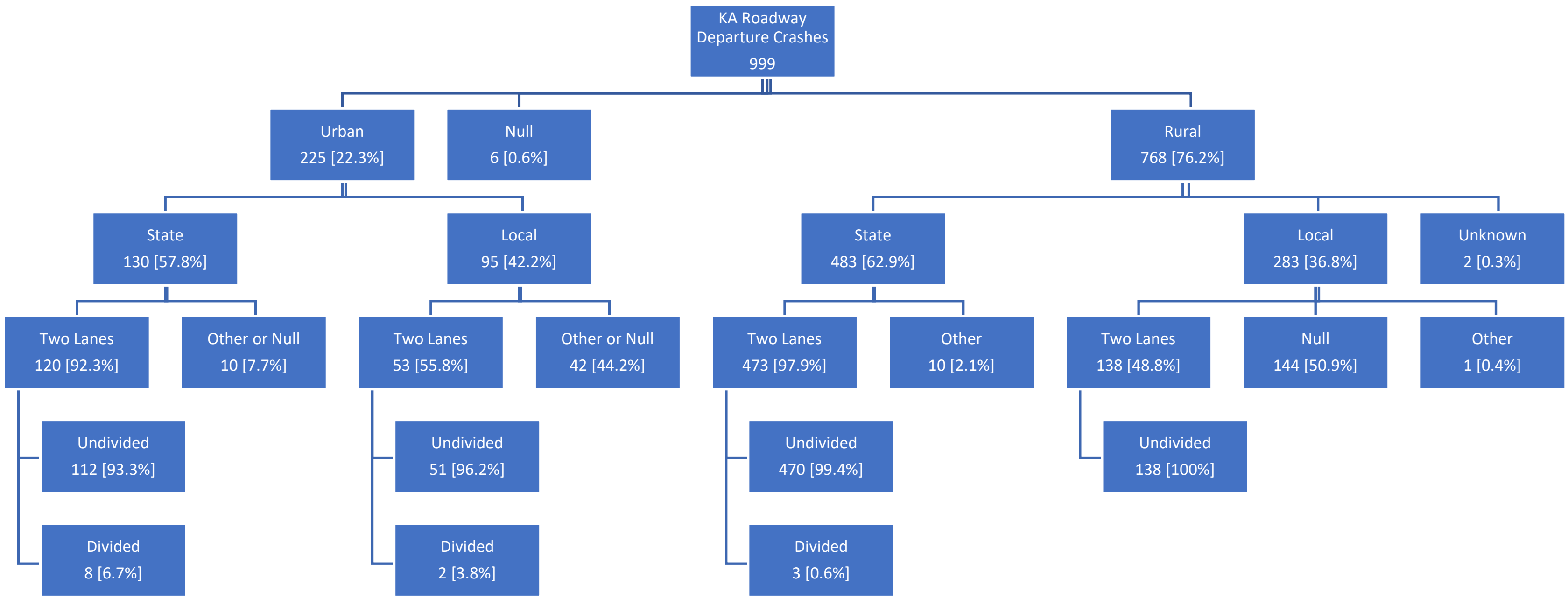
All RwD Crashes, KA Severity Rural Focus



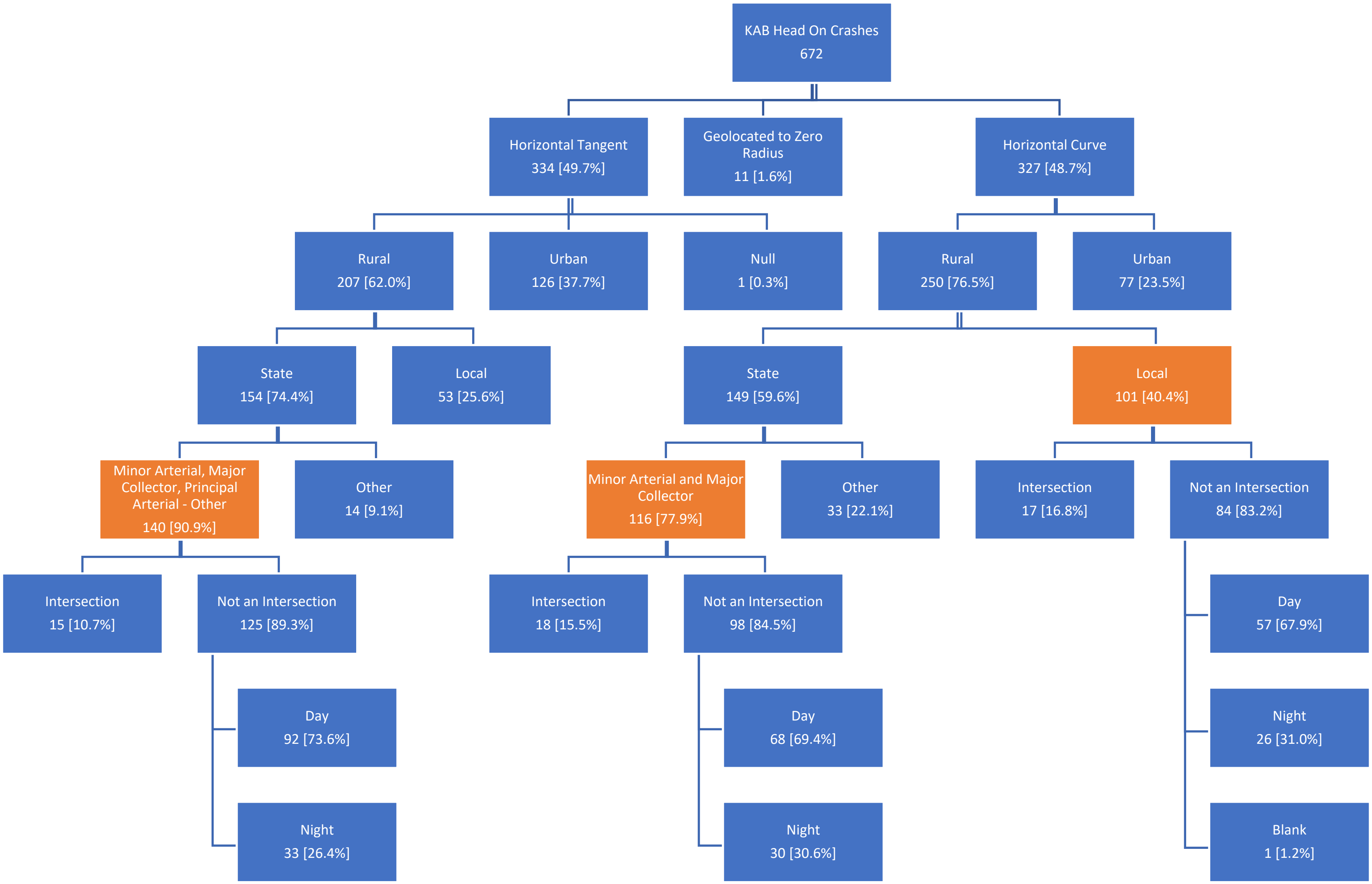
All RwD Crashes, KA Severity Urban Focus



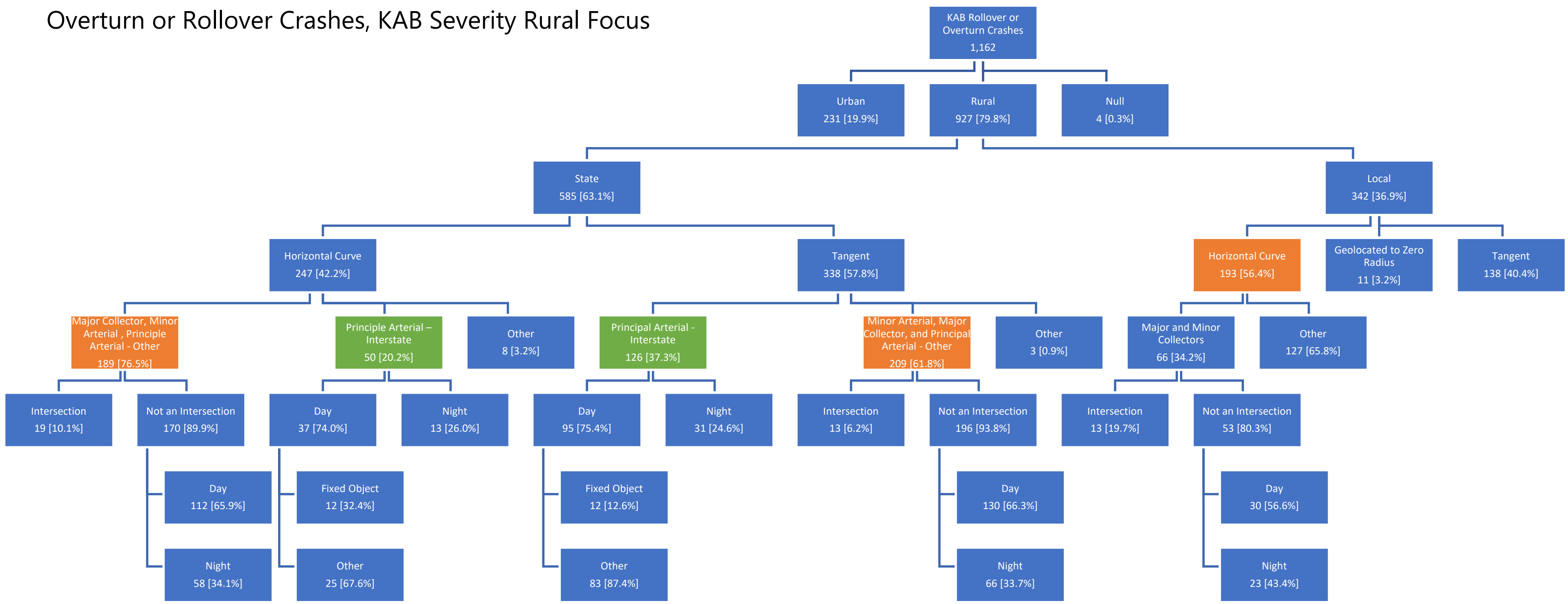
All RwD Crashes, KA Severity



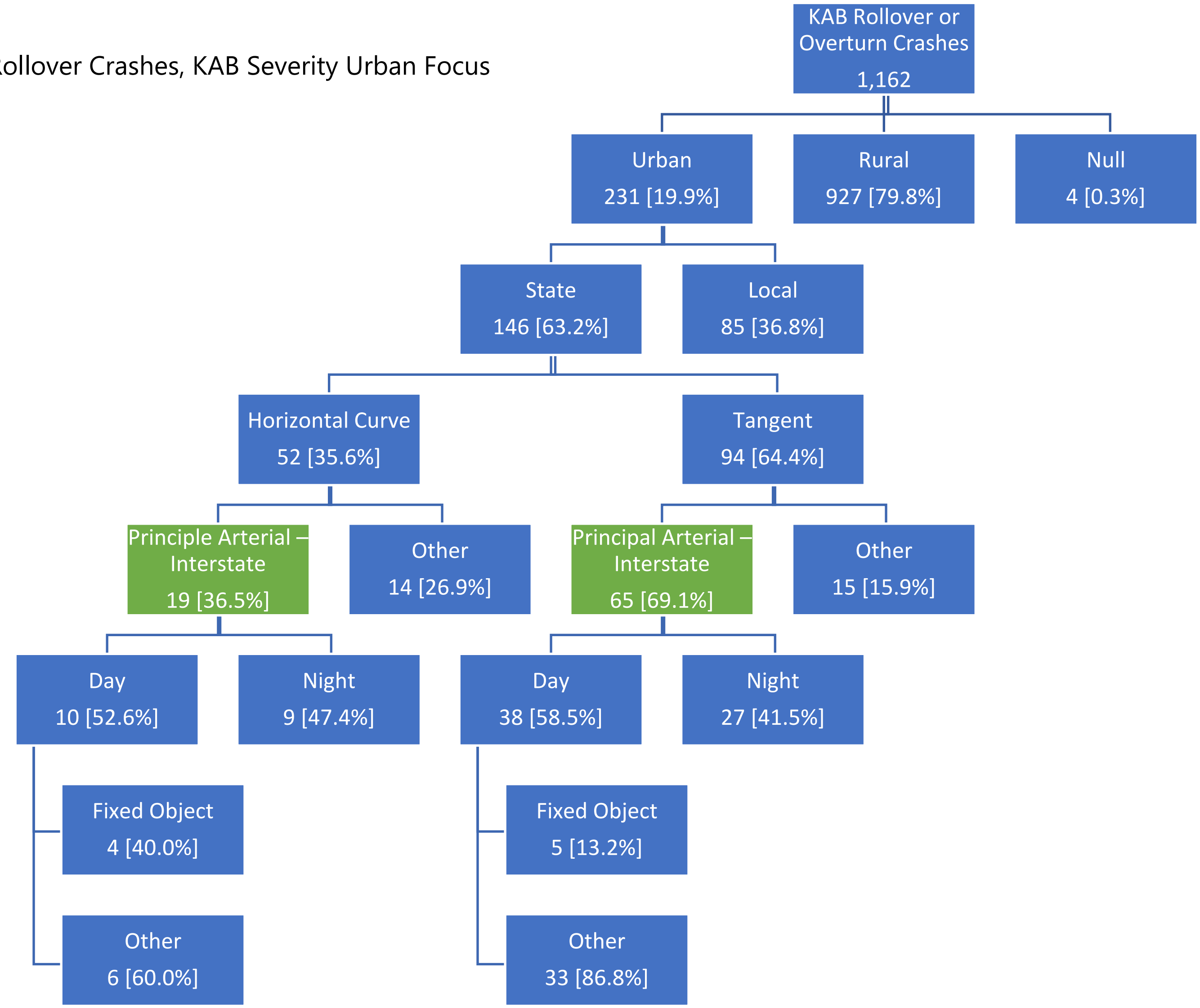
Head On Crashes, KAB Severity



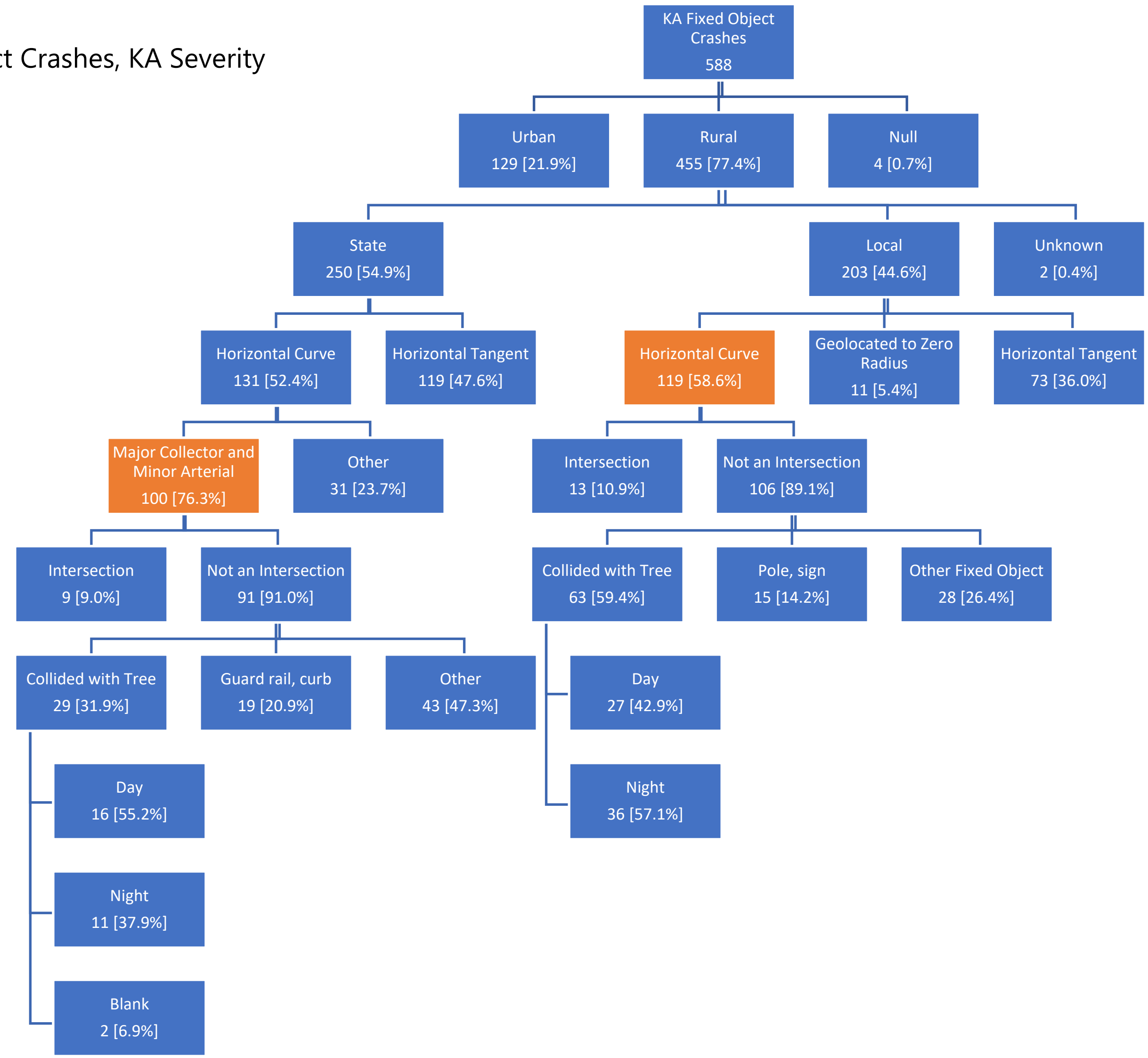
Overturn or Rollover Crashes, KAB Severity Rural Focus



