

MEMO

To: OTO
From: Lochmueller Group
Date: June 18, 2024
Subject: OTO Safety Action Plan – Safety Analysis (FINAL)

Systemic Safety Analysis

A systemic approach to safety includes developing countermeasures at locations with the greatest risk of fatal and serious injury crashes. A systemic safety analysis is a data-driven, multi-step process that includes identifying and evaluating risk factors, identifying locations with the greatest risk, and selecting appropriate countermeasures to mitigate risk and improve safety outcomes. Different from a typical network screening methodology that relies on observed crash history to identify high crash locations, such as a high injury network, a systemic safety analysis identifies high-risk roadway features throughout the network to identify locations with the greatest risk. The purpose of the systemic safety analysis is to evaluate the risk of roadway characteristics, identify locations with the greatest risk of fatal and serious injuries, and to develop systemic safety countermeasures to improve safety outcomes throughout the network.

Note: The identification of risk factors does not mean that a certain roadway feature contributes or causes fatal or serious injury crashes. Rather, risk factors are simply used to identify common features of roadways on which fatal and serious injury crashes occur in order to identify other roadways with similar risk.

Data

All data for this project was acquired and provided by OTO. Historic crashes included 5-year data from 2018 through 2022, originally sourced from MoDOT. Crash data was enriched by OTO to include roadway characteristics, demographics, and other contextual details. Roadway characteristic data was originally sourced from MoDOT; some roadway characteristic data are only available for roadways on the state system.

Definitions

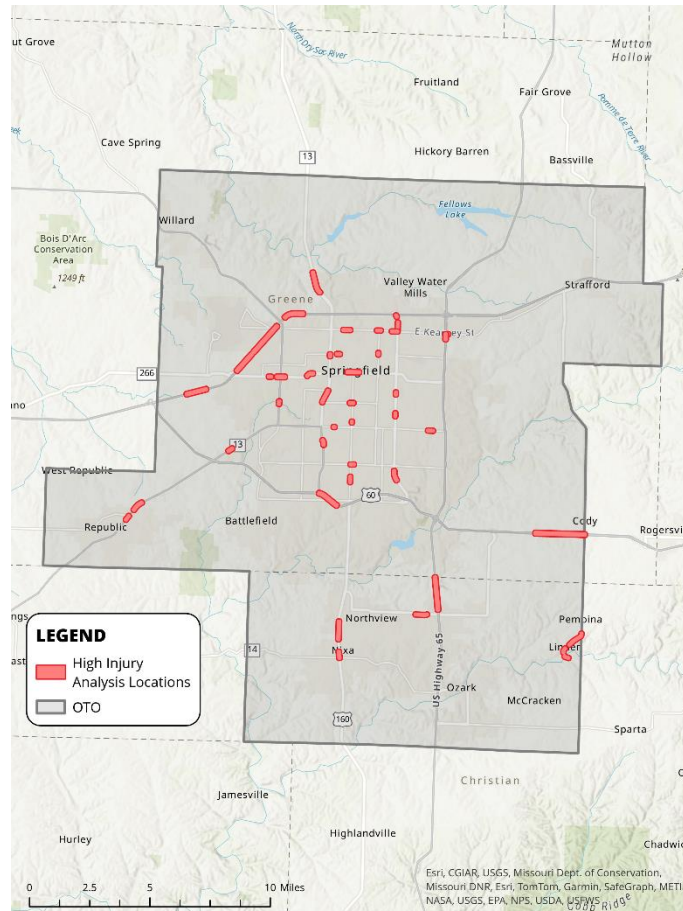
- **Risk** – exposure to a crash that results in a fatal or serious injury.
- **Killed or Seriously Injured (KSI)** – any crash that results in a fatal or serious injury.
- **Risk Factor** – roadway characteristic or other contextual feature that increases risk of a KSI crash; risk factors are ratios based on the percentage of KSI crashes and roadway length (or other appropriate roadway measure).
- **High Injury Analysis Location** – developed by OTO, these 40 locations are a subset of the high injury network that experience a high number of KSI crashes and collectively illustrate various roadway types, roadway characteristics, and member jurisdictions throughout the OTO region.

- **High-Risk (Roadway) Feature** – roadway features with a risk factor greater than one are considered a high-risk roadway feature.
- **Risk Index** – a composite index that combines includes all high-risk roadway features in a single index score that can be mapped and visualized to assess overall risk throughout the network.