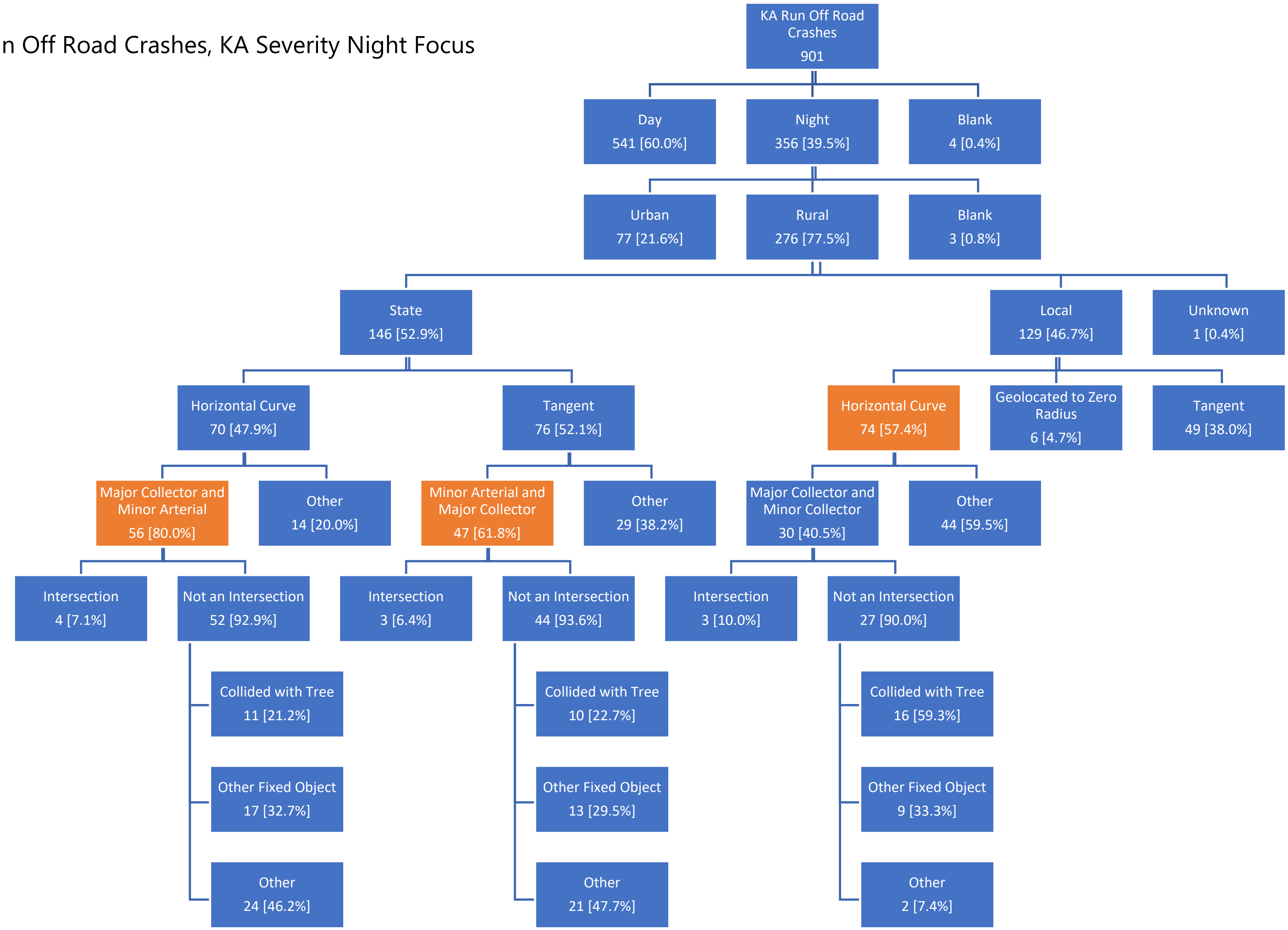
Overturn or Rollover Crashes, KAB Severity Urban Focus



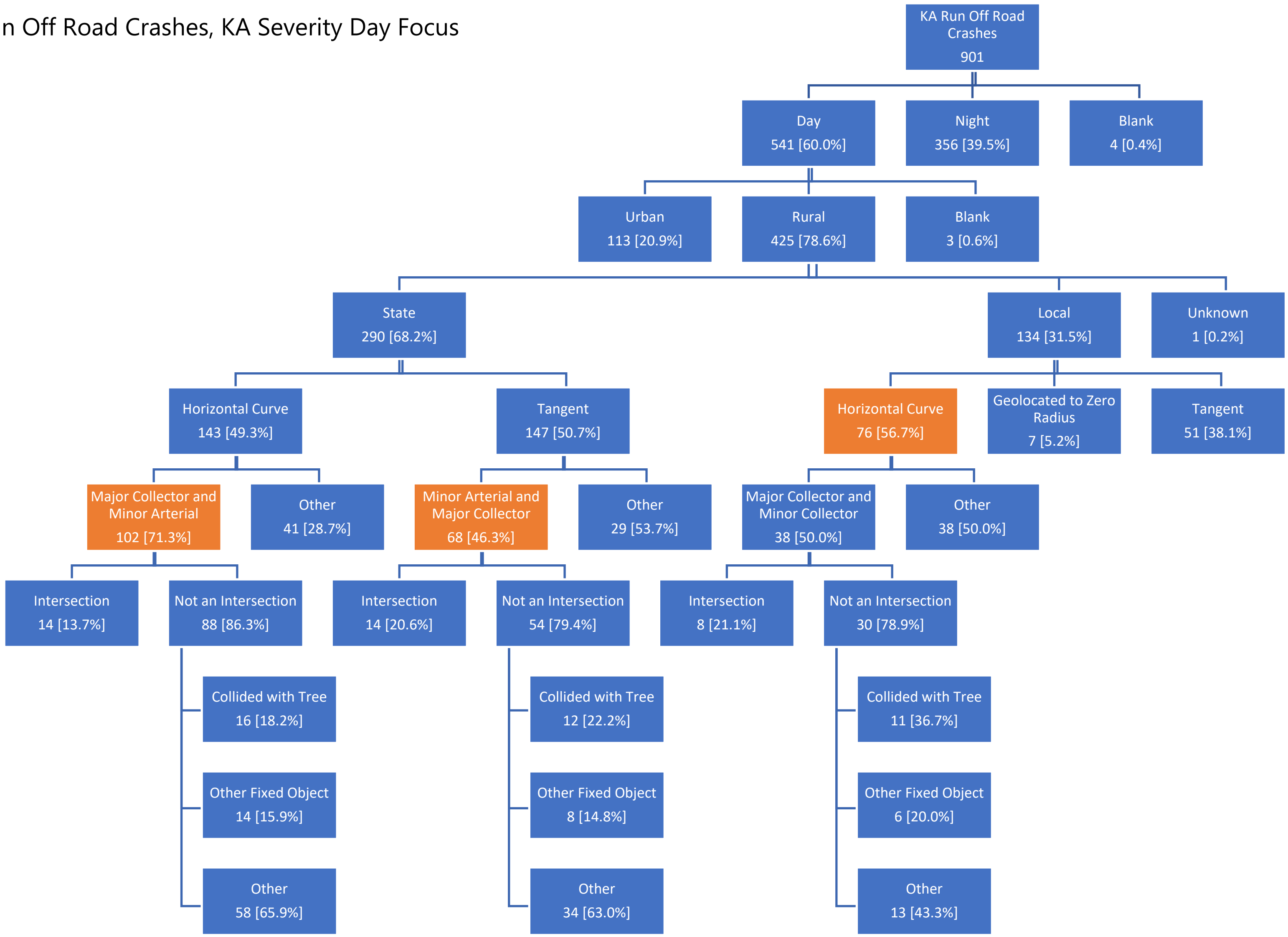
Fixed Object Crashes, KA Severity



Run Off Road Crashes, KA Severity Night Focus



Run Off Road Crashes, KA Severity Day Focus



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 February 15, 2023.

Background

In the previous memorandum, VHB described efforts to identify focus crash types and focus facility types. VHB acquired crash, roadway, traffic volume, and asset data from VTrans and integrated the crash database and roadway segment databases. From these data, VHB identified focus crash types and created crash trees. From the crash trees, VHB and VTrans selected focus facility types for each focus crash type. VHB recommended 14 risk factor analyses, which were approved by VTrans. The 14 analyses include the following crash and facility type combinations (crash severity, crash sample size, and mileage are shown):

1. Head-on crashes on rural local road curves – (KAB[1]) 100 crashes over 4,989 miles.
2. Overturn crashes on rural local road curves – (KAB) 195 crashes over 4,989 miles.
3. Run-off road crashes on rural local road curves – (KA[2]) 151 crashes over 4,989 miles.
4. Fixed object crashes on rural local road curves – (KA) 120 crashes over 4,989 miles.
5. Night-time run-off road crashes on rural local road curves – (KAB) 280 crashes over 4,989 miles.
6. Head-on crashes on rural state curves of minor arterials and major collectors – (KAB) 113 crashes over 717 miles.
7. Overturn crashes on rural state curves of minor arterials, major collectors, and principal arterials - other – (KAB) 189 crashes over 831 miles.
8. Run-off road crashes on rural state curves of minor arterials and major collectors – (KA) 161 crashes over 717 miles.

[1] 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.
[2] KA represents the KABCO injury severity scale, where K is a fatal crash and A is a suspected serious injury crash.

9. Fixed object crashes on rural state curves of minor arterials and major collectors – (KA) 105 crashes over 717 miles.
10. Night-time run-off road crashes on rural state curves of minor arterials and major collectors – (KAB) 202 crashes over 717 miles.
11. Overturn crashes on Interstates – (KA) 54 crashes over 716 miles.
12. Head on crashes on rural state tangents of minor arterials, major collectors, and principal arterials – other – (KAB) 137 crashes over 1,234 miles.
13. Overturn crashes on rural state tangents of minor arterials, major collectors, and principal arterials – other – (KAB) 211 crashes over 1,234 miles.
14. Run-off road crashes on rural state tangents of minor arterials and major collectors. – (KA) 116 crashes over 1,020 miles.

The following sections describe the risk factor identification process used by VHB. For each model, VHB describes the correlations, recommended risk factors, and suggested risk factor weight. Risk factor weight is applied in the next step of the systemic process – prioritizing sites for improvement. The standard recommended weight is 1 – meaning for each risk factor present, a site receives an additional point. In some cases, VHB recommends weights different than 1.0 based on the model results.

Note there are several instances where the analysis produced counterintuitive risk factors, such as presumably safer conditions correlated with severe crash probability. VHB considers these “surrogate” risk factors, as they are typically capturing the effect of data which are unavailable. For instance, it is commonly accepted that intersections with high left-turn volume are at an increased risk for severe angle crashes. To address left-turns from a safety and operational perspective, agencies typically install left-turn lanes. When performing a network analysis of those crashes, left-turn volume is rarely available for each intersection, but left-turn lane presence is. As such, left-turn lane presence enters the model as a surrogate for high-volume left-turn movements, producing the counterintuitive safety result that left-turn lanes are correlated with increased severe angle crash risk. VHB typically includes these as risk factors with the caveat that they function as surrogates.

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 a tangent or curve) 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 14 recommended analyses. The binary logit models predict the probability of a focus crash type occurring on a roadway segment 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 roadway departure 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 0.400 were generally considered insignificant and removed.

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. For example, having a degree of curvature between 6 and 8 degrees uses a binary threshold (yes or no) versus including degree of curvature as a continuous variable. In some cases, VHB included continuous variables, including the natural log of the degree of curvature and the natural log of segment length. Note that segment length was included in each model to normalize for the length of the segment; however, it is not included as a recommended risk factor. For these analyses, VHB included factors related to AADT, degree of curvature, intersections, curve geometry, vertical geometry, and roadside features Through experimentation and optimization, VHB came to the resulting 14 crash models, from which we can recommend risk factors. Each of the 14 binary logit model outputs are described below.

Head-On Crashes, Rural Local Curves

Table 1 describes the model output for KAB Head-On crashes on rural local curves. VHB found several features to be positively correlated with head-on crashes, including segment length, undivided or an unprotected narrow median, an isolated horizontal curve, natural log of degree of curvature between 2 and 4 degrees, and the presence of an intersection in the segment. Note that AADT was not available for rural local curve segments. Given the elevated odds ratios for no or narrow median and the presence of an intersection, those features should have a higher weight. The final column of the table shows the recommended weights for each of the risk factors.

Table 1. Prediction Model for Head-On Crashes on Rural Local Curves

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
No median or unprotected area less than 4 feet wide	4.697	1.095	6.64	0.000	2.974	7.417	2
Independent Horizontal Curve	1.385	0.352	1.28	0.200	0.842	2.281	1
Natural Log of Degree of Curvature between 2 and 4	1.745	0.435	2.23	0.026	1.071	2.845	1
Presence of an intersection in the segment	3.229	0.812	4.66	0.000	1.973	5.286	2
Natural log of the length of the segments in miles	2.228	0.421	4.24	0.000	1.538	3.227	N/A
Constant	0.003	0.002	-7.80	0.000	0.001	0.012	N/A

Note: Number of observations = 179,796; Log likelihood = -636.05791; Pseudo R2 = 0.0673; LR chi2(5) = 91.74;

Prob > chi2 = 0.0000. N/A = not applicable

Overturn Crashes, Rural Local Curves

Table 2 describes the model output for KAB Overturn crashes on rural local curves. VHB found several features to be positively correlated with overturn crashes, including segment length, the presence of shoulders wider than 1 foot, a functional class of minor or major collector, the presence of an intersection in the segment, the curve is not independent, and horizontal curvature between 2.7 and 55 degrees. The final column of the table shows the recommended weights for each of the risk factors. Curve is not independent and average shoulder width should have a risk score of 1, while functional class and presence of an intersection should have a weight of two. Finally, degree of curvature can be distributed by thresholds – the top 10 percent of curves by degree of curvature receive 3 risk factor points, those in the next 40 percent receive a score of 2, and the remaining 50 percent receive a score of 1.

Table 2. Prediction Model for Overturn Crashes on Rural Local Curves

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Natural log of the length of the segment in miles	2.695	0.350	7.63	0.000	2.089	3.478	N/A
Average Shoulder width over 1 foot	1.806	0.525	2.03	0.042	1.021	3.193	1
Road is a Minor or Major Collector	2.399	0.432	4.86	0.000	1.686	3.413	2
Presence of an intersection in the segment	3.031	0.529	6.35	0.000	2.153	4.269	2
Curve is not independent	1.198	0.202	1.07	0.282	0.861	1.667	1
Natural log of degree of curvature between 1 and 4	1.410	0.325	1.49	0.137	0.897	2.217	Top 10% = 3 50-90% = 2 <50% = 1
Constant	0.017	0.009	-7.64	0.000	0.006	0.048	N/A

Note: Number of observations = 179,796; Log likelihood = -1290.1729; Pseudo R2 = 0.0567; LR chi2(6) = 155.01; Prob > chi2 = 0.0000. N/A = not applicable

Run-Off Road Crashes, Rural Local Curves

Table 3 describes the model output for KA Run-Off Road crashes on rural local curves. VHB found that segment length, an undivided or narrow unprotected median, the presence of a reverse or compound horizontal curve, the presence of an intersection, and the natural log of degree of curvature are positively correlated with crash probability. The final column of the table shows the recommended weights for each of the risk factors. Based on odds ratios, presence of a reverse or compound horizontal curve should have a risk score of 1, degree of curvature should be scored using thresholds as described previously, and undivided or unprotected narrow median and intersection presence should have a score of 2.

Table 3. Prediction Model for Run-off Road Crashes on Rural Local Curves

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
No median or unprotected area less than 4 feet wide	4.978	0.884	9.04	0.000	3.514	7.050	2
Presence of reverse and compound horizontal curve transitions	1.540	0.570	1.17	0.243	0.746	3.182	1
Natural log of the length of the segment in miles	2.313	0.331	5.87	0.000	1.748	3.061	N/A
Presence of an intersection in the segment	2.951	0.578	5.53	0.000	2.011	4.331	2
Natural log of degree of curvature between 2 and 4	1.466	0.259	2.16	0.031	1.036	2.073	Top 10% = 3 50-90% = 2 <50% = 1
Constant	0.007	0.004	-9.16	0.000	0.002	0.020	N/A

Note: Number of observations = 179,796; Log likelihood = -1028.7406; Pseudo R2 = 0.0700; LR chi2(5) = 154.88; Prob > chi2 = 0.0000. N/A = not applicable

Fixed Object Crashes, Rural Local Curves

Table 4 describes the model output for KA Fixed-Object crashes on rural local curves. VHB found that undivided or unprotected narrow medians, the presence of reverse or compound horizontal curvature, segment length, presence of an intersection in the segment, and degree of curvature are positively correlated with severe fixed object crashes. The final column of the table shows the recommended weights for each of the risk factors. Based on odds ratios, the presence of a reverse or compound horizontal curve should have a risk score of 1, degree of curvature should be scored using thresholds as described previously, and undivided or unprotected narrow median and intersection presence should have a score of 2.

Table 4. Prediction Model for Fixed Object Crashes on Rural Local Curves

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
No median or unprotected area less than 4 feet wide	5.283	1.048	8.39	0.000	3.582	7.792	2
Presence of reverse and compound horizontal curve transitions	1.723	0.685	1.37	0.171	0.790	3.754	1
Natural log of the length of the segment in miles	1.941	0.315	4.08	0.000	1.412	2.669	N/A
Presence of an intersection in the segment	3.260	0.697	5.52	0.000	2.143	4.958	2
Natural log of degree of curvature between 2 and 4	1.429	0.283	1.80	0.072	0.969	2.108	Top 10% = 3 50-90% = 2 <50% = 1
Constant	0.003	0.002	-9.40	0.000	0.001	0.010	N/A

Note: Number of observations = 179,796; Log likelihood = -847.922; Pseudo R2 = 0.0672; LR chi2(5) = 122.26; Prob > chi2 = 0.0000. N/A = not applicable

Nighttime Run-Off Road Crashes, Rural Local Curves

Table 5 describes the model output for KAB Nighttime Run-Off Road crashes on rural local curves. VHB found that undivided or narrow unprotected medians, shoulders wider than 1 foot, compound horizontal curve presence, segment length, intersection presence, and degree of curvature are all positively correlated with nighttime run-off road crashes. The final column of the table shows the recommended weights for each of the risk factors. Based on odds ratios, shoulder width and compound curves should receive a risk score of 1 and the remaining features a risk score of 2, with the exception of degree of curvature, which should be scored using thresholds as described previously.

Table 5. Prediction Model for Nighttime Run-off Crashes on Rural Local Curves

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
No median or unprotected area less than 4 feet wide	3.359	0.485	8.39	0.000	2.531	4.459	2
Average shoulder width over 1 foot	1.714	0.392	2.36	0.018	1.095	2.694	1
Presence of compound horizontal curves	1.221	0.168	1.46	0.145	0.933	1.598	1
Natural log of the length of the segment in miles	2.638	0.281	912	0.000	2.141	3.249	N/A
Presence of an intersection in the segment	2.098	0.328	4.73	0.000	1.543	2.851	2
Natural log of degree of curvature between 3 and 5	2.035	0.371	3.90	0.000	1.424	2.907	Top 10% = 3 50-90% = 2 <50% = 1
Constant	0.026	0.010	-9.41	0.000	0.012	0.056	N/A

Note: Number of observations = 179,796; Log likelihood = -1783.5522; Pseudo R2 = 0.0585; LR chi2(6) = 221.61; Prob > chi2 = 0.0000. N/A = not applicable

Head-On Crashes, Rural State Curves

Table 6 describes the model output for KAB Head-On crashes on the rural state curves of minor arterials and major collectors. VHB found several roadway features correlated with the probability of these crashes, including functional class of minor arterial, segment length, traffic volume exceeding 4,000 vpd, degree of curvature, the presence of an intersection, the presence of type A warning signs, and reverse and compound curves. On the other hand, guardrail, shoulders wider than 4 feet, and vertical grades (as opposed to vertical curves) are correlated with decreased probability. The final column of the table shows the recommended weights for each of the risk factors. Recommended risk scoring includes scores of 1 for shoulders narrower than 4 feet, the absence of guardrail, the presence of vertical curves, AADT exceeding 4,000 vpd, the presence of an intersection, and the presence of Type A warning signs. Minor arterial and reverse and compound curvature should receive a risk score of 2. Finally, degree of curvature can be scored using the previously described thresholds.

Table 6. Prediction Model for Head-On Crashes on Rural State Curves of Minor Arterials and Major Collectors

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Total Shoulder width over 4 feet	0.604	0.142	-2.15	0.032	0.381	0.957	1 (shoulder<4 ft)
Minor Arterial instead of Major Collector	2.045	0.468	3.12	0.002	1.306	3.204	2
Natural log of the length of the segment in miles	2.374	0.420	4.89	0.000	1.679	3.357	N/A
AADT over 4000 vpd	1.990	0.537	2.55	0.011	1.173	3.377	1
Natural log of degree of curvature between 2 and 4	1.641	0.406	2.00	0.046	1.010	2.666	Top 10% = 3 50-90% = 2 <50% = 1
Presence of an intersection	1.823	0.485	2.26	0.024	1.082	3.072	1
Presence of Type A warning signs	1.410	0.317	1.53	0.126	0.907	2.192	1
Presence of Guardrail	0.791	0.176	-1.05	0.293	0.511	1.224	1 (if guardrail is not present)
Presence of line up or down vertical curves	0.594	0.178	-1.73	0.083	0.330	1.076	1 (if vertical curve is present)
Presence of reverse and compound horizontal curve transitions	3.909	2.068	2.58	0.010	1.386	11.026	2
Constant	0.067	0.046	-3.94	0.000	0.017	0.258	N/A

Note: Number of observations = 24,722; Log likelihood = -576.67025; Pseudo R2 = 0.0578; LR chi2(10) = 70.72; Prob > chi2 = 0.0000. N/A = not applicable

Overturn Crashes, Rural State Curves

Table 7 describes the model output for KAB Overturn crashes on the rural state curves of minor arterials, major collectors, and principal arterials - other. VHB found that several features are positively correlated with overturn crash likelihood, including segment length, degree of curvature, traffic volume exceeding 5,000 vpd, two through lanes (as opposed to more), crest vertical curves, type A warning sign presence, intersection presence, short structure presence, and a posted speed limit exceeding 45 MPH. On the other hand, shoulders wider than 3 feet, major collectors, and guardrail presence were found to be negatively correlated with crash likelihood. The final column of the table shows the recommended weights for each of the risk factors. Using odds ratios, shoulders narrower than 3 feet, minor arterials and principal arterials, traffic volume over 5,000 vpd, crest vertical curves, absence of guardrails, type A warning signs, presence of intersections, and short structures should have a risk score of 1. Two through lanes should have a risk score of 2. Finally, degree of curvature can be scored using the previously described thresholds.

Table 7. Prediction Model for Overturn Crashes on Rural State Curves of Minor Arterials, Major Collectors, and Principal Arterial - Other

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Total shoulder width over 3 feet	0.600	0.164	-1.87	0.061	0.352	1.025	1 (shoulder<3 ft)
Functional Class is Major Collector	0.729	0.130	-1.77	0.077	0.514	1.034	1 (minor and principal arterials)
Natural log of the length of the segment in miles	2.291	0.300	6.33	0.000	1.772	2.961	N/A
Natural log of degree of curvature between 2 and 5	1.729	0.343	2.76	0.006	1.173	2.550	Top 10% = 3 50-90% = 2 <50% = 1
AADT over 5000 vpd	1.902	0.405	3.02	0.003	1.254	2.887	1
Two through lanes	5.415	5.451	1.68	0.093	0.753	38.951	2
Presence of a crest vertical curve	1.266	0.202	1.47	0.141	0.925	1.732	1
Any guardrail is present	0.785	0.134	-1.42	0.155	0.562	1.096	1 (if guardrail not present)
Presence of Type A warning signs	1.258	0.220	1.31	0.191	0.892	1.773	1
Presence of Intersections	1.434	0.318	1.63	0.103	0.929	2.214	1
Presence of short structures	2.187	0.831	2.06	0.039	1.039	4.605	1
Posted speed limit over 45 mph	1.898	0.403	3.02	0.003	1.252	2.877	1
Constant	0.018	0.021	-3.45	0.001	0.002	0.175	N/A

Note: Number of observations = 28,272; Log likelihood = -956.17867; Pseudo R2 = 0.0466; LR chi2(12) = 93.52; Prob > chi2 = 0.0000. N/A = not applicable

Run-Off Road Crashes, Rural State Curves

Table 8 describes the model output for KA Run-Off Road crashes on rural state curves of minor arterials and major collectors. VHB found many features correlated with increased run-off road crash probability, including shoulders wider than 3 feet, minor arterials, traffic volume exceeding 3,000 vehicles per day, the presence of compound horizontal curves, type A warning signs, crest vertical curves, and intersections, a posted speed limit higher than 35 MPH, degree of curvature, and segment length. Additionally, long structures were found to be correlated with decreased crash frequency, presumably due to the presence of bridge barrier. The final column of the table shows the recommended weights for each of the risk factors. All features should receive a risk score of 1, except for a score of (-1) for the presence of a long structure and a threshold scoring for degree of curvature.

Table 8. Prediction Model for Run-off Road Crashes on Rural State Curves of Minor Arterials and Major Collectors

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Total shoulder width over 3 feet	1.916	0.808	1.54	0.123	0.838	4.381	1
Functional Class is Minor Arterial	1.398	0.257	1.82	0.069	0.975	2.005	1
AADT over 3000 vpd	1.496	0.297	2.03	0.043	1.014	2.207	1
Presence of compound horizontal curves	1.493	0.284	2.11	0.035	1.028	2.167	1
Presence of Type A Warning signs	1.233	0.231	1.12	0.264	0.854	1.782	1
Posted speed limit over 35 mph	1.436	0.452	1.15	0.250	0.775	2.660	1
Presence of crest vertical curves	1.258	0.216	1.34	0.181	0.899	1.762	1
Presence of intersections	1.376	0.330	1.33	0.183	0.860	2.202	1
Natural Log of degree of curvature between 2 and 5	2.018	0.413	3.43	0.001	1.351	3.014	Top 10% = 3 50-90% = 2 <50% = 1
Presence of long structures	0.365	0.367	-1.00	0.317	0.051	2.626	-1
Natural Log of segment length	2.178	0.316	5.36	0.000	1.639	2.896	N/A
Constant	0.019	0.014	-5.18	0.000	0.004	0.084	N/A

Note: Number of observations = 24,722; Log likelihood = -824.79188; Pseudo R2 = 0.0453;
LR chi2(11) = 78.29; Prob > chi2 = 0.0000. N/A = not applicable

Fixed-Object Crashes, Rural State Curves

Table 9 describes the model output for KA Fixed-Object crashes on the rural state curves of minor arterials and major collectors. VHB found several features positively correlated with fixed object crash probability, including two lanes, shoulders narrower than 5 feet, speed limit exceeding 45 MPH, traffic volume exceeding 2,980 vpd, the curve not being independent, presence of an intersection in the curve, degree of curvature, and segment length. The final column of the table shows the recommended weights for each of the risk factors. All features should receive a risk factor of 1, except for two lanes and AADT exceeding 2,980 vpd, which should be scored 2, and degree of curvature, which should be scored using a threshold approach.

Table 9. Prediction Model for Fixed Object Crashes on Rural State Curves of Minor Arterials and Major Collectors

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
The segment is two lanes	2.828	1.720	1.71	0.087	0.859	9.313	2
Average shoulder width less than 5 feet wide	1.853	0.812	1.41	0.159	0.785	4.372	1
Speed Limit over 45 MPH	1.282	0.317	1.00	0.315	0.790	2.092	1
Natural Log of AADT exceeds 8 (AADT exceeds 2,980 veh/day)	2.059	0.458	3.24	0.001	1.331	3.186	2
The curve is not independent	1.701	0.392	2.31	0.021	1.083	2.672	1
An intersection is present within the curve	1.452	0.409	1.32	0.186	0.835	2.522	1
Natural log of degree of curvature from 2 to 5 degrees	1.925	0.487	2.59	0.010	1.172	3.162	Top 10% = 3 50-90% = 2 <50% = 1
Natural log of length in miles	2.054	0.363	4.07	<0.001	1.453	2.905	N/A
Constant	0.002	0.003	-4.75	<0.001	0.0002	0.028	N/A

Note: Number of observations = 24,722; Log likelihood = -583.33451; Pseudo R2 = 0.0505; LR chi2(9) = 61.78; Prob > chi2 = 0.0000. N/A = not applicable

Nighttime Run-Off Road Crashes, Rural State Curves

Table 10 describes the model output for KAB Nighttime Run-Off Road crashes on the rural state curves of minor arterials and major collectors. VHB found several factors correlated with nighttime run-off road crashes, including shoulders narrower than 5 feet, minor arterials, non-independent horizontal curves, traffic volume exceeding 3,000 vpd, the absence of guardrail, the presence of an intersection or short structure, degree of curvature, and segment length. The final column of the table shows the recommended weights for each of the risk factors. All features should receive a risk score of 1, with the exception of degree of curvature, which should be scored using thresholds.

Table 10. Prediction Model for Night-time Run-off Road Crashes on Rural State Curves of Minor Arterials and Major Collectors

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Total Shoulder Width Less than 5 Feet	1.538	0.263	2.52	0.012	1.100	2.150	1
Functional Class is Minor Arterial	2.067	0.353	4.25	<0.001	1.478	2.889	1
Horizontal curve not independent	1.284	0.240	1.34	0.180	0.891	1.852	1
AADT over 3000 vpd	1.619	0.285	2.73	0.006	1.146	2.287	1
No Guardrail Present	1.233	0.206	1.26	0.209	0.889	1.711	1
Presence of intersections	1.446	0.299	1.79	0.074	0.965	2.167	1
Presence of short structures	2.191	0.791	2.17	0.030	1.080	4.446	1
Natural Log of degree of curvature	1.560	0.208	3.33	0.001	1.201	2.026	Top 10% = 3 50-90% = 2 <50% = 1
Natural Log of length of segment	2.251	0.289	6.31	<0.001	1.749	2.896	N/A
Constant	0.029	0.015	-6.73	<0.001	0.010	0.081	N/A

Note: Number of observations = 24,722; Log likelihood = -966.0392; Pseudo R2 = 0.0538; LR chi2(11) = 109.77; Prob > chi2 = 0.0000. N/A = not applicable

Overturn Crashes, Interstates

Table 11 describes the model output for KA Overturn crashes on Interstates. Unfortunately, VHB was not able to find many factors in the data correlated with overturn crashes. Risk factors include traffic volume exceeding 15,000 vpd, the absence of guardrail, and the presence of Type A warning signs. The final column of the table shows the recommended weights for each of the risk factors. The AADT and guardrail features should receive a risk score of 1, while the Type A warning sign should receive a risk score of 2.

Table 11. Prediction Model for Overturn Crashes on Interstates

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
AADT over 15000 vpd	1.931	0.580	2.19	0.029	1.071	3.480	1
Presence of guardrail	0.639	0.234	-1.22	0.222	0.312	1.312	1 (if guardrail is not present)
Presence of Type A Warning signs	2.427	1.057	2.04	0.042	1.034	5.699	2
Natural Log of length of segment	2.297	0.298	6.41	0.000	1.781	2.961	N/A
Constant	0.035	0.021	-5.49	0.000	0.010	0.115	N/A

Note: Number of observations = 5,774; Log likelihood = -237.90055; Pseudo R2 = 0.1852; LR chi2(4) = 108.14; Prob > chi2 = 0.0000. N/A = not applicable

Head-On Crashes, Rural State Tangents

Table 12 describes the model output for KAB Head-On crashes on rural state tangents of minor arterials, major collectors, and principal arterials – other. Risk factors identified by VHB include traffic volume exceeding 3,000 vpd, minor arterial functional class, the absence of shoulder rumble strips, the presence of guardrail, narrow lane and shoulder width, traffic volume, and segment length. The final column of the table shows the recommended weights for each of the risk factors. All risk factors should receive a score of 1, except for AADT exceeding 3,000 vpd and absence of shoulder rumble strips, which receive a score of 2. Segment length should be excluded from the risk scoring. Finally, natural log of AADT will be scored continuously based on percentile ranking, ranging from 0 at the lowest value to 1 at the highest value, as shown in Figure 1.

Table 12. Prediction Model for Head-On Crashes on Rural State Tangents of Minor Arterials, Major Collectors, and Principal Arterials – Other

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
AADT over 3000 vpd	2.246	0.819	2.25	0.025	1.108	4.552	2
Functional Class is Minor Arterial	1.376	0.266	1.65	0.098	0.943	2.010	1
Absence of Outside Rumble Strips	3.627	2.704	1.73	0.084	0.841	15.634	2
Presence of Guardrail	1.511	0.296	2.11	0.035	1.029	2.217	1
Sum of Average Lane and Shoulder Width is Less than 15 feet	1.178	0.249	0.77	0.440	0.778	1.783	1
Natural Log of traffic volume	1.898	0.444	2.74	0.006	1.201	3.001	0 to 1, continuous (normalized to min. and max. values)
Natural Log of length of segment	2.150	0.264	6.23	<0.001	1.690	2.734	N/A
Constant	0.00004	0.00008	-5.07	<0.001	8.17e-07	0.002	N/A

Note: Number of observations = 22,792; Log likelihood = -736.7461; Pseudo R2 = 0.0746; LR chi2(7) = 118.76; Prob > chi2 = 0.0000. N/A = not applicable

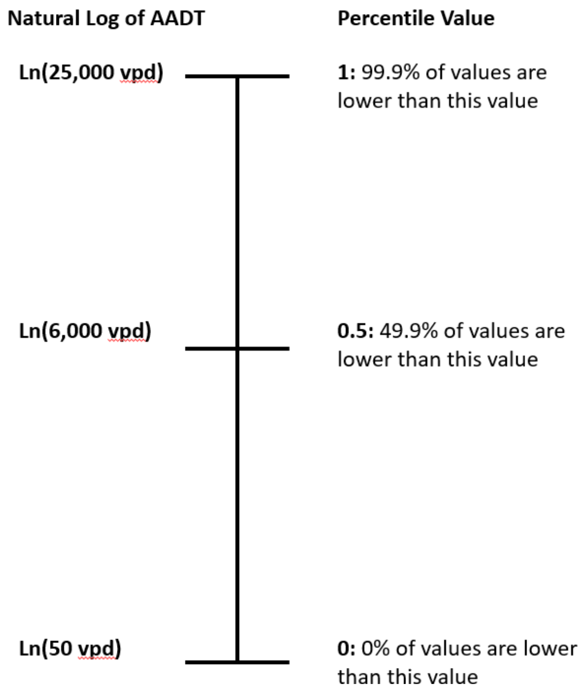


Figure 1. Continuous percentile scoring approach.

Overturn Crashes, Rural State Tangents

Table 13 describes the model output for KAB Overturn crashes on rural state tangents of minor arterials, major collectors, and principal arterials – other. VHB identified several risk factors, including the presence of intersections, daily traffic volume exceeding 2,000 vpd, posted speed limit exceeding 35 MPH, the presence of centerline rumble strips, shoulders 5 feet or narrower, segment length, and traffic volume. The final column of the table shows the recommended weights for each of the risk factors. All risk factors should receive a score of 1, except for natural log of AADT, which is scored using the continuous approach described in Figure 1.

Table 13. Prediction Model for Overturn Crashes on Rural State Tangents of Minor Arterials, Major Collectors, and Principal Arterials – Other

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Presence of intersections	1.459	0.250	2.20	0.028	1.043	2.041	1
AADT over 2000 vpd	2.008	0.592	2.36	0.018	1.127	3.578	1
Posted speed limit over 35 mph	2.074	0.764	1.98	0.047	1.008	4.270	1
Presence of rumble strips along the centerline	1.453	0.323	1.68	0.093	0.940	2.246	1

Average Shoulder Width 5 Feet or Less	1.649	0.362	2.28	0.023	1.073	2.535	1
Natural Log of length of segment	2.475	0.244	9.18	<0.001	2.039	3.002	N/A
Natural Log of AADT	1.279	0.219	1.44	0.151	0.914	1.788	0-1, continuous
Constant	0.035	0.005	-4.08	<0.001	0.0002	0.053	N/A

Note: Number of observations = 19,283; Log likelihood = -946.944; Pseudo R2 = 0.0763; LR chi2(7) = 156.40; Prob > chi2 = 0.0000. N/A = not applicable

Run-Off Road Crashes, Rural State Tangents

Table 14 describes the model output for KA Run-Off Road crashes on rural state tangents of minor arterials, major collectors, and principal arterials – other. VHB identified several features that are positively correlated with run-off road crashes, including a posted speed limit over 45 MPH, minor arterial functional class, shoulders wider than 5 feet, the presence of an intersection in the segment, traffic volume exceeding 9,000 vpd, segment length, and daily traffic volume. The final column of the table shows the recommended weights for each of the risk factors. For risk scoring, all features should be assigned a score of 1, except for natural log of AADT, which is scored using the continuous approach described in Figure 1.

Table 14. Prediction Model for Run-off Road Crashes on Rural State Tangents of Minor Arterials, Major Collectors, and Principal Arterials – Other

Variable	Odds Ratio	Standard Error	z-value	P>|z|	95% Confidence Interval		Recommended Weight
Speed Limit over 45 MPH	1.774	0.454	2.24	0.025	1.074	2.930	1
Functional Class is Minor Arterial	1.490	0.276	2.16	0.031	1.037	2.141	1
Average Shoulder Width is over 5 Feet	1.368	0.306	1.40	0.161	0.883	2.121	1
Intersection is Present in Segment	1.284	0.261	1.23	0.218	0.863	1.912	1
AADT under 9,000 veh/day	1.735	0.705	1.36	0.175	0.782	3.848	1
Natural Log of length of segment	2.369	0.268	7.63	<0.001	1.898	2.957	N/A
Natural log of AADT	1.845	0.275	4.10	<0.001	1.377	2.472	0 to 1, continuous
Constant	0.0002	0.0002	-5.86	<0.001	0.00001	0.003	N/A

Note: Number of observations = 19,283; Log likelihood = -730.210; Pseudo R2 = 0.0808; LR chi2(11) = 128.44; Prob > chi2 = 0.0000. N/A = not applicable

Next Steps

After VTrans reviews and confirms the revised final risk factors, VHB will prepare updated risk maps showing the high priority sites on the network.

Memorandum #4-Risk Maps

The purpose of this memo is to present the risk maps created according to the revised risk factors in our 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 March 14, 2023.