Risk Factors Methodology

To focus the analysis on high-risk roadway features that contribute to Killed or Serious Injury (KSI) crashes, OTO identified 40 high injury analysis locations. The high injury analysis locations are all located on the high injury network, experience a high number of KSI crashes, and collectively illustrate various roadway types, roadway characteristics, and member jurisdictions throughout the OTO region. **Only KSI crashes at high injury analysis locations were used to determine risk factors.** From 2018-2022, there were 269 KSI crashes within the high injury analysis locations, representing about 25% of all KSI crashes in the OTO region. The high injury analysis locations are shown in Figure 1.

FIGURE 1: HIGH INJURY ANALYSIS LOCATIONS



Ten roadway characteristics were selected and included in the development of risk factors. For each roadway characteristic, the percentage of KSI crashes was compared to the percentage of roadway length or other roadway measure to determine the risk factor for that characteristic. Roadway features with risk factors above one have a higher-than-average risk and are considered a high-risk roadway feature. The ten roadway characteristics include:

- Intersection Type
- Functional Classification
- Number of Lanes
- Shoulder Type
- Shoulder Width
- Access Control
- Horizontal Curvature
- Roadway Type
- Area Type
- Multimodal Activity

$$\text{Risk Factor} = \frac{\text{Percent of KSI Crashes}}{\text{Percent of Roadway Length}}$$

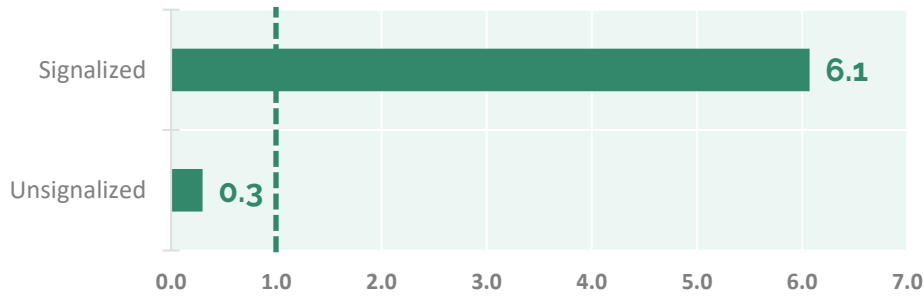
For example, if 30% of KSI crashes occurred along 20% of roadways (length) with a given feature, the risk factor calculation is 30%/20% for a risk factor of 1.5. In this example, roadways with the given risk feature have 1.5 times the expected number of KSI crashes.

Once risk factors were calculated for each of the roadway features, an index scoring system was created. The index scoring system was used to create a risk index and determine the highest risk locations to include in the application of systemic countermeasures. More information on the risk index is found in the Regional Risk Assessment.

Intersection Type

Signalized intersections have a greater percentage of KSI crashes relative to the percentage of all intersections. With a risk factor of 6.1, signalized intersections have 6.1 times the average number of KSI crashes.

FIGURE 2: INTERSECTION TYPE RISK FACTORS

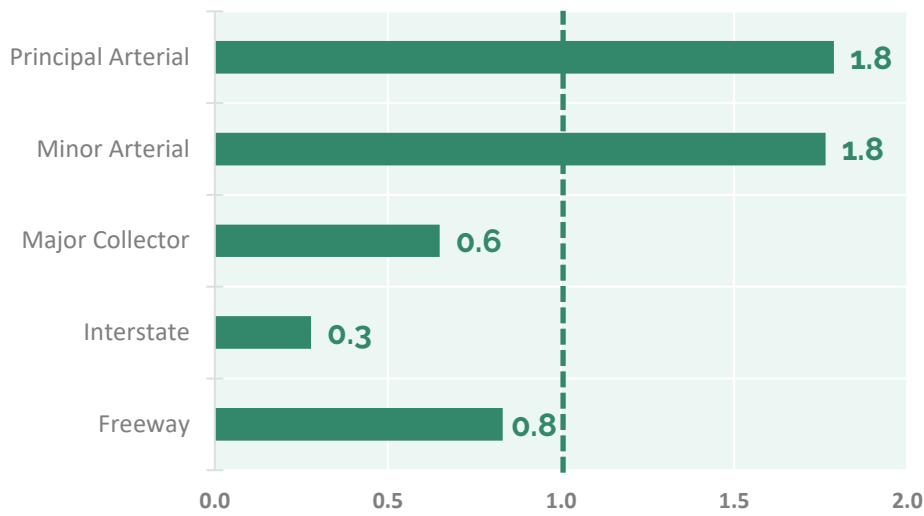


Intersection Type	Percent of KSI Crashes	Percent of Intersections	Risk Factor
Signalized Intersection	73.7%	12.2%	6.1
Unsignalized Intersection	26.3%	87.8%	0.3