Background

In the Risk Factors memorandum, VHB described creating 14 crash models, one for each focus crash and facility type combination. VHB acquired crash, roadway characteristics, traffic volume, and asset data from VTrans and created integrated crash and roadway segment databases. From these data, VHB identified focus crash types and created crash trees to select focus facility types. VHB recommended 14 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, mileage, and risk factor weight are shown):

1. Head-on crashes on rural local road curves – (KAB[1]) 100 crashes over 4,989 miles. (Maximum score of 6)
    a. No median or unprotected area less than 4 feet wide (weight of 2)
    b. Independent Horizontal Curve (weight of 1)
    c. Natural Log of Degree of Curvature between 2 and 4 (weight of 1)
    d. Presence of an intersection in the segment (weight of 2)
2. Overturn crashes on rural local road curves – (KAB) 195 crashes over 4,989 miles. (Maximum score of 9)
    a. Average Shoulder width over 1 foot (weight of 1)
    b. Road is a Minor or Major Collector (weight of 2)

[1] 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.

c. Presence of an intersection in the segment (weight of 2)
d. Curve is not independent (weight of 1)
e. Natural log of degree of curvature between 1 and 4 (top 10 percent weight of 3, next 40 percent weight of 2, remaining 50 percent weight of 1)

3. Run-off road crashes on rural local road curves – (KA[2]) 151 crashes over 4,989 miles. (Maximum score of 8)
    a. No median or unprotected area less than 4 feet wide (weight of 2)
    b. Presence of reverse and compound horizontal curve transitions (weights of 1)
    c. Presence of an intersection in the segment (weight of 2)
    d. Natural log of degree of curvature between 2 and 4 (top 10% weight of 3, next 40% weight of 2, remaining 50% weight of 1)
4. Fixed object crashes on rural local road curves – (KA) 120 crashes over 4,989 miles. (Maximum score of 8)
    a. No median or unprotected area less than 4 feet wide (weight of 2)
    b. Presence of reverse and compound horizontal curve transitions (weight of 1)
    c. Presence of an intersection in the segment (weight of 2)
    d. Natural log of degree of curvature between 2 and 4 (top 10% weight of 3, next 40% weight of 2, remaining 50% weight of 1)
5. Night-time run-off road crashes on rural local road curves – (KAB) 280 crashes over 4,989 miles. (Maximum score of 9)
    a. No median or unprotected area less than 4 feet wide (weight of 2)
    b. Average shoulder width over 1 foot (weight of 1)
    c. Presence of compound horizontal curves (weight of 1)
    d. Presence of an intersection in the segment (weight of 2)
    e. Natural log of degree of curvature between 3 and 5 (top 10 percent weight of 3, next 40 percent weight of 2, remaining 50 percent weight of 1)
6. Head-on crashes on rural state curves of minor arterials and major collectors – (KAB) 113 crashes over 717 miles. (Maximum score of 13)
    a. Total shoulder width over 4 feet (weight of 1)
    b. Minor arterial instead of major collector (weight of 2)
    c. AADT over 4000 vpd (weight of 1)

[2] KA represents the KABCO injury severity scale, where K is a fatal crash and A is a suspected serious injury crash.

   d. Natural log of degree of curvature between 2 and 4 (top 10 percent weight of 3, next 40 percent weight of 2, remaining 50 percent weight of 1)
   e. Presence of an intersection (weight of 1)
   f. Presence of Type A warning signs (weight of 1)
   g. Presence of guardrail (weight of 1, if guardrail is not present)
   h. Presence of line up or down vertical curves (weight of 1, if vertical curve is present)
   i. Presence of reverse and compound horizontal curve transitions (weight of 2)

7. Overturn crashes on rural state curves of minor arterials, major collectors, and principal arterials - other – (KAB) 189 crashes over 831 miles. (Maximum score of 14)
   a. Total shoulder width over 3 feet (weight of 1)
   b. Functional class is a major collector (weight of 1)
   c. Natural log of degree of curvature between 2 and 5 (top 10 percent weight of 3, next 40 percent weight of 2, remaining 50 percent weight of 1)
   d. AADT over 5000 vpd (weight of 1)
   e. Two through lanes (weight of 2)
   f. Presence of a crest vertical curve (weight of 1)
   g. Any guardrail is present (weight of 1, if guardrail is not present)
   h. Presence of Type A warning sign (weight of 1)
   i. Presence of intersections (weight of 1)
   j. Presence of short structures (weight of 1)
   k. Posted speed limit over 45 mph (weight of 1)

8. Run-off road crashes on rural state curves of minor arterials and major collectors – (KA) 161 crashes over 717 miles. (Maximum score of 11)
   a. Total shoulder width over 3 feet (weight of 1)
   b. Functional class is minor arterial (weight of 1)
   c. AADT over 3000 vpd (weight of 1)
   d. Presence of compound horizontal curves (weight of 1)
   e. Presence of Type A warning signs (weight of 1)
   f. Posted speed limit over 35 mph (weight of 1)
   g. Presence of crest vertical curves (weight of 1)
   h. Presence of intersections (weight of 1)

i. Natural log of degree of curvature between 2 and 5 (top 10 percent weight of 3, next 40 percent weight of 2, remaining 50 percent weight of 1)
j. Presence of long structures (weight of -1)

9. Fixed object crashes on rural state curves of minor arterials and major collectors – (KA) 105 crashes over 717 miles. (Maximum score of 11)
   a. The segment is two lanes (weight of 2)
   b. Average shoulder width less than 5 feet wide (weight of 1)
   c. Speed limit over 45 mph (weight of 1)
   d. Natural log of AADT exceeds 8 (AADT exceeds 2980 vpd) (weight of 2)
   e. The curve is not independent (weight of 1)
   f. An intersection is present within the curve (weight of 1)
   g. Natural log of degree from 2 to 5 degrees (top 10 percent weight of 3, next 40 percent weight of 2, remaining 50 percent weight of 1)
10. Night-time run-off road crashes on rural state curves of minor arterials and major collectors – (KAB) 202 crashes over 717 miles. (Maximum score of 10)
   a. Total shoulder width less than 5 feet (weight of 1)
   b. Functional class is a minor arterial (weight of 1)
   c. Horizontal curve is not independent (weight of 1)
   d. AADT over 3000 vpd (weight of 1)
   e. No guardrail present (weight of 1)
   f. Presence of intersections (weight of 1)
   g. Presence of short structures (weight of 1)
   h. Natural log of degree of curvature (top 10 percent weight of 3, next 40 percent weight of 2, remaining 50 percent weight of 1)
11. Overturn crashes on Interstates – (KA) 54 crashes over 716 miles. (Maximum score of 4)
   a. AADT over 15,000 vpd (weight of 1)
   b. Lack of guardrail (weight of 1)
   c. Type A warning signs (weight of 2)
12. Head on crashes on rural state tangents of minor arterials, major collectors, and principal arterials – other – (KAB) 137 crashes over 1,234 miles. (Maximum score of 8)
   a. AADT over 3,000 vpd (weight of 2)
   b. Functional class is a minor arterial (weight of 1)

c. Absence of outside rumble strips (weight of 2)
d. Presence of guardrail (weight of 1)
e. Sum of average lane and shoulder width is less than 15 feet (weight of 1)
f. Natural Log of traffic volumes (weight of 0 to 1, continuous)

13. Overturn crashes on rural state tangents of minor arterials, major collectors, and principal arterials – other – (KAB) 211 crashes over 1,234 miles. (Maximum score of 6)
    a. Presence of Intersections (weight of 1)
    b. AADT over 2,000 vpd (weight of 1)
    c. Posted speed limit over 35 mph (weight of 1)
    d. Presence of rumble strips along the centerline (weight of 1)
    e. Average shoulder width 5 feet or less (weight of 1)
    f. Natural log of AADT (weight of 0-1, continuous)
14. Run-off road crashes on rural state tangents of minor arterials and major collectors. – (KA) 116 crashes over 1,020 miles. (Maximum score of 6)
    a. Speed limit over 45 mph (weight of 1)
    b. Functional class is minor arterial (weight of 1)
    c. Average shoulder width is over 5 feet (weight of 1)
    d. Intersection is present in segment (weight of 1)
    e. AADT under 9000 vpd (weight of 1)
    f. Natural log of AADT (weight of 0-1, continuous)

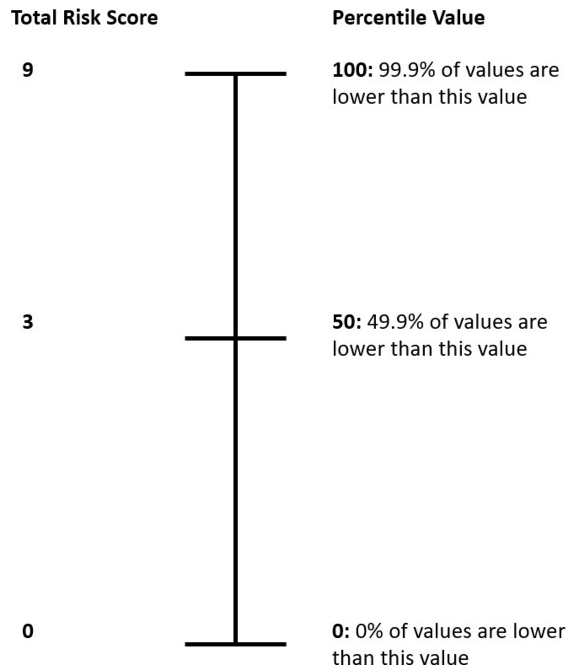
VTrans reviewed and approved VHB's proposed risk factors. VHB proceeded to create risk maps using the weighted scoring method.

Risk Maps

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

VHB then assigned percentile rankings to each segment based on the total risk score relative to the other segments. Figure 1 is a visual representation of the percentile scoring process. VHB correlated the percentile scores to the risk categories used by in the International Roadway Assessment Programme (iRAP). Table 1 summarizes the proposed risk categories based on the percentile score range. It also includes the color of segments used in the maps.

Figure 1. Percentile ranking of sites.



VHB then overlaid each of the 14 focus crash and facility types on a GIS map, coloring the segments by their risk score. Sample maps of each of the 14 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.)

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

Head-On Crashes, Rural Local Curves

Figure 2 shows a representative section of the risk map for KAB head-on crashes on rural local curves. Table 2 shows the distribution of risk scores by percentage of mileage and focus crash type. For Head-on crashes on rural local curves, the predominant risk category is medium.

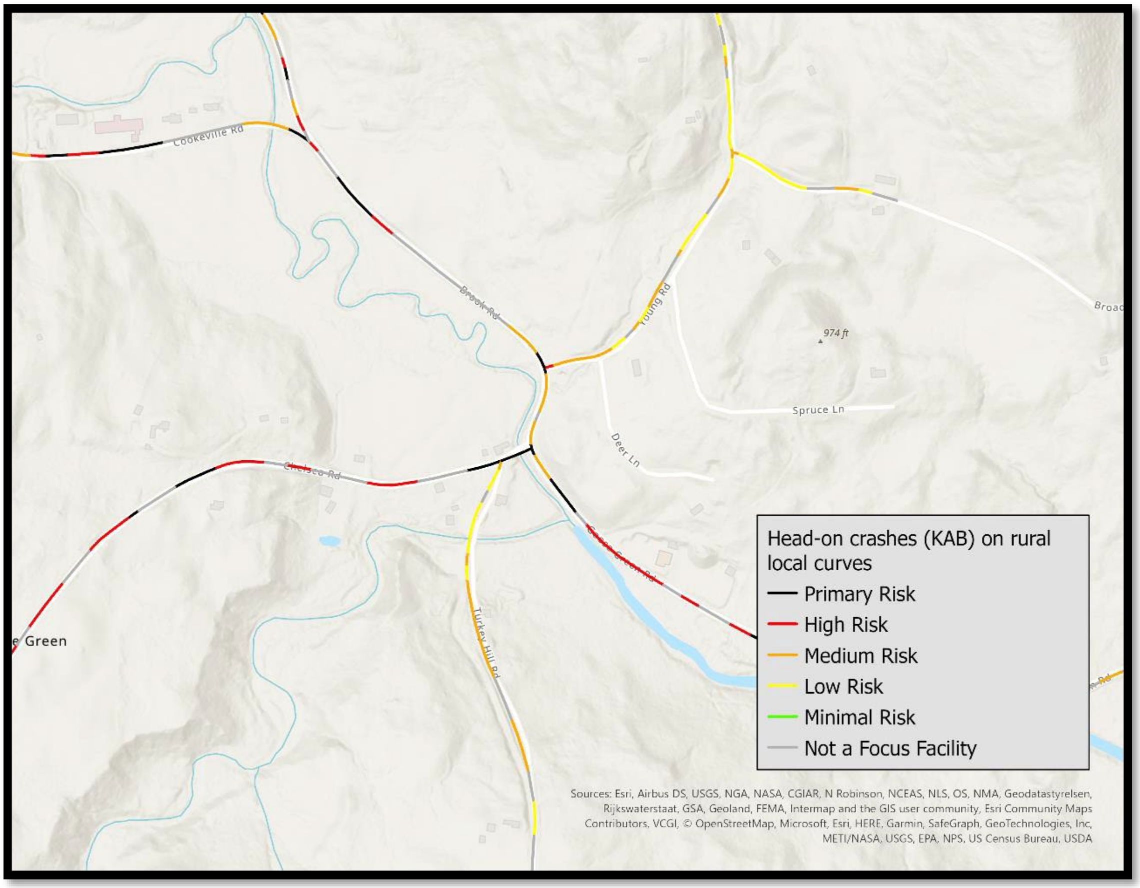


Figure 2. Section of Risk Map for Head-on crashes (KAB) on Rural Local Curves

Table 2 Percentage of Mileage and Head-On KA Crashes by Risk Score on Rural Local Curves

Risk Category	Mileage (Percent)	KA Crashes (Percent)
Primary Risk	331 (7%)	27 (27%)
High Risk	469 (9%)	18 (18%)
Medium Risk	2543 (51%)	42 (42%)
Low Risk	1646 (33%)	13 (13%)
Minimal Risk	0 (0%)	0 (0%)

Overturn Crashes, Rural Local Curves

Figure 3 shows a representative section of the risk map for KAB overturn crashes on rural local curves. Table 3 shows the distribution of risk scores by percentage of mileage and focus crash type. For Overturn crashes on rural local curves, the predominant risk category is "Medium".

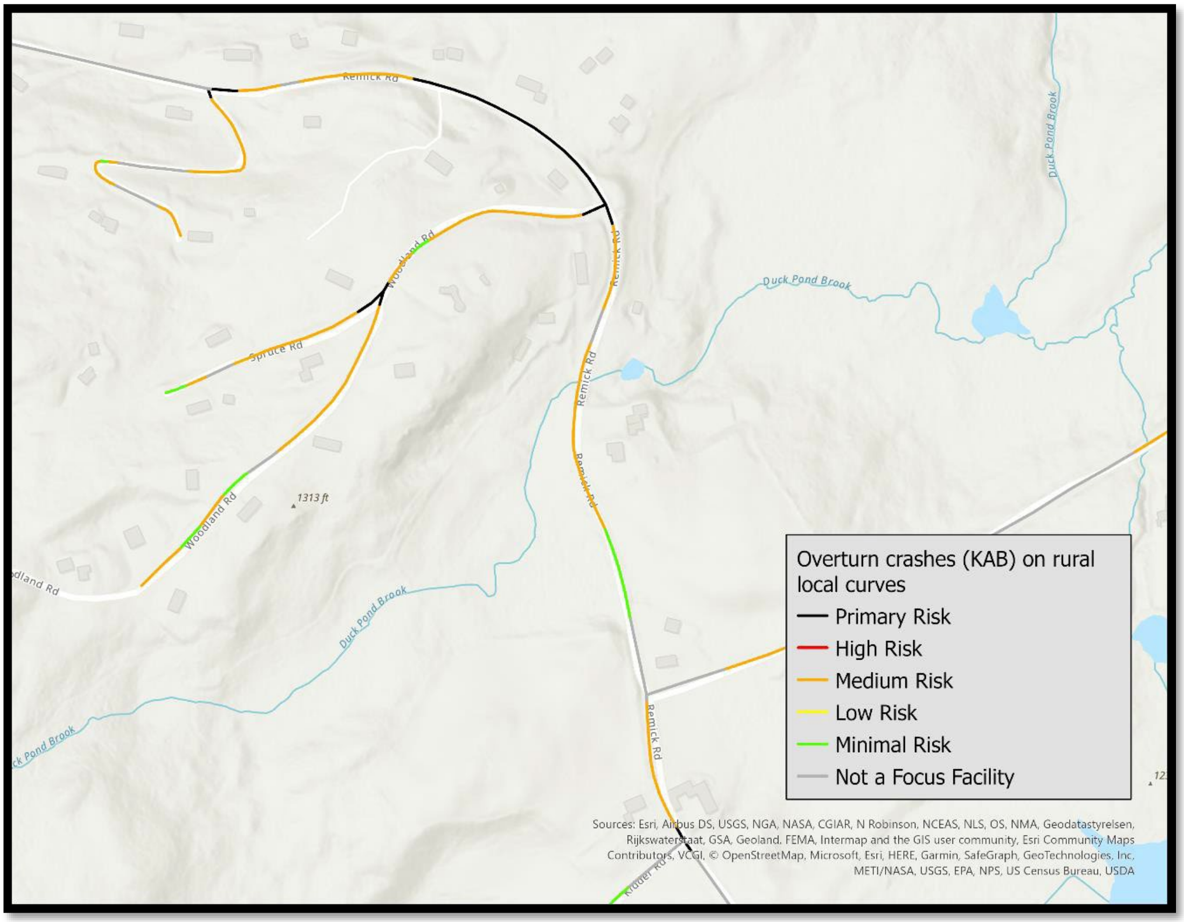


Figure 3. Section of Risk Map for Overturn crashes (KAB) on Rural Local Curves

Table 3 Percentage of Mileage and Overturn KAB Crashes by Risk Score on Rural Local Curves

Risk Category	Mileage (Percent[3])	KAB Crashes (Percent)
Primary Risk	903 (18%)	85 (44%)
High Risk	0 (0%)	0 (0%)
Medium Risk	3246 (65%)	92 (47%)
Low Risk	0 (0%)	0 (0%)
Minimal Risk	840 (17%)	18 (9%)

[3] Mileage percentages shown do not add to 100% due to rounding.

Run-Off Road Crashes, Rural Local Curves

Figure 4 shows a representative section of the risk map for KA run-off road crashes on rural local curves. Table 4 shows the distribution of risk scores by percentage of mileage and focus crash type. For Run-off Road crashes on rural local curves, the predominant risk category is “Low”.

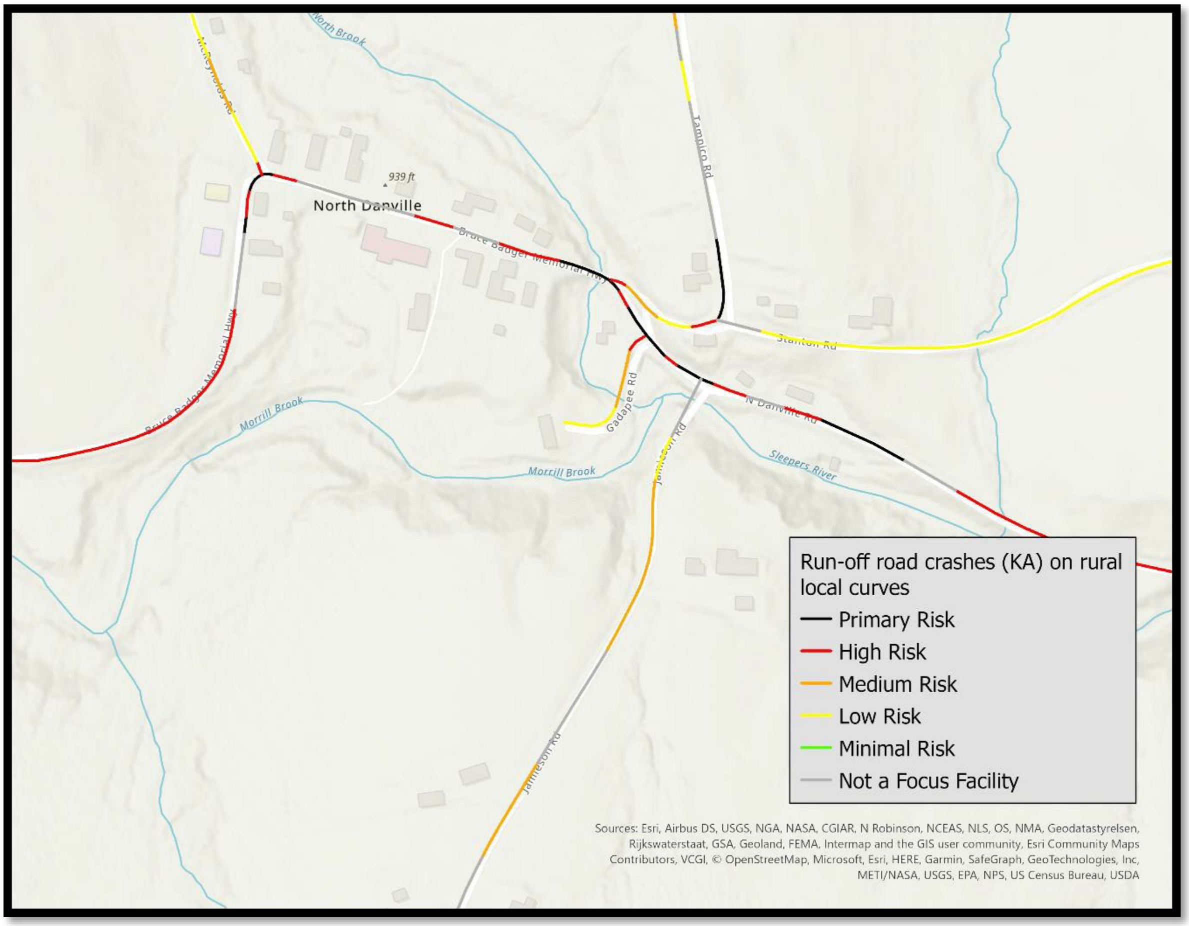


Figure 4. Section of Risk Map for Run-off Road crashes (KA) on Rural Local Curves

Table 4 Percentage of Mileage and Run-off Road KA Crashes by Risk Score on Rural Local Curves

Risk Category	Mileage (Percent)	KA Crashes (Percent)
Primary Risk	387 (8%)	40 (26%)
High Risk	810 (16%)	54 (36%)
Medium Risk	986 (20%)	13 (9%)
Low Risk	2806 (56%)	44 (29%)
Minimal Risk	0 (0%)	0 (0%)

Fixed Object Crashes, Rural Local Curves

Figure 5 shows a representative section of the risk map for KA fixed object crashes on rural local curves. Table 5 shows the distribution of risk scores by percentage of mileage and focus crash type. For fixed object crashes on rural local curves, the predominant risk category is "Low".

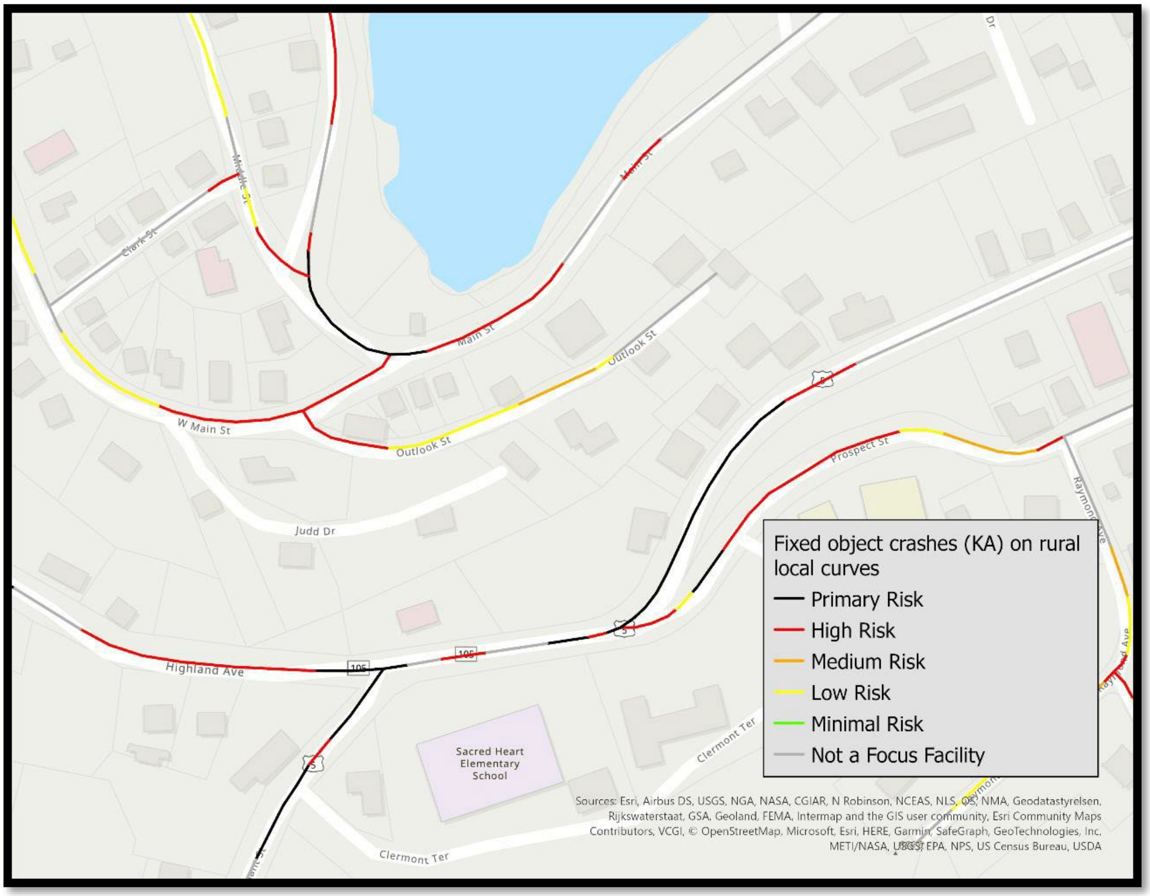


Figure 5. Section of Risk Map for Fixed object crashes (KA) on Rural Local Curves

Table 5 Percentage of Mileage and Fixed Object KA Crashes by Risk Score on Rural Local Curves

Risk Category	Mileage (Percent)	KA Crashes (Percent)
Primary Risk	387 (8%)	30 (25%)
High Risk	810 (16%)	47 (39%)
Medium Risk	986 (20%)	10 (8%)
Low Risk	2806 (56%)	33 (28%)
Minimal Risk	0 (%)	0 (0%)

Nighttime Run-Off Road Crashes, Rural Local Curves

Figure 6 shows a representative section of the risk map for KAB night-time run-off road crashes on rural local curves. Table 6 shows the distribution of risk scores by percentage of mileage and focus crash type. For night-time run-off road crashes on rural local curves, the predominant risk category is "Low".

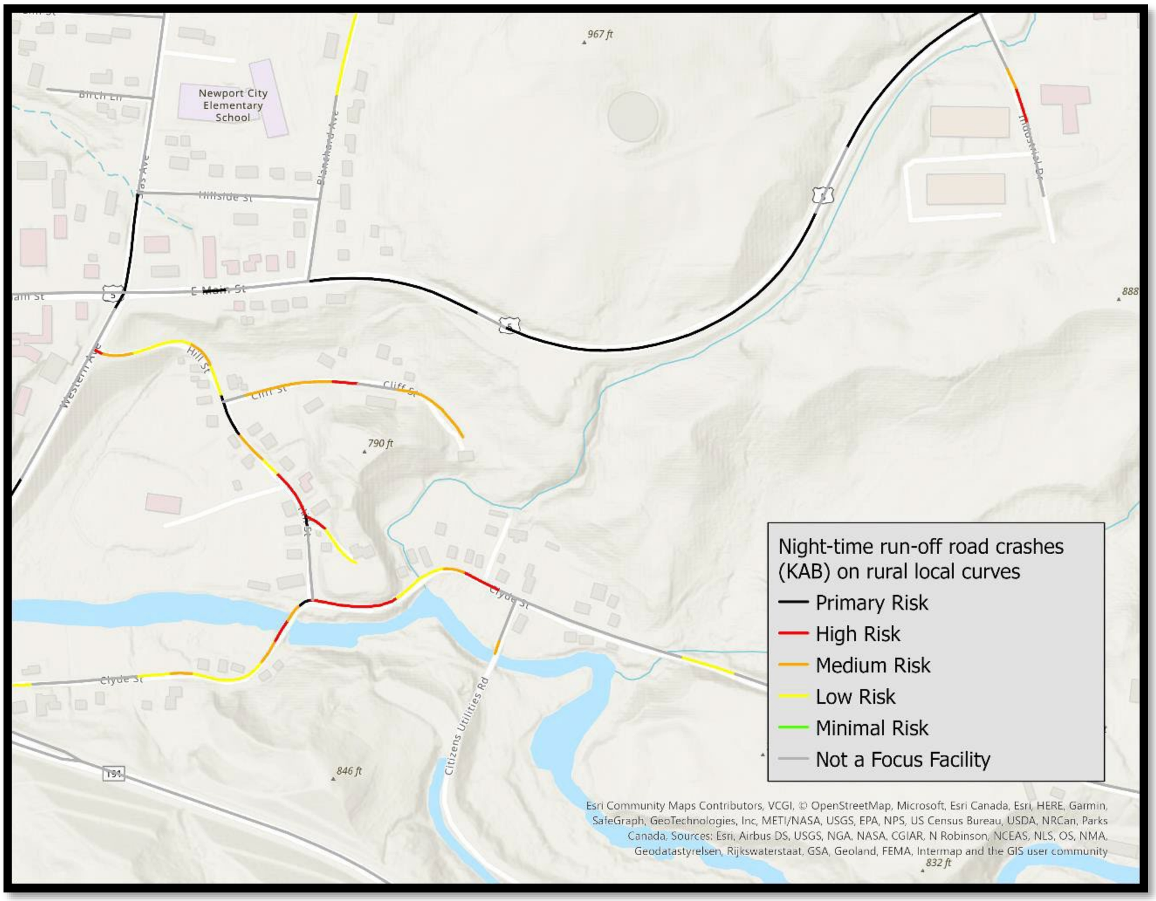


Figure 6. Section of Risk Map for Night-time run-off road crashes (KAB) on Rural Local Curves

Table 6 Percentage of Mileage and Night-time Run-off Road Crashes by Risk Score on Rural Local Curves

Risk Category	Mileage (Percent)	KAB Crashes (Percent)
Primary Risk	627 (13%)	99 (35%)
High Risk	748 (15%)	60 (21%)
Medium Risk	1414 (28%)	58 (21%)
Low Risk	2200 (44%)	63 (23%)
Minimal Risk	0 (0%)	0 (0%)

Head-On Crashes, Rural State Curves

Figure 7 shows a representative section of the risk map for KAB head-on crashes on rural state curves of minor arterials and major collectors. Table 7 shows the distribution of risk scores by percentage of mileage and focus crash type. Note that the distribution of sites is rather smooth across the risk categories.

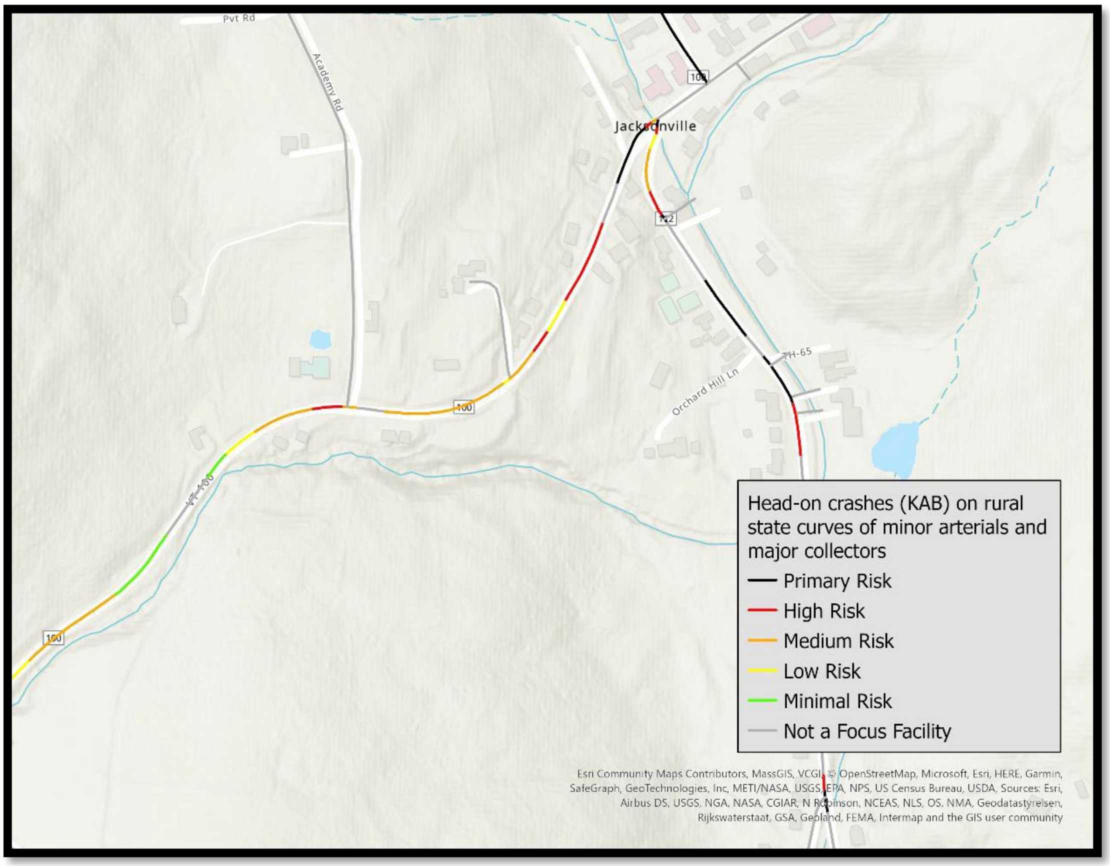


Figure 7. Section of Risk Map for Head-on crashes (KAB) on rural state curves of minor arterials and major collectors

Table 7 Percentage of Mileage and Head-on KAB Crashes by Risk Score on Rural State Curves of Minor Arterials and Major Collectors

Risk Category	Mileage (Percent)	KAB Crashes (Percent)
Primary Risk	81 (11%)	24 (21%)
High Risk	107 (15%)	23 (21%)
Medium Risk	156 (22%)	33 (29%)
Low Risk	175 (24%)	15 (13%)
Minimal Risk	197 (28%)	18 (16%)

Overturn Crashes, Rural State Curves

Figure 8 shows a representative section of the risk map for KAB overturn crashes on rural state curves of minor arterials, major collectors, and principal arterials- other. Table 8 shows the distribution of risk scores by percentage of mileage and focus crash type. The most predominant risk category is "Medium".

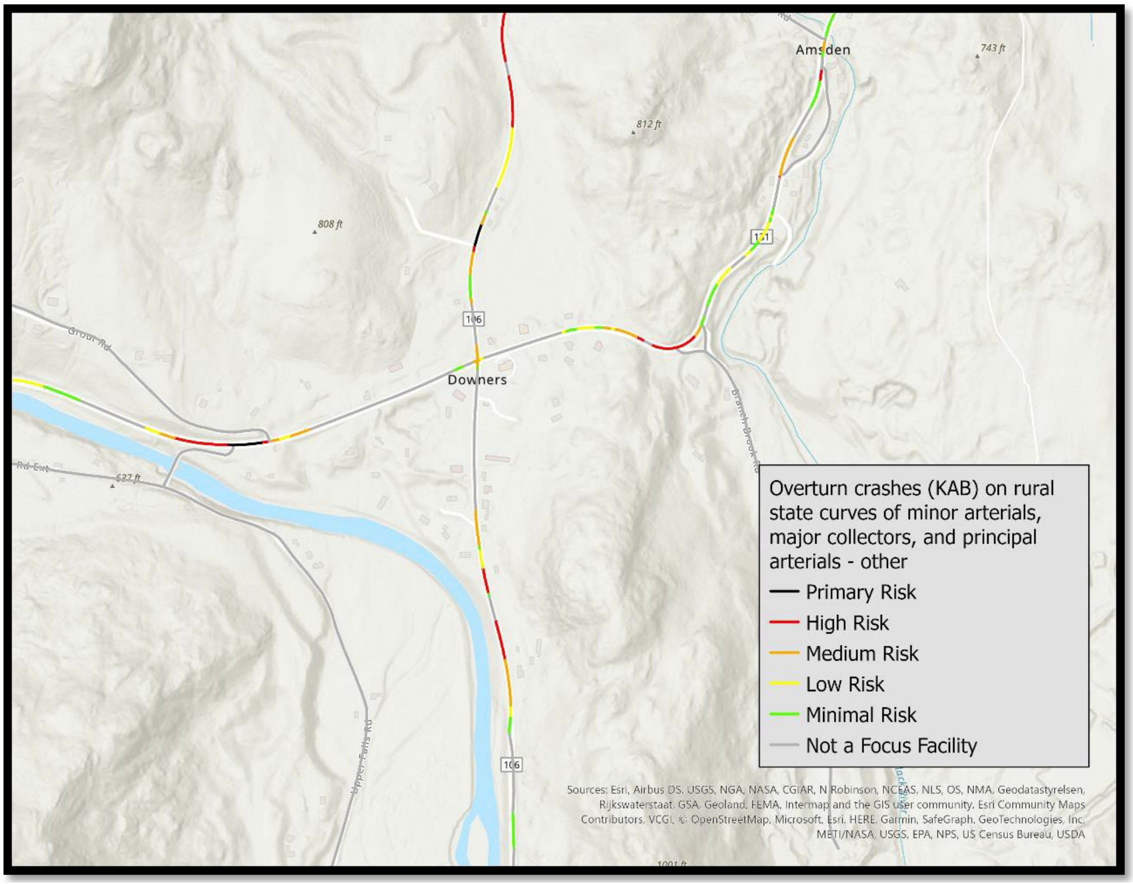


Figure 8. Section of Risk Map for Overturn crashes (KAB) on Rural state curves of minor arterials, major collectors, and principal arterials- other

Table 8 Percentage of Mileage and Overturn KAB Crashes by Risk Score on Rural States Curves of Minor Arterials, Major Collectors, and Principal Arterials

Risk Category	Mileage (Percent)	KAB Crashes (Percent)
Primary Risk	138 (17%)	45 (24%)
High Risk	196 (23%)	52 (28%)
Medium Risk	247 (30%)	51 (27%)
Low Risk	174 (21%)	31 (16%)
Minimal Risk	76 (9%)	10 (5%)

Run-Off Road Crashes, Rural State Curves

Figure 9 shows a representative section of the risk map for KA run-off road crashes on rural state curves of minor arterials and major collectors. Table 9 shows the distribution of risk scores by percentage of mileage and focus crash type. The "Medium" and "Low" risk categories both have similar levels of mileage.