Functional Classification

Minor arterials and major arterials both have risk factors of 1.8. No other functional classification has a risk factor greater than one. Functional classes such as local and minor collector were not included in the high injury analysis locations and therefore not included in the risk factor analysis.

FIGURE 3: FUNCTIONAL CLASSIFICATION RISK FACTORS

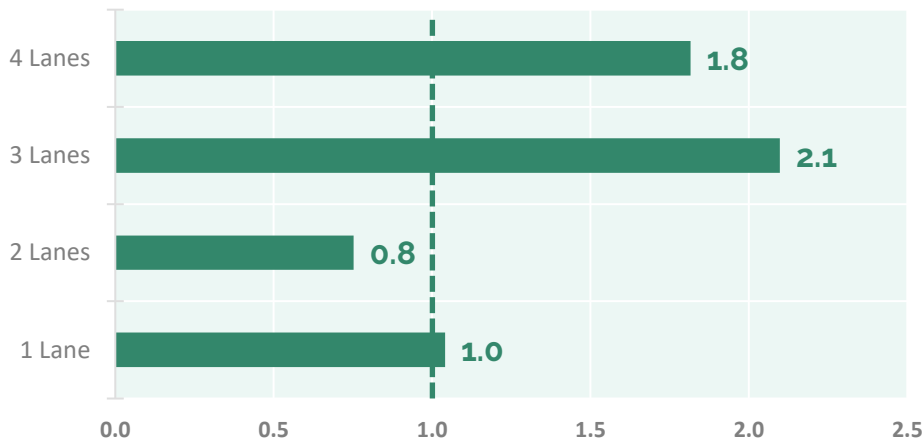


Functional Class	Percent of KSI Crashes	Percent of Roadway Length	Risk Factor
Freeway	39.4%	47.3%	0.8
Interstate	4.7%	16.8%	0.3
Major Collector	4.5%	7.0%	0.6
Minor Arterial	16.5%	9.3%	1.8
Principal Arterial	35.5%	19.6%	1.8

Number of Lanes

Roadways with a high number of lanes are more likely to have a higher percentage of KSI crashes relative to roadway length. The number of lanes represent the directional total. Both 3- and 4-lane roadway configurations are considered high-risk features with risk factors greater than 1 (2.1 and 1.8 respectively).

FIGURE 4: NUMBER OF LANES RISK FACTORS

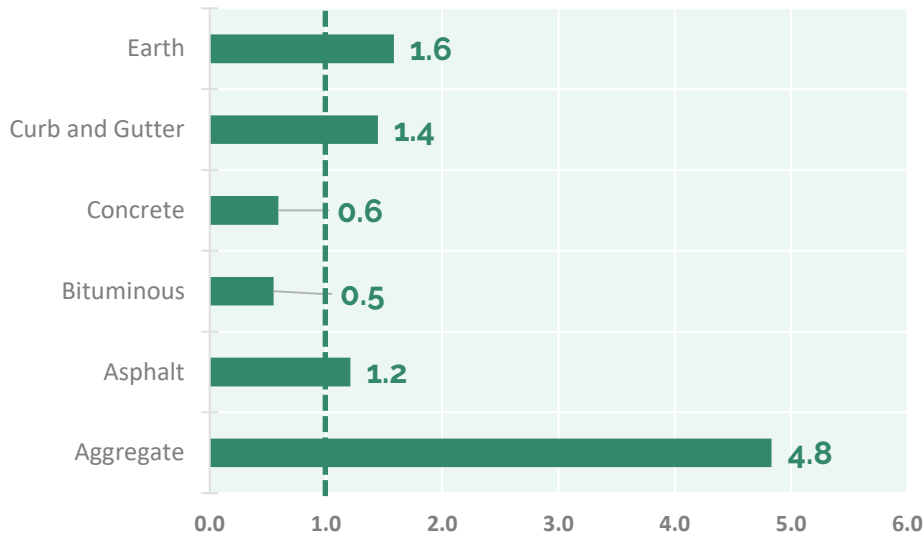


Number of Lanes	Percent of KSI Crashes	Percent of Roadway Length	Risk Factor
1 lane	19.3%	18.5%	1.0
2 lanes	50.5%	67.0%	0.8
3 lanes	30.0%	14.3%	2.1
4 lanes	0.3%	0.2%	1.8