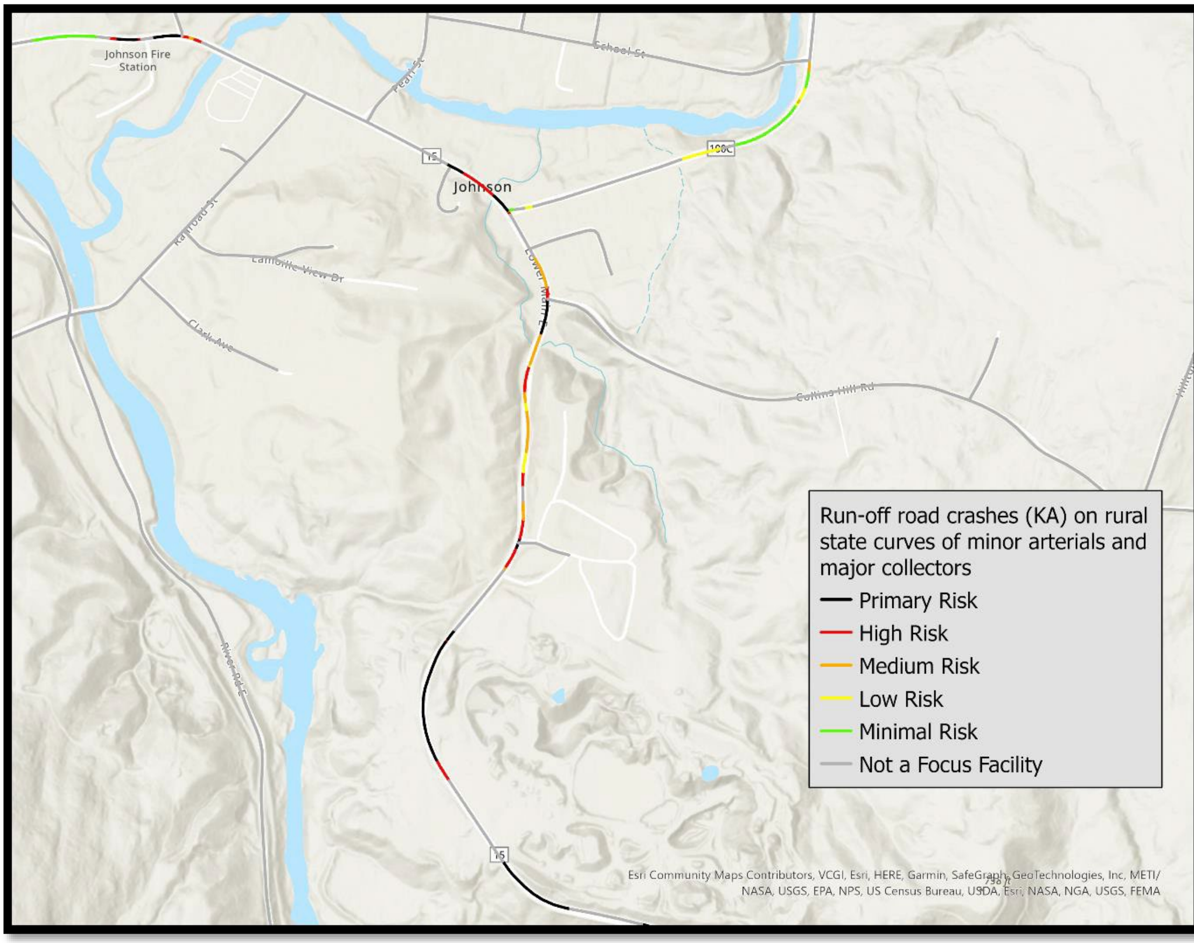


Figure 9. Section of Risk Map for Run-off Road crashes (KA) on Rural State Curves of minor arterials and major collectors

Table 9 Percentage of Mileage and Run-off Road KA Crashes by Risk Score on Rural State Curves of Minor Arterials and Major Collectors

Risk Category	Mileage (Percent)	KA Crashes (Percent)
Primary Risk	86 (12%)	34 (21%)
High Risk	136 (19%)	36 (22%)
Medium Risk	202 (28%)	51 (32%)
Low Risk	191 (27%)	31 (19%)
Minimal Risk	102 (14%)	9 (6%)

Fixed-Object Crashes, Rural State Curves

Figure 10 shows a representative section of the risk map for KA fixed object crashes on rural state curves of minor arterials and major collectors. Table 10 shows the distribution of risk scores by percentage of mileage and focus crash type. The plurality of mileage is in the "Low" risk category.

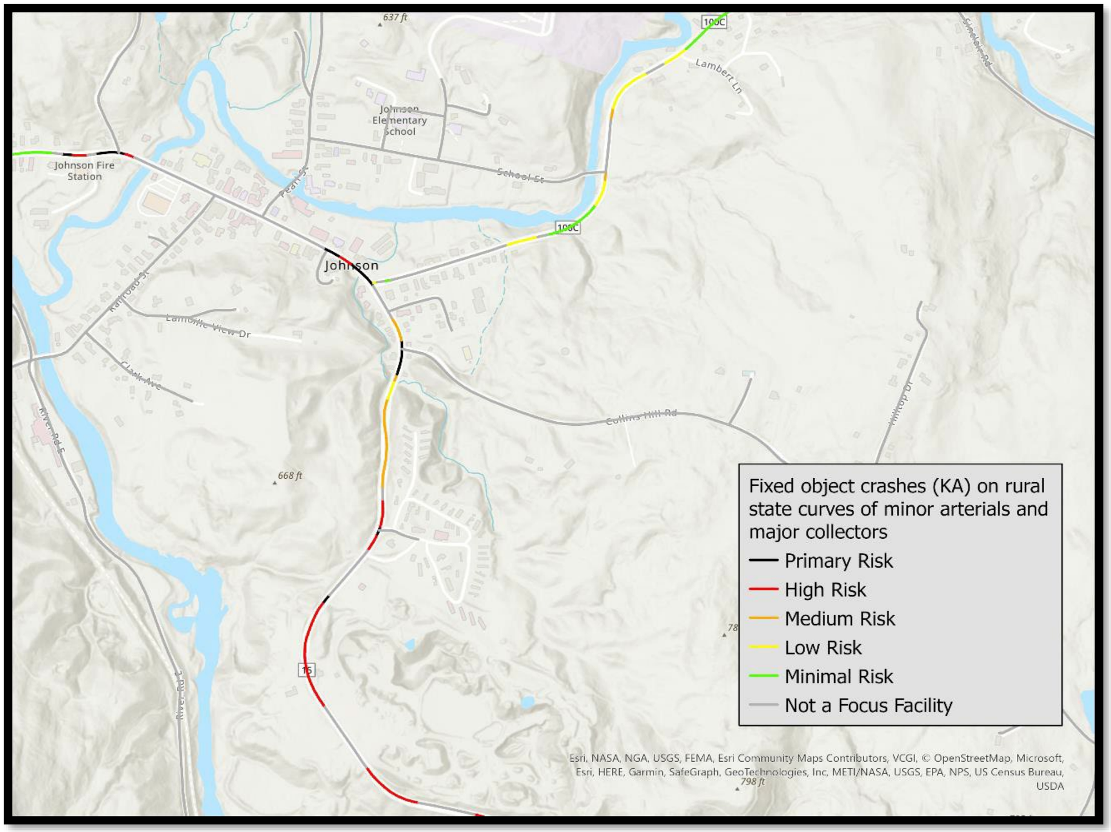


Figure 10. Section of Risk Map for Fixed object crashes (KA) on Rural State Curves of minor arterials and major collectors

Table 10 Percentage of Mileage and Fixed Object KA Crashes by Risk Score on Rural State Curves of Minor Arterials and Major Collectors

Risk Category	Mileage (Percent)	KA Crashes (Percent)
Primary Risk	74 (10%)	20 (19%)
High Risk	111 (16%)	21 (20%)
Medium Risk	260 (36%)	29 (28%)
Low Risk	214 (30%)	24 (23%)
Minimal Risk	59 (8%)	11 (10%)

Nighttime Run-Off Road Crashes, Rural State Curves

Figure 11 shows a representative section of the risk map for KAB Night-time run-off road crashes on rural state curves of minor arterials and major collectors. Table 11 shows the distribution of risk scores by percentage of mileage and focus crash type. The plurality of mileage falls in the "Low" risk category.

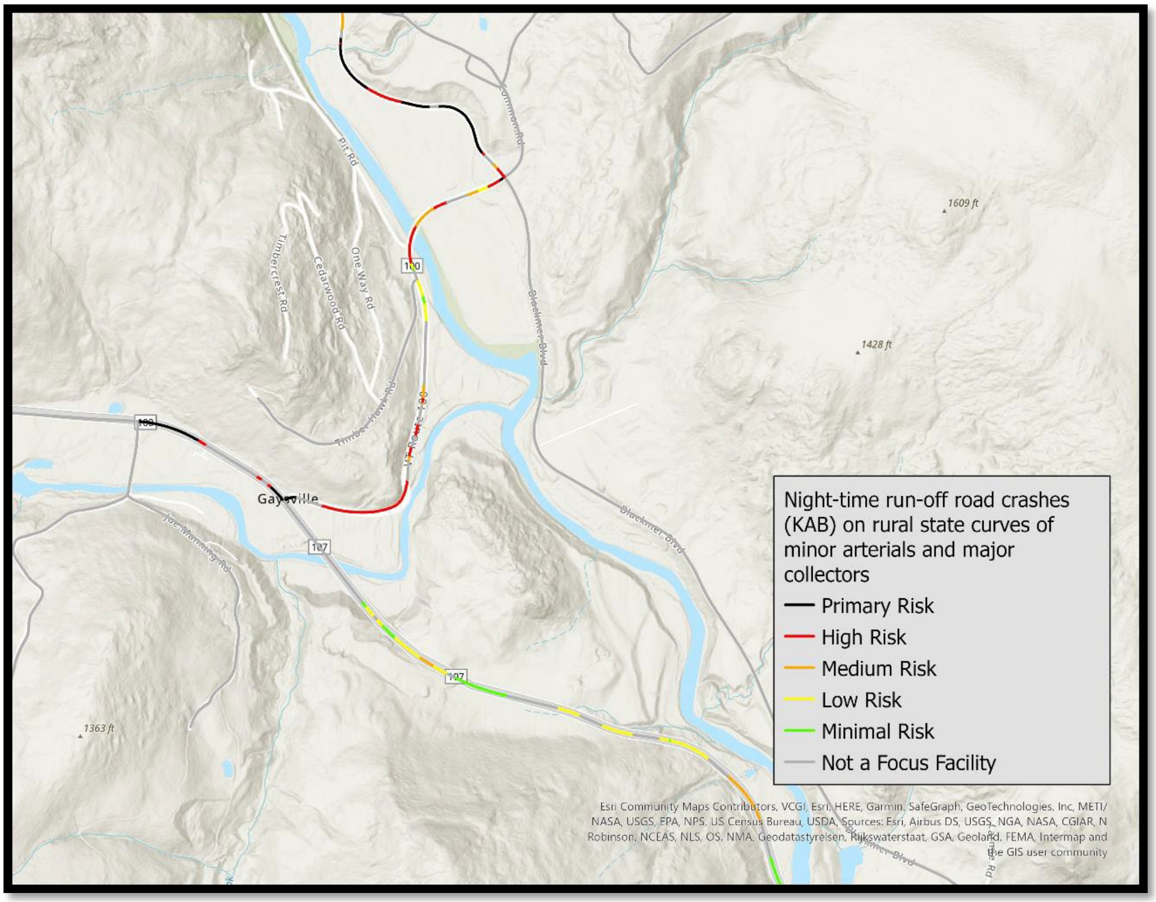


Figure 11. Section of Risk Map for Night-time run-off road crashes (KAB) on rural state curves of minor arterials and major collectors

Table 11 Percentage of Mileage and Night-time Run-off Road KAB Crashes by Risk Score on Rural State Curves of Minor Arterials and Major Collectors

Risk Category	Mileage (Percent)	KAB Crashes (Percent)
Primary Risk	31 (4%)	27 (13%)
High Risk	84 (12%)	48 (24%)
Medium Risk	174 (24%)	58 (29%)
Low Risk	233 (33%)	47 (23%)
Minimal Risk	194 (27%)	22 (11%)

Overturn Crashes, Interstates

Figure 12 shows a representative section of the risk map for KA overturn crashes on interstates. Table 12 shows the distribution of risk scores by percentage of mileage and focus crash type. More than half of the mileage falls under the "medium" risk category.

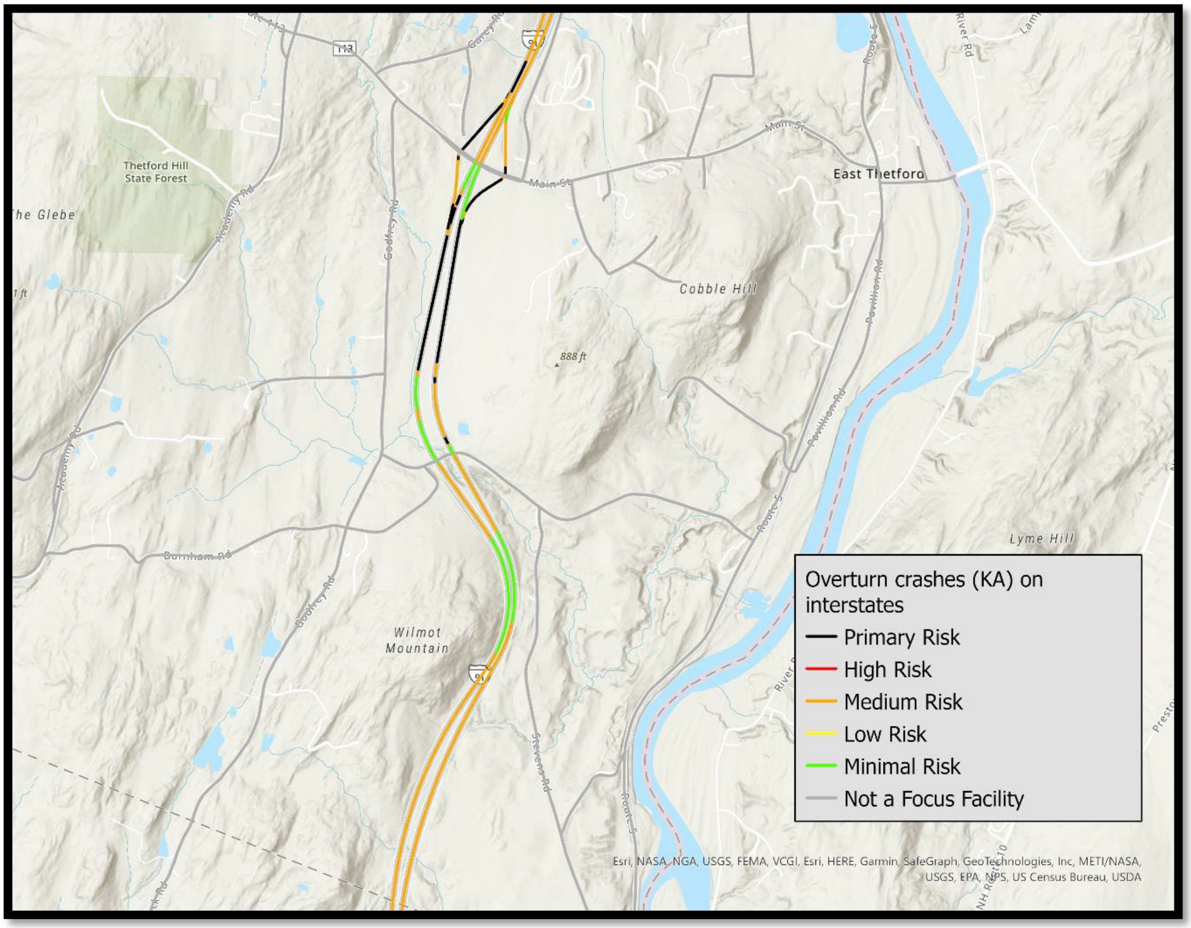


Figure 12. Section of Risk Map for Overturn crashes (KA) on Interstates

Table 12 Percentage of Mileage and Overturn KA Crashes by Risk Score on Interstates

Risk Category	Mileage (Percent)	KA Crashes (Percent)
Primary Risk	272 (38%)	30 (56%)
High Risk	0 (0%)	0 (0%)
Medium Risk	373 (52%)	23 (42%)
Low Risk	0 (0%)	0 (0%)
Minimal Risk	71 (10%)	1 (2%)

Head-On Crashes, Rural State Tangents

Figure 13 shows a representative section of the risk map for KAB head-on crashes on rural state tangents of minor arterials, major collectors, and principal arterials- other. Table 13 shows the distribution of risk scores by percentage of mileage and focus crash type. There is an almost even distribution of mileage between the "Medium", "Low", and "Minimal" risk categories.

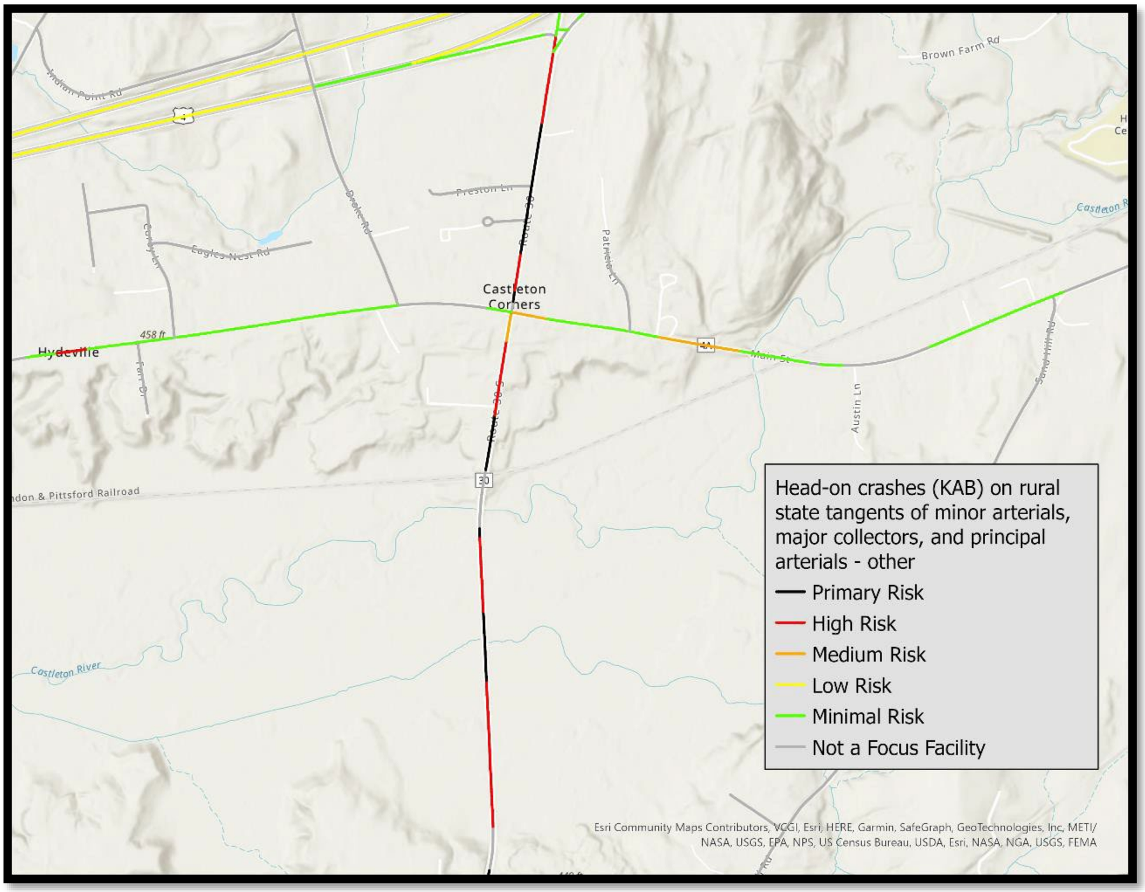


Figure 13. Section of Risk Map for Head-on crashes (KAB) on rural state tangents of minor arterials, major collectors, and principal arterials - other

Table 13 Percentage of Mileage and Head-on KAB Crashes by Risk Score on Rural State Tangents of Minor Arterials, Major Collectors, Principal Arterials- Other

Risk Category	Mileage (Percent)	KAB Crashes (Percent)
Primary Risk	61 (5%)	16 (12%)
High Risk	135 (11%)	32 (23%)
Medium Risk	322 (26%)	50 (36%)
Low Risk	366 (30%)	24 (18%)
Minimal Risk	350 (28%)	15 (11%)

Overturn Crashes, Rural State Tangents

Figure 14 shows a representative section of the risk map for KAB overturn crashes on rural state tangents of minor arterials, major collectors, and principal arterials- other. Table 14 shows the distribution of risk scores by percentage of mileage and focus crash type. The plurality of mileage is classified as "Low" risk.

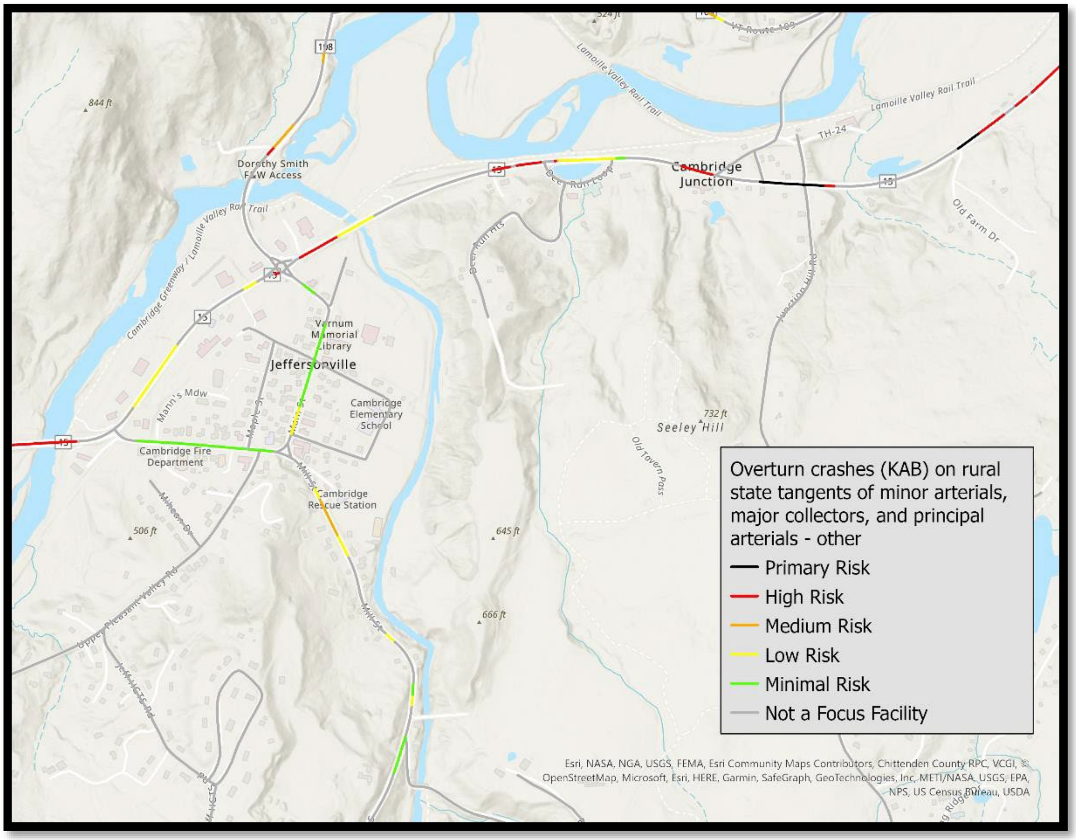


Figure 14. Section of Risk Map for Overturn crashes (KAB) on rural state tangents of minor arterials, major collectors, and principal arterials- other

Table 14 Percentage of Mileage and Overturn KAB Crashes by Risk Score on Rural State Tangents of Minor Arterials, Major Collectors, and Principal Arterials- Other

Risk Category	Mileage (Percent)	KAB Crashes (Percent)
Primary Risk	75 (6%)	28 (13%)
High Risk	148 (12%)	40 (19%)
Medium Risk	324 (26%)	74 (35%)
Low Risk	367 (30%)	40 (19%)
Minimal Risk	320 (26%)	29 (14%)

Run-Off Road Crashes, Rural State Tangents

Figure 15 shows a representative section of the risk map for KA run-off road crashes on rural state tangents of minor arterials and major collectors. Table 15 shows the distribution of risk scores by percentage of mileage and focus crash type. Most of the mileage is classified as "Medium" or "Low" risk.

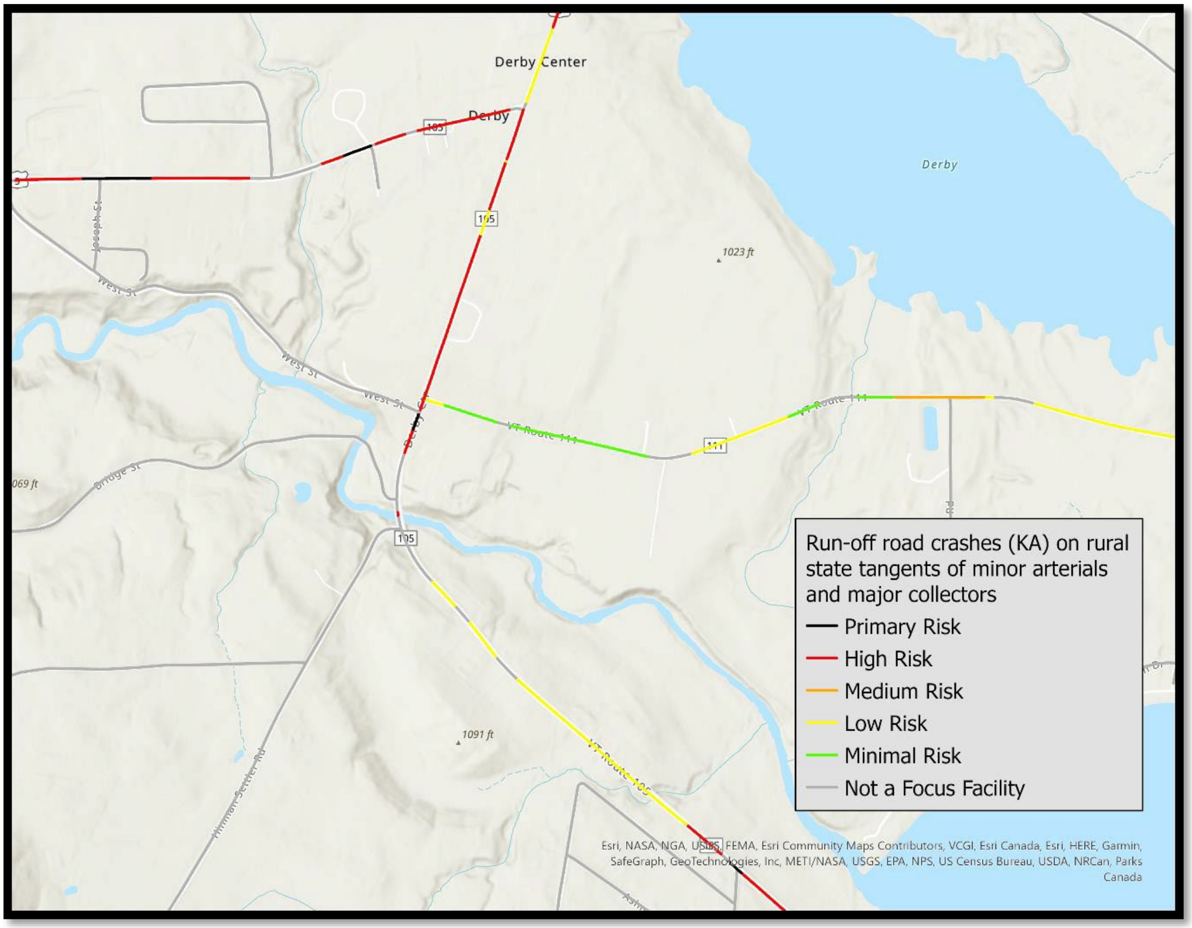


Figure 15. Section of Risk Map for Run-off Road crashes (KA) on rural state tangents of minor arterials and major collectors

Table 15 Percentage of Mileage and Run-off Road KA Crashes by Risk Score on Rural State Tangents of Minor Arterials and Major Collectors

Risk Category	Mileage (Percent)	KA Crashes (Percent)
Primary Risk	64 (6%)	23 (20%)
High Risk	107 (11%)	19 (16%)
Medium Risk	289 (28%)	30 (26%)
Low Risk	293 (29%)	31 (27%)
Minimal Risk	266 (26%)	13 (11%)

Next Steps

VHB is submitting the final 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.

VHB will proceed with submitting draft countermeasure packages to VTrans for their consideration. The countermeasure packages are 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 September 19, 2023.

Background

VTrans and VHB used the systemic safety approach to screen the Vermont roadway network and identify those network locations at highest risk of severe roadway departure crashes. VHB and VTrans selected fourteen focus crash and facility types to analyze, representing the combinations on which severe roadway departure crashes occurred most frequently. These include the following:

1. Head-on crashes on rural local road curves.
2. Overturn crashes on rural local road curves.
3. Run-off road crashes on rural local road curves.
4. Fixed object crashes on rural local road curves.
5. Night-time run-off road crashes on rural local road curves.
6. Head-on crashes on rural state-owned minor arterial and major collector curves.
7. Overturn crashes on rural state-owned principal arterials – other, minor arterial, and major collector curves .
8. Run-off road crashes on rural state-owned minor arterial and major collector curves.
9. Fixed object crashes on rural state-owned minor arterial and major collector curves.
10. Night-time run-off road crashes on rural state-owned minor arterial and major collector curves.
11. Overturn crashes on interstates.
12. Head-on crashes on rural state-owned minor arterial, major collector, and principal arterial – other tangents.
13. Overturn crashes on rural state-owned minor arterial, major collector, and principal arterial – other tangents .
14. Run-off road crashes on rural state-owned minor arterial and major collector tangents.

VHB used statistical regression analysis for each focus area to correlate focus crash frequency (collected from 2016-2020) with other factors to identify risk factors. This method allows for risk factors to be identified in consideration of each other instead of assuming each independently. Risk factors included a subset of the Model Inventory of Roadway Elements (MIRE) data elements as well as traffic data for each segment. VHB worked with VTrans to assign weights to each risk factor and assign risk scores to each element in each focus area, prioritizing them into several risk categories based on the percentile ranking of normalized risk score (see Table 1). VHB and VTrans then identified preferred countermeasures based on the focus crash type, focus facility type, and risk category.

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

Countermeasure Matrix

To implement the systemic safety approach, VTrans will target roadway departure risks that are distributed throughout the road system rather than concentrated at high-crash locations. The countermeasure matrix (see Appendix A) is intended to help focus resources for efficiently reducing roadway departure risk. To begin, VHB paired potential countermeasures with each focus crash and facility type. These recommendations are tiered 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 included 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.

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 – engineering judgment is essential in selecting sites and countermeasures to build. 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 (see Table 2). Conditions must be field verified prior to programming any improvements.

Table 2. Prioritization Criteria for Primary Risk Countermeasures

Countermeasure	Prioritization Criteria
Centerline Buffer Area	• No median or two-way left-turn lane (TWLTL) is present. • One point for every cross-centerline crash within a half-mile of the location. • One point for every foot above 30 feet for combined lane and shoulder width.
Median Barrier	• Median is present and traversable. • One point for every cross-median crash within a mile of the segment. • One point for every 5-feet narrower than 30 feet in median width.
High Friction Surface Treatment (HFST)	• One point for every wet pavement crash in the last 5 years within a half-mile of the segment. • One point if curve warning signs are present.
Flashing Beacons	• One point for presence of type A warning signs at a horizontal curve. • One point for every roadway departure crash in the last 5 years within a half-mile of the segment. • One point for every nighttime crash within a half-mile of the segment. • Standard warning delineation is already present at the curve and safety issue persists. • Sight distance limitations are present at the curve.
Dynamic Chevrons	• One point for presence of type A warning signs. • One point for every roadway departure crash in the last 5 years within a half-mile of the segment. • One point for every nighttime crash within a half-mile of the segment. • Standard warning delineation is already present at the curve. • Flashing beacon is already present at the curve and safety issue persists. • Sight distance limitations are present at the curve. • Curve is on or at the bottom of a significant downgrade.

Roadside Improvements - Roadside Barrier	• One point for every fixed object crash (excluding barrier) or rollover crash within a half mile in the last 5 years. • One point for every foot the shoulder is narrower than 4 feet. • One point for every foot the lane width is narrower than 11 feet.
Roadside Improvements - Slope Flattening	• One point for every rollover crash within a half mile in the last 5 years. • One point for every foot the shoulder is narrower than 4 feet. • One point for every foot the lane width is narrower than 11 feet.
Roadside Improvements - Clear Zone Widening	• One point for every fixed object crash or rollover crash within a half mile in the last 5 years. • One point for every foot the shoulder is narrower than 4 feet. • One point for every foot the lane width is narrower than 11 feet.
Roadside Improvements – Shoulder Widening	• One point for every roadway departure crash within a half mile in the last 5 years. • One point for every foot the shoulder is narrower than 4 feet. • One point for every foot the lane width is narrower than 11 feet.
Lighting	• Ineligible if lighting is present. • One point for every nighttime crash within a half mile in the last 5 years. • One point for every pedestrian or bicycle crash within a half mile in the last 5 years. • One point for every crest vertical curve present within a half mile of the segment. • One point for every intersection present within a half mile of the segment.

VHB ranked sites eligible (by risk tier) for these countermeasures based on the frequency of specific crash types within a specified distance, as well as the presence of other relevant potential contributing factors. This prioritization, which is presented in the ranking tables, can be used absent other factors (as discussed under Delivery Approaches) to select sites for a systemic project.

There is common overlap for prioritization of sites recommending roadside barrier, slope flattening, shoulder widening, and clear zone widening. To decide the appropriate improvement, Operations and Safety Bureau (OSB) and designers can use the Roadside Safety Analysis Program (RSAP) to assess the roadside design alternatives for a site. The Microsoft Excel-based tool uses an encroachment-based approach to estimate the total costs of crashes from a roadside design. The tool then calculates a benefit-cost analysis based on the cost of each roadside design alternative. VTrans can select the roadside design improvement or combination which produces the best benefit-cost ratio, largest reduction in crash costs, or verify the project cost is justified.

Delivery Approaches

The list of eligible sites is intentionally lengthy to allow flexibility in delivering improvements. Sites should be selected based on practical factors such as cost-effective bundling, remaining service life of the treated element (e.g., high-friction surface treatment [HFST] should be applied to newer pavement with a solid pavement structure), and opportunities to coordinate with other work. VTrans should not limit efforts to implementing projects on "Primary Risk Sites"; rather, OSB and stakeholders should work to develop projects at all risk levels.

VHB recommends five tracks for project programming as shown in Figure 1 (shaded boxes indicate a new process as of this writing). Separate tracks are recommended for state and local projects. Although improvements will be delivered primarily through the Highway Safety Improvement Program (HSIP), the recommended countermeasures should be shared across the agency for potential incorporation into non-HSIP led projects. At a minimum, the risk maps should be shared with the Asset Management Bureau (AMB) for inclusion in New Project Summaries, where designers can identify opportunities to insert low-cost, targeted countermeasures (such as rumble strips, signage, and pavement marking improvements) into already programmed projects.

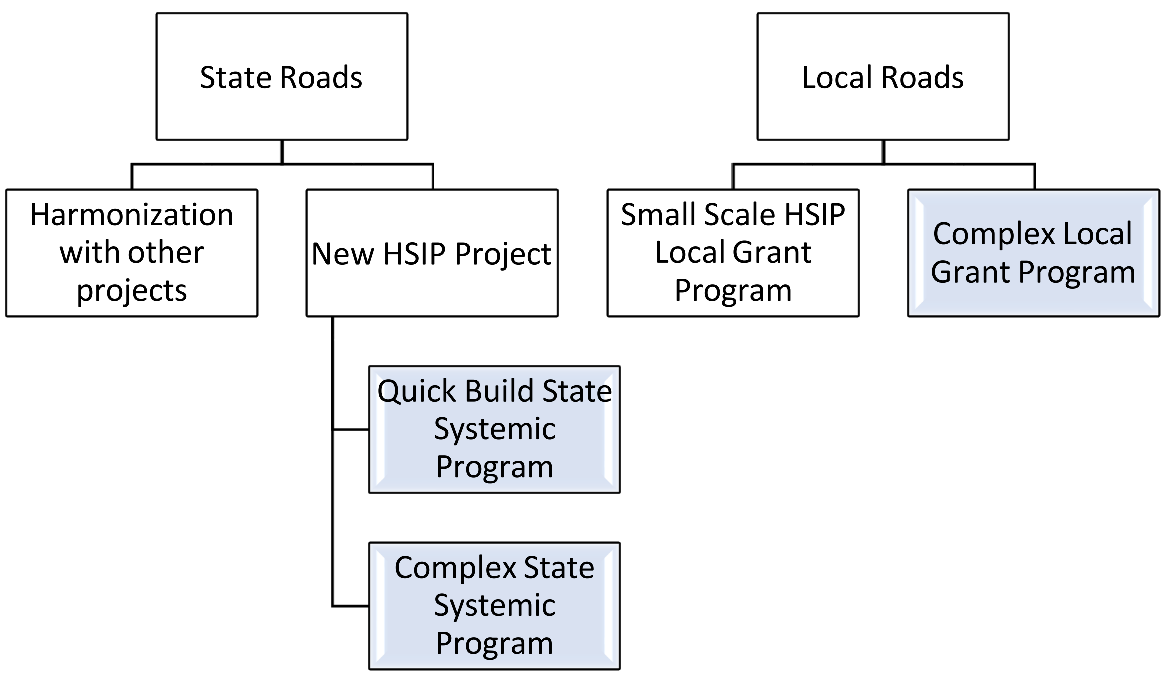


Figure 1. Delivery tracks for systemic improvements (shaded boxes indicate a new process).