Shoulder Type

For the purpose of this risk analysis, similar shoulder types were grouped together to establish a smaller number of similar shoulder types. Aggregate shoulder types have the highest risk factor but are present in just 1% of roadways. Earth, curb and gutter, and asphalt are each considered high-risk features with risk factors greater than one.

FIGURE 5: SHOULDER TYPE RISK FACTORS

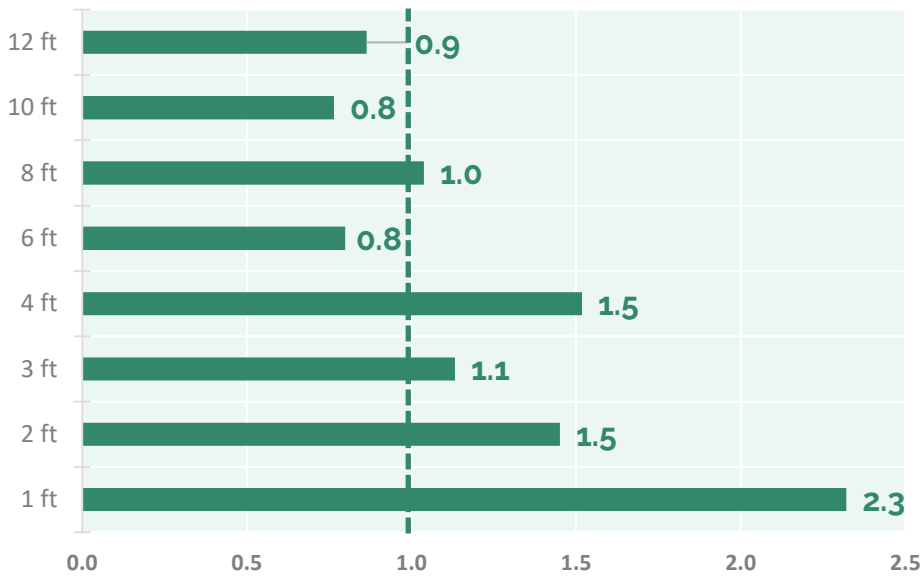


Shoulder Type	Percent of KSI Crashes	Percent of Roadway Length	Risk Factor
Aggregate	4.8%	1.0%	4.8
Asphalt	25.7%	21.2%	1.2
Bituminous	24.5%	44.7%	0.5
Concrete	2.6%	4.4%	0.6
Curb and Gutter	32.7%	22.6%	1.4
Earth	9.7%	6.1%	1.6

Shoulder Width

Shoulder widths range from one foot to twelve feet. Narrower shoulder widths of four feet and under are considered high-risk features with risk factors greater than one. Roadways with one-foot shoulders have the highest risk factor of 2.3.

FIGURE 6: SHOULDER WIDTH RISK FACTORS

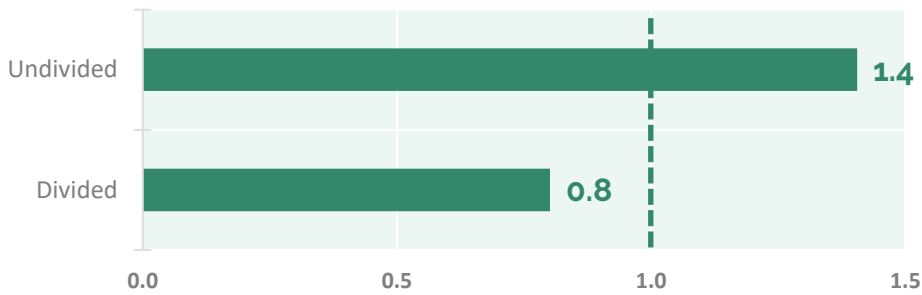


Shoulder Width	Percent of KSI Crashes	Percent of Roadway Length	Risk Factor
1ft	6.6%	2.8%	2.3
2ft	20.1%	13.9%	1.5
3ft	17.8%	15.7%	1.1
4ft	3.5%	2.3%	1.5
6ft	2.4%	3.0%	0.8
8ft	6.8%	6.6%	1.0
10ft	41.2%	53.9%	0.8
12ft	1.6%	1.8%	0.9