Harmonization with Other Projects

There are significant advantages to integrating safety treatments into other projects, including a lower administrative burden and mobilization costs compared to a standalone project. VTrans may consider this avenue for focus facility types 6-14, which are for state-owned roads. The recommended countermeasures are most compatible with paving projects and bridge replacement or rehabilitation projects. Most countermeasures can be added to a full-depth reconstruction project, while reclaims or mill and overlays will usually be limited to signing and marking add-ons, though others can prove cost-effective given mobilization is already occurring. Generally, roadside safety improvements (i.e., roadside barrier installation, clear zone widening, shoulder widening, and sideslope flattening) should be delivered in this manner.

OSB should provide risk maps and countermeasure recommendations to the AMB for reference during New Project Summary creations. This will supplement, not replace, the individualized review of crash history and safety concerns that is currently completed. OSB should coordinate with AMB to add this check to the New Project Summary checklist.

If a project contains site(s) listed in the countermeasure matrix, AMB should contact the HSIP Engineer. The two bureaus should jointly determine whether any of the optioned countermeasures will be included, considering appropriateness to the specific site, compatibility with the underlying project, and crash reduction factors. All sites within the project limits should be considered as a group, with a consistent treatment approach.

Once countermeasures have been selected, they can be included in the project requirements as it goes to design. 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.

In the near term, there are paving projects already in design or pre-construction that did not have this screening information at the New Project Summary stage. The HSIP Engineer should work with AMB to review currently programmed projects and identify opportunities to add treatments from this project. Similar to what was done this year for Cambridge-Johnson STP 2925(1) and Sheldon-Enosburg STP FPAV(68), add-ons should be coordinated where feasible with the Project Delivery Bureau (PDB).

Quick Build State Systemic Program

This is a new program for low-complexity countermeasures that can be built without stamped engineering plans within the existing operational right of way. The HSIP Engineer will administer the program through project definition before handing off to PDB for delivery. Sites from focus facility types 6 to 14 (i.e., focus types on state roads) are eligible for this method. This should focus on medium risk, high risk, and primary risk sites, though most priority risk sites likely have these countermeasures installed already. Generally, countermeasures should be considered at any sites at or above the risk tier listed (e.g., medium risk tier countermeasures should be considered for medium risk sites, high risk sites, and primary risk sites).

Currently, VTrans targets an HSIP spending distribution of 30 percent on state rural systemic projects and 8 percent on state urban systemic projects. This requires investing around $9 million annually in projects driven by systemic screening. Because it may take 12 months or longer to receive environmental clearance, development of the first screening projects should begin immediately with an expectation that the first ones go to construction in summer of 2024.

The type of high-volume projects envisioned here are new for OSB. In the first year, the HSIP Engineer should choose only one or two countermeasures to launch with. The HSIP Engineer should screen the list of eligible sites to those compatible with these countermeasures. If another treatment from the matrix would be preferred, the site should be deferred to a future project. These strict criteria will help fast track the first round of improvements and avoid the need for additional prioritization criteria.

To achieve efficiencies of scale, sites should be bundled for contracting; grouped by similar scopes of work and regional proximity. Treatments that require specialized equipment, such as HFST, may be bundled as a statewide project. Sites should be selected first by the prioritization factors in the matrix (if any) and secondly to achieve geographic dispersion. Sites with upcoming (four years or sooner) construction that would require replacing the countermeasure should be excluded, as the countermeasures should be installed as part of the previous track (Harmonization with Other Projects).

After creating preliminary project lists, VTrans should perform a due diligence review for each site to verify field conditions. Where possible, this can be a desktop review. After this step, the HSIP Engineer should coordinate with PDB to program the project and submit it to the Environmental Section for National Environmental Policy Act (NEPA) clearance[1]. These projects will be delivered by PDB.

Complex State Systemic Program

Countermeasures that require engineering plans to install will follow a more traditional project development process. Primary risk sites from focus facility types 6 to 14 (i.e., focus types on state roads) eligible for this method. Lower-tier countermeasures should still be considered at primary risk sites, with delivery through the Quick Build program.

For design efficiency and to generate a reasonable evaluation sample size, the program should focus on one to three countermeasures each year and deliver them at multiple locations. The HSIP Engineer should consult the prioritization criteria for these countermeasures to develop a preliminary site list. They should then consider site conditions and use engineering judgment to prioritize sites. After sites are selected,, OSB will hand these off to PDB to contract for design and construction. Individual improvements should be bundled as a single statewide project. After the first year, OSB and PDB should assess how processes may be adapted to streamline delivery in future years.

Small Scale HSIP Local Grant Program

The HSIP Local Grant Program is the recommended vehicle for delivering countermeasures on local roads (focus types 1 through 5), including Class 1 Town Highways. Currently, towns choose the sites they want to improve and apply for countermeasures from a predefined list. As VTrans moves forward, the program should be modified to encourage projects in line with the countermeasure matrix.

The HSIP Engineer will set requirements for applicants again next year. The level of interest in the grant program is still unknown. If demand for the grant funding is high this year (applications were due June 16th), the Fiscal Year (FY) 25 program should be limited to sites identified through this screening (and the intersection screening). If demand is more moderate (i.e., the budget is not exhausted), rules might establish a cap for the discretionary types of projects allowed now and a higher cap for systemic projects on the screening list.

[1] Note that most of these projects likely fall under a Categorical Exclusion.

Grant materials and outreach, such as a grant training webinar, countermeasures briefs, and/or a presentation at the Transportation Planning Initiative (TPI) Conference must clearly communicate the recommendations of this project to towns and Regional Planning Commissions (RPCs). Focus types one through five should be made available on a GIS dashboard that filters by town. Based on the countermeasure matrix, this dashboard should also show eligible countermeasures for each site (and allow filtering by this value). Sites should be identified with a unique ID (e.g., "Town xxx Site #9").

Once towns apply for a project on the list, the grant program should function as it does now. 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. The HSIP Engineer reviews and approves grant applications, verifying eligibility and balancing awards geographically. A grant agreement is signed between the VTrans and the awardee, which includes a commitment to maintain the improvement.

Complex Local Grant Program

The Small Scale HSIP Grant Program is well-suited to deliver countermeasures that do not require engineering plans. To fully implement screening results on local roads, a grant process must also be established for primary risk countermeasures. These should be gradually added as "Complex Treatments" offered only to a prescreened eligibility list.

The HSIP Engineer should choose one or two primary risk countermeasures at first. The eligibility list may be simply all relevant primary risk sites or a certain percentile according to the prioritization criteria. These should be listed with the other prescreened countermeasure options on the grant application form. The HSIP Engineer will need to ensure the grant cap can accommodate these countermeasures (one option is to set a higher cap for primary risk). The presumption will be that towns contract for engineering and construction, but VTrans delivery may be an option for some projects (e.g., where bundling specialty work across multiple sites is beneficial).

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.

Appendices

A Countermeasure Matrix

B Final Scoring Formulas

Appendix A – Countermeasure Matrix

The following tables list relevant countermeasures applicable to each combination of focus crash type and facility type by risk level. 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 3 Countermeasure Matrix for Primary Risk Sites

Risk Level	Countermeasure (Focus Crash and Facility Type)	Target Crash Types and Facilities						
		Head-On Crashes, Curves and Tangents (1, 6, 12)	Overturn, Curves (2, 7)	Fixed Object Crashes, Curves (4, 9)	Run-Off-Road, Curves (3, 8)	Overturn, Interstate (11)	Nighttime Run-Off-Road Crashes, Curves and Tangents (5, 10)	Overturn, Run-Off Road, Tangents (13, 14)
Primary	Centerline Buffer Area	●						
	Median Buffer	●						
	HFST	●		●	●		●	
	In-Pavement Curve Warning Markings		●	●	●		●	
	Dynamic Chevrons		●	●	●		●	
	Flashing Beacons on Curve Warning Signage		●	●	●		●	
	Roadside Barrier		●	●	●	●	●	●
	Slope Flattening		●		●	●	●	●
	Removal of Trip Hazards		●		●	●	●	●
	Clear Zone Widening			●	●		●	
	Lighting						●	

Table 4. Countermeasure Matrix for High Risk Sites

Risk Level	Countermeasure (Focus Crash and Facility Type)	Target Crash Types and Facilities						
		Head-On Crashes, Curves and Tangents (1, 6, 12)	Overturn, Curves (2, 7)	Fixed Object Crashes, Curves (4, 9)	Run-Off-Road, Curves (3, 8)	Overturn, Interstate (11)	Nighttime Run-Off-Road Crashes, Curves and Tangents (5, 10)	Overturn, Run-Off Road, Tangents (13, 14)
High	Centerline Mumble Strips	●						
	Centerline Rumble Strips	●						
	Designate No Passing Zone	●						
	Address Trip Hazards[2]		●			●		●
	Paved Shoulder Widening		●	●	●	●	●	●
	Targeted Clear Zone Widening			●				
	Reflective Pavement Markings						●	

[2] As opposed to removal, "addressing" a risk hazard includes redesigning the trip hazard, relocating it to elsewhere in the clear zone, using barrier to protect vehicles from the trip hazard, or otherwise delineating the trip hazard.

Table 5. Countermeasure Matrix for Medium Risk Sites

Risk Level	Countermeasure (Focus Crash and Facility Type)	Target Crash Types and Facilities						
		Head-On Crashes, Curves and Tangents (1, 6, 12)	Overturn, Curves (2, 7)	Fixed Object Crashes, Curves (4, 9)	Run-Off-Road, Curves (3, 8)	Overturn, Interstate (11)	Nighttime Run-Off-Road Crashes, Curves and Tangents (5, 10)	Overturn, Run-Off Road, Tangents (13, 14)
Medium	Widened Centerline Markings	●						
	Supplemental MUTCD Curve Warning Signs[3]	●	●	●	●			
	Post-Mounted Delineators		●	●	●	●	●	●
	Shoulder Rumble Strips		●	●	●		●	●

Table 6. Countermeasure Matrix for All Sites

Risk Level	Countermeasure (Focus Crash and Facility Type)	Target Crash Types and Facilities						
		Head-On Crashes, Curves and Tangents (1, 6, 12)	Overturn, Curves (2, 7)	Fixed Object Crashes, Curves (4, 9)	Run-Off-Road, Curves (3, 8)	Overturn, Interstate (11)	Nighttime Run-Off-Road Crashes, Curves and Tangents (5, 10)	Overturn, Run-Off Road, Tangents (13, 14)
Standard	Centerline Pavement Markings	●					●	
	Sloped Pavement Edge	●	●	●	●	●	●	●
	Breakaway Devices	●	●	●	●	●	●	●
	Edgeline Markings	●	●	●	●	●	●	●

[3] Found in MUTCD Table 2C-5. Use fluorescent sheeting for High and Primary risk site applications. Consider gate posting warning signs for Primary risk site applications.

Appendix B – Scoring Formulas

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

1. Head-on crashes on rural local road curves – (KAB[4]) 100 crashes over 4,989 miles (Maximum score of 6).
    a. No median or unprotected area less than 4 feet wide (weight of 2).
    b. Independent Horizontal Curve (weight of 1).
    c. Natural Log of Degree of Curvature between 2 and 4 (weight of 1).
    d. Presence of an intersection in the segment (weight of 2).
2. Overturn crashes on rural local road curves – (KAB) 195 crashes over 4,989 miles (Maximum score of 9).
    a. Average Shoulder width over 1 foot (weight of 1).
    b. Road is a Minor or Major Collector (weight of 2).
    c. Presence of an intersection in the segment (weight of 2).
    d. Curve is not independent (weight of 1).
    e. Natural log of degree of curvature between 1 and 4 (top 10 percent weight of 3, next 40 percent weight of 2, remaining 50 percent weight of 1).
3. Run-off road crashes on rural local road curves – (KA[5]) 151 crashes over 4,989 miles (Maximum score of 8).
    a. No median or unprotected area less than 4 feet wide (weight of 2).
    b. Presence of reverse and compound horizontal curve transitions (weights of 1).
    c. Presence of an intersection in the segment (weight of 2).
    d. Natural log of degree of curvature between 2 and 4 (top 10% weight of 3, next 40% weight of 2, remaining 50% weight of 1).
4. Fixed object crashes on rural local road curves – (KA) 120 crashes over 4,989 miles (Maximum score of 8).
    a. No median or unprotected area less than 4 feet wide (weight of 2).
    b. Presence of reverse and compound horizontal curve transitions (weight of 1).
    c. Presence of an intersection in the segment (weight of 2).
    d. Natural log of degree of curvature between 2 and 4 (top 10% weight of 3, next 40% weight of 2, remaining 50% weight of 1).
5. Night-time run-off road crashes on rural local road curves – (KAB) 280 crashes over 4,989 miles (Maximum score of 9).

[4] 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.
[5] KA represents the KABCO injury severity scale, where K is a fatal crash and A is a suspected serious injury crash.

   a. No median or unprotected area less than 4 feet wide (weight of 2).
   b. Average shoulder width over 1 foot (weight of 1).
   c. Presence of compound horizontal curves (weight of 1).
   d. Presence of an intersection in the segment (weight of 2).
   e. Natural log of degree of curvature between 3 and 5 (top 10 percent weight of 3, next 40 percent weight of 2, remaining 50 percent weight of 1).
6. Head-on crashes on rural state curves of minor arterials and major collectors – (KAB) 113 crashes over 717 miles (Maximum score of 13).
   a. Total shoulder width over 4 feet (weight of 1).
   b. Minor arterial instead of major collector (weight of 2).
   c. AADT over 4000 vpd (weight of 1).
   d. Natural log of degree of curvature between 2 and 4 (top 10 percent weight of 3, next 40 percent weight of 2, remaining 50 percent weight of 1).
   e. Presence of an intersection (weight of 1).
   f. Presence of Type A warning signs (weight of 1).
   g. Presence of guardrail (weight of 1, if guardrail is not present).
   h. Presence of line up or down vertical curves (weight of 1, if vertical curve is present).
   i. Presence of reverse and compound horizontal curve transitions (weight of 2).
7. Overturn crashes on rural state curves of minor arterials, major collectors, and principal arterials - other – (KAB) 189 crashes over 831 miles (Maximum score of 14).
   a. Total shoulder width over 3 feet (weight of 1).
   b. Functional class is a major collector (weight of 1).
   c. Natural log of degree of curvature between 2 and 5 (top 10 percent weight of 3, next 40 percent weight of 2, remaining 50 percent weight of 1).
   d. AADT over 5000 vpd (weight of 1).
   e. Two through lanes (weight of 2).
   f. Presence of a crest vertical curve (weight of 1).
   g. Any guardrail is present (weight of 1, if guardrail is not present).
   h. Presence of Type A warning sign (weight of 1).
   i. Presence of intersections (weight of 1).
   j. Presence of short structures (weight of 1).
   k. Posted speed limit over 45 mph (weight of 1).

8. Run-off road crashes on rural state curves of minor arterials and major collectors – (KA) 161 crashes over 717 miles (Maximum score of 11).
    a. Total shoulder width over 3 feet (weight of 1).
    b. Functional class is minor arterial (weight of 1).
    c. AADT over 3000 vpd (weight of 1).
    d. Presence of compound horizontal curves (weight of 1).
    e. Presence of Type A warning signs (weight of 1).
    f. Posted speed limit over 35 mph (weight of 1).
    g. Presence of crest vertical curves (weight of 1).
    h. Presence of intersections (weight of 1).
    i. Natural log of degree of curvature between 2 and 5 (top 10 percent weight of 3, next 40 percent weight of 2, remaining 50 percent weight of 1).
    j. Presence of long structures (weight of -1).
9. Fixed object crashes on rural state curves of minor arterials and major collectors – (KA) 105 crashes over 717 miles (Maximum score of 11).
    a. The segment is two lanes (weight of 2).
    b. Average shoulder width less than 5 feet wide (weight of 1).
    c. Speed limit over 45 mph (weight of 1).
    d. Natural log of AADT exceeds 8 (AADT exceeds 2980 vpd) (weight of 2).
    e. The curve is not independent (weight of 1).
    f. An intersection is present within the curve (weight of 1).
    g. Natural log of degree from 2 to 5 degrees (top 10 percent weight of 3, next 40 percent weight of 2, remaining 50 percent weight of 1).
10. Night-time run-off road crashes on rural state curves of minor arterials and major collectors – (KAB) 202 crashes over 717 miles (Maximum score of 10).
    a. Total shoulder width less than 5 feet (weight of 1).
    b. Functional class is a minor arterial (weight of 1).
    c. Horizontal curve is not independent (weight of 1).
    d. AADT over 3000 vpd (weight of 1).
    e. No guardrail present (weight of 1).
    f. Presence of intersections (weight of 1).
    g. Presence of short structures (weight of 1).

   h. Natural log of degree of curvature (top 10 percent weight of 3, next 40 percent weight of 2, remaining 50 percent weight of 1).

11. Overturn crashes on Interstates – (KA) 54 crashes over 716 miles (Maximum score of 4).
    a. AADT (weight of 0 to 1, continuous).
    b. Lack of guardrail (weight of 1).
    c. Type A warning signs (weight of 2).
12. Head on crashes on rural state tangents of minor arterials, major collectors, and principal arterials – other – (KAB) 137 crashes over 1,234 miles (Maximum score of 8).
    a. AADT over 3,000 vpd (weight of 2).
    b. Functional class is a minor arterial (weight of 1).
    c. Absence of outside rumble strips (weight of 2).
    d. Presence of guardrail (weight of 1).
    e. Sum of average lane and shoulder width is less than 15 feet (weight of 1).
    f. Natural Log of traffic volumes (weight of 0 to 1, continuous).
13. Overturn crashes on rural state tangents of minor arterials, major collectors, and principal arterials – other – (KAB) 211 crashes over 1,234 miles (Maximum score of 6).
    a. Presence of Intersections (weight of 1).
    b. AADT over 2,000 vpd (weight of 1).
    c. Posted speed limit over 35 mph (weight of 1).
    d. Presence of rumble strips along the centerline (weight of 1).
    e. Average shoulder width 5 feet or less (weight of 1).
    f. Natural log of AADT (weight of 0-1, continuous).
14. Run-off road crashes on rural state tangents of minor arterials and major collectors. – (KA) 116 crashes over 1,020 miles (Maximum score of 6).
    a. Speed limit over 45 mph (weight of 1).
    b. Functional class is minor arterial (weight of 1).
    c. Average shoulder width is over 5 feet (weight of 1).
    d. Intersection is present in segment (weight of 1).
    e. AADT under 9000 vpd (weight of 1).
    f. Natural log of AADT (weight of 0-1, continuous).