Median Access Control

Median access control refers to the presence of a center median and if the roadway is considered a divided roadway. Undivided roadways experience a higher share of KSI crashes and are considered a high-risk feature with a risk factor of 1.4.

FIGURE 7: MEDIAN ACCESS CONTROL RISK FACTORS



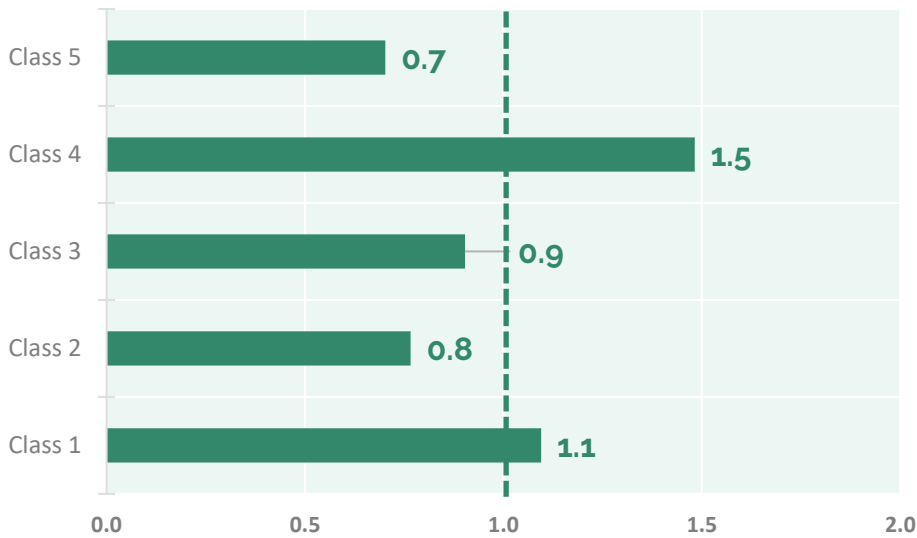
Median Access Control	Percent of KSI Crashes	Percent of Roadway Length	Risk Factor
Divided	53.7%	67.1%	0.8
Undivided	46.3%	32.9%	1.4

Horizontal Curvature

To assess horizontal curvature, curves within the high injury analysis locations were classified by quantile class to create five classes with an approximately equal number of curves. Curves classes range from class 1 which includes curves with the highest radii to class 5 which includes the lowest radii (sharpest curves are class 5).

Nationally, roadway curves are present in around 25% of all fatal crashes and curves generally experience more crashes than straight roadway segments. Curve classes 1-3 each have a risk factor near one, while class 4 curves experience a greater percentage of KSI crashes with a risk factor of 1.5. Class 5 curves experience a lower share of KSI crashes with a risk factor of just 0.7 even though it could be assumed that a sharper curve would experience more serious crashes. This could be due to the analysis being focused on the high injury analysis locations or that sharper curves cause drivers to significantly reduce speed and therefore reduce the risk of a serious injury crash.

FIGURE 8: HORIZONTAL CURVATURE RISK FACTORS



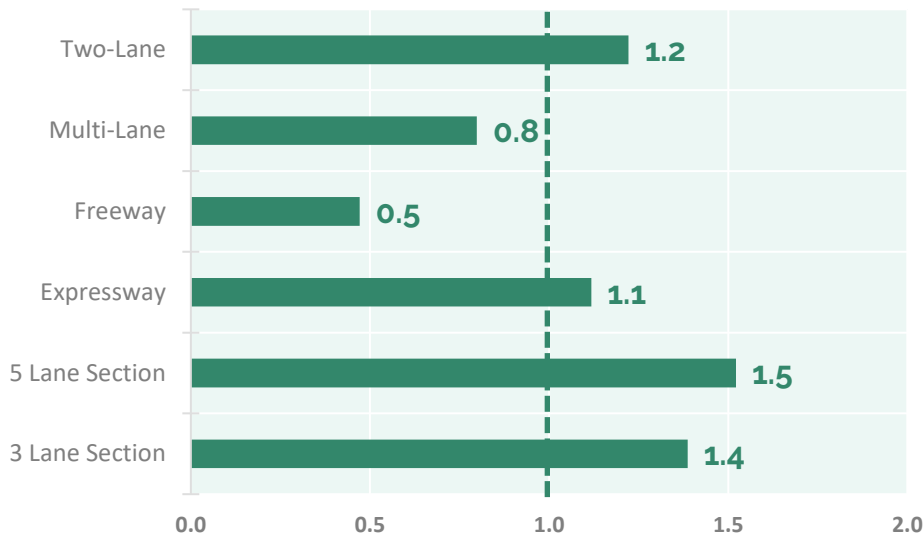
Curve Class	Percent of KSI Crashes	Percent of Curves	Risk Factor
Class 1	20.4%	18.6%	1.1
Class 2	14.3%	18.6%	0.8
Class 3	18.4%	20.3%	0.9
Class 4	32.7%	22.0%	1.5
Class 5	14.3%	20.3%	0.7

Roadway Type

Roadway types are categories of roadway as defined by MoDOT. Roadway type categories may combine other risk features such as access control, number of lanes, lane width, and/or shoulder types.

Most likely an outlier due to the analysis looking exclusively at the high injury analysis locations, one-way roadways have a risk factor of 12.0. This is far outside the range seen by other roadway types and is also based on less than 1% of roadway length being of this type. Both 3-lane and 5-lane sections have higher percentages of KSI crashes with risk factors of 1.4 and 1.5, respectively. 2-lane roadway types also experience a higher percentage of KSI crashes with a risk factor of 1.2.

FIGURE 9: ROADWAY TYPE RISK FACTORS



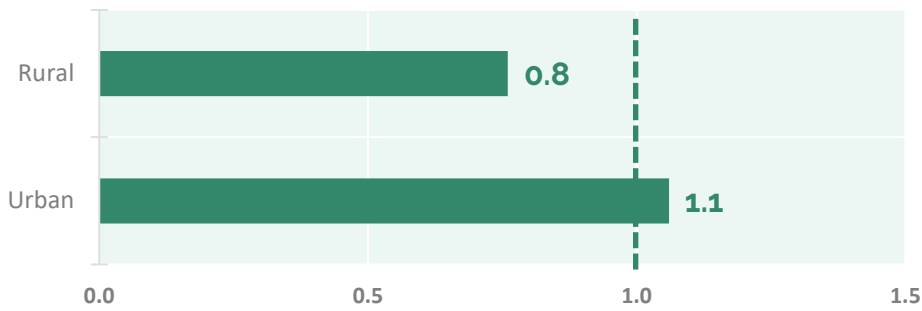
*Risk factor for one-way roadway type is not shown on chart and is not included in the risk index.

Roadway Type	Percent of KSI Crashes	Percent of Roadway Length	Risk Factor
3-Lane Section	3.7%	2.7%	1.4
5-Lane Section	27.5%	18.1%	1.5
Expressway	37.9%	33.9%	1.1
Freeway	12.3%	26.0%	0.5
Multi-Lane	4.5%	5.6%	0.8
One-Way	2.2%	0.2%	12.0
Two-Lane	11.9%	9.7%	1.2

Area Type

Area type refers to whether the location of the roadway or crash is within the Springfield, MO urbanized area. Roadways within the urban area have a higher percentage of KSI crashes with a risk factor of 1.1.

FIGURE 10: AREA TYPE RISK FACTORS

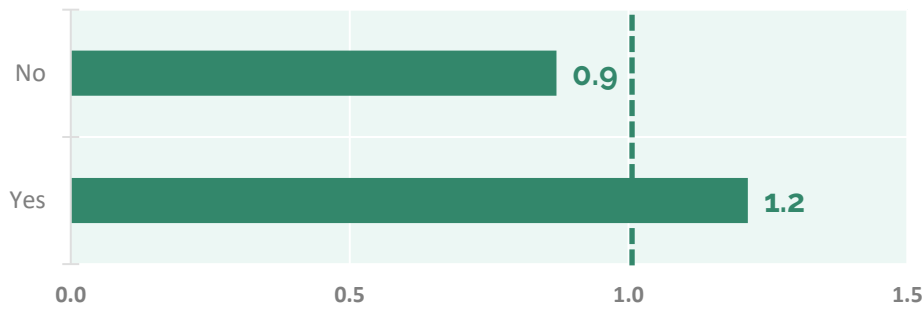


Area Type	Percent of KSI Crashes	Percent of Roadway Length	Risk Factor
Urban	84.8%	80.0%	1.1
Rural	15.2%	20.0%	0.8

Multimodal Activity

Multimodal activity refers to proximity to a dedicated bicycle or pedestrian facility such as a trail, trailhead, greenway, or bike route. Proximity to a multimodal facility considers the risk of vulnerable road users (VRUs) and the likelihood of vulnerable road users experiencing a serious injury as a result of a crash with a vehicle. Conflicts between VRUs and vehicles are more likely to occur in locations with greater bicyclist and pedestrian activity. Roadways within ¼ of a dedicated multimodal facility experience a higher percentage of KSI crashes with a risk factor of 1.2.

FIGURE 11: MULTIMODAL ACTIVITY RISK FACTORS



Multimodal Activity	Percent of KSI Crashes	Percent of Roadway Length	Risk Factor
Yes	45.7%	37.7%	1.2
No	54.3%	62.3%	0.9

Regional Risk Assessment

Roadway features were selected and evaluated for the development of risk factors based on KSI crashes observed at OTO high injury analysis locations. To determine risk throughout the entire OTO regional network, risk factors were used to develop a risk index scoring system that was applied to the regional roadway network. The scoring system follows the process outlined in the Federal Highway Administration's (FHWA) ["Systemic Safety Project Selection Tool"](#). Roadway features that were found to have risk factors greater than one are considered high-risk features and are therefore included in the composite risk index.

The score for each high-risk feature is based on a confidence metric (KSI crash overrepresentation) and the total share of KSI crashes. High-risk features with a confidence of 10% or more AND a percent of KSI crashes of 30% or more are given a score of 1. High-risk features that do not meet both of these conditions are given a score of 0.5. The risk index scoring is shown in Table 1. The scores for all high-risk features are summed to create the risk index.

The results of the regional risk assessment (risk index) are shown in the maps in Figure 12, Figure 13, Figure 14, Figure 15, and Figure 16 where higher risk index means more high-risk features and/or more significant high-risk features. The risk index illustrates roadways with high-risk features based on the risk profile of the high injury analysis locations and helps identify locations at which to deploy a systemic application of safety countermeasures aimed at mitigating the risk of serious and fatal injury crashes. Corridors with higher risk index scores include:

- Grant Avenue
- National Avenue
- Glenstone Avenue
- S Campbell Avenue
- Kearney Street
- Division Street
- Chestnut Expressway
- Sunshine Street
- Battlefield Street
- Republic Street
- MO-14 (Nixa and Ozark)
- US-60 (Republic)

TABLE 1: HIGH-RISK FEATURE SCORING

Roadway Characteristic	High-Risk Feature	Risk Factor	Percent of KSI Crashes	Confidence	Score
Intersection Type	Signalized Intersection	6.1	73.7%	61.6%	1
Functional Class	Minor Arterial	1.8	16.5%	7.1%	0.5
	Principal Arterial	1.8	35.0%	15.4%	1
Shoulder Type	Aggregate	4.8	4.8%	3.8%	0.5
	Asphalt	1.2	25.7%	4.5%	0.5
	Curb and Gutter	1.4	32.7%	10.1%	1
	Earth	1.6	9.7%	3.6%	0.5
Shoulder Width	1ft	2.3	6.6%	3.7%	0.5
	2ft	1.5	20.1%	6.3%	0.5
	3ft	1.1	17.8%	2.1%	0.5
	4ft	1.5	3.5%	1.2%	0.5
Number of Lanes	3 lanes	2.1	30.0%	15.7%	1
	4 lanes	1.8	0.3%	0.1%	0.5
Undivided	Undivided	1.4	46.3%	13.3%	1
Horizontal Curvature	Class 4	1.5	32.7%	10.6%	1
Multimodal Activity	Yes	1.2	45.7%	8.1%	0.5
Area Type	Urban	1.1	84.8%	4.8%	0.5
Roadway Type	3 Lane Section	1.4	3.7%	1.0%	0.5
	5 Lane Section	1.5	27.5%	9.4%	0.5
	Expressway	1.1	37.9%	4.0%	0.5
	Two Lane	1.2	11.90%	2.2%	0.5

FIGURE 12: RISK INDEX, OTO

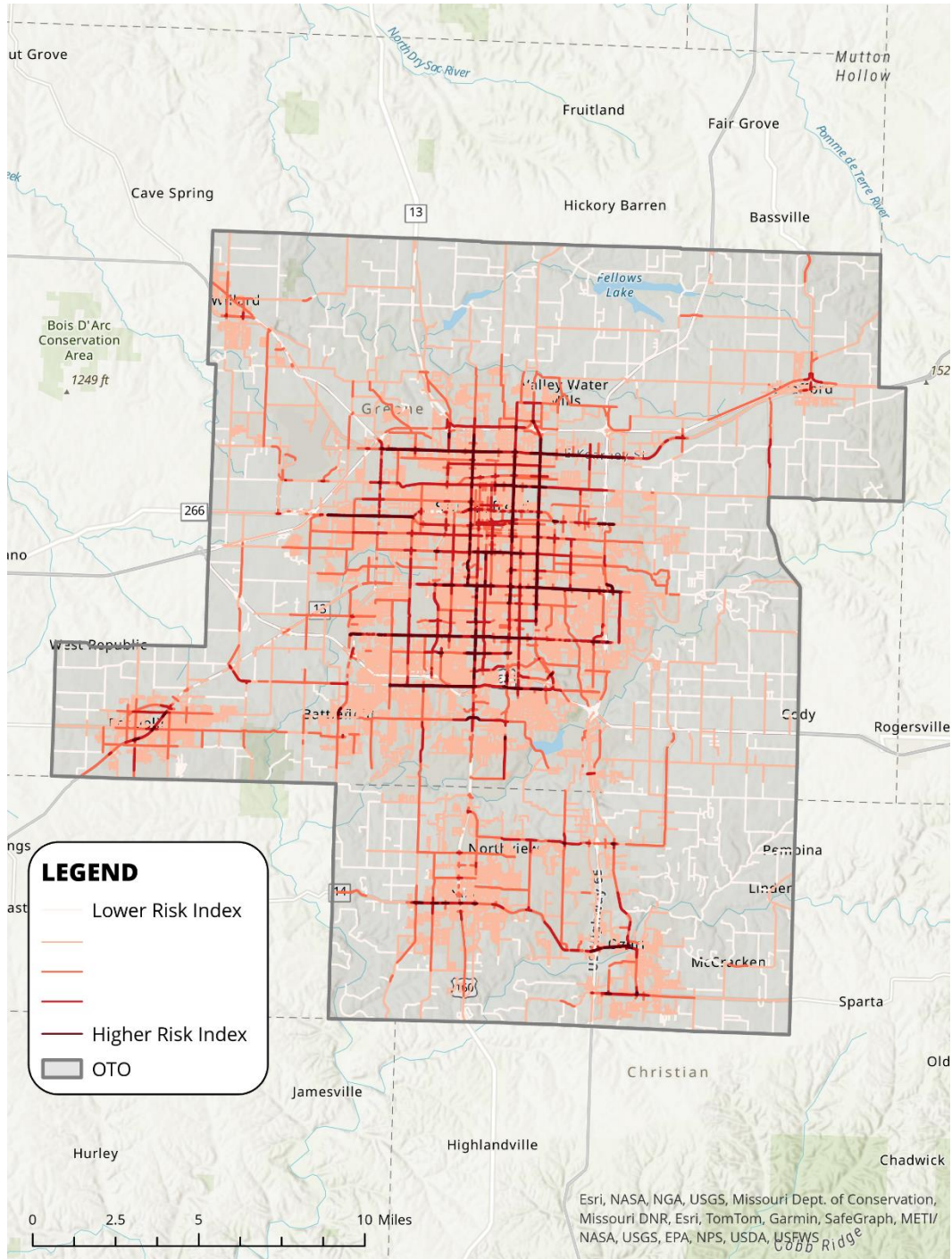


FIGURE 13: RISK INDEX, SPRINGFIELD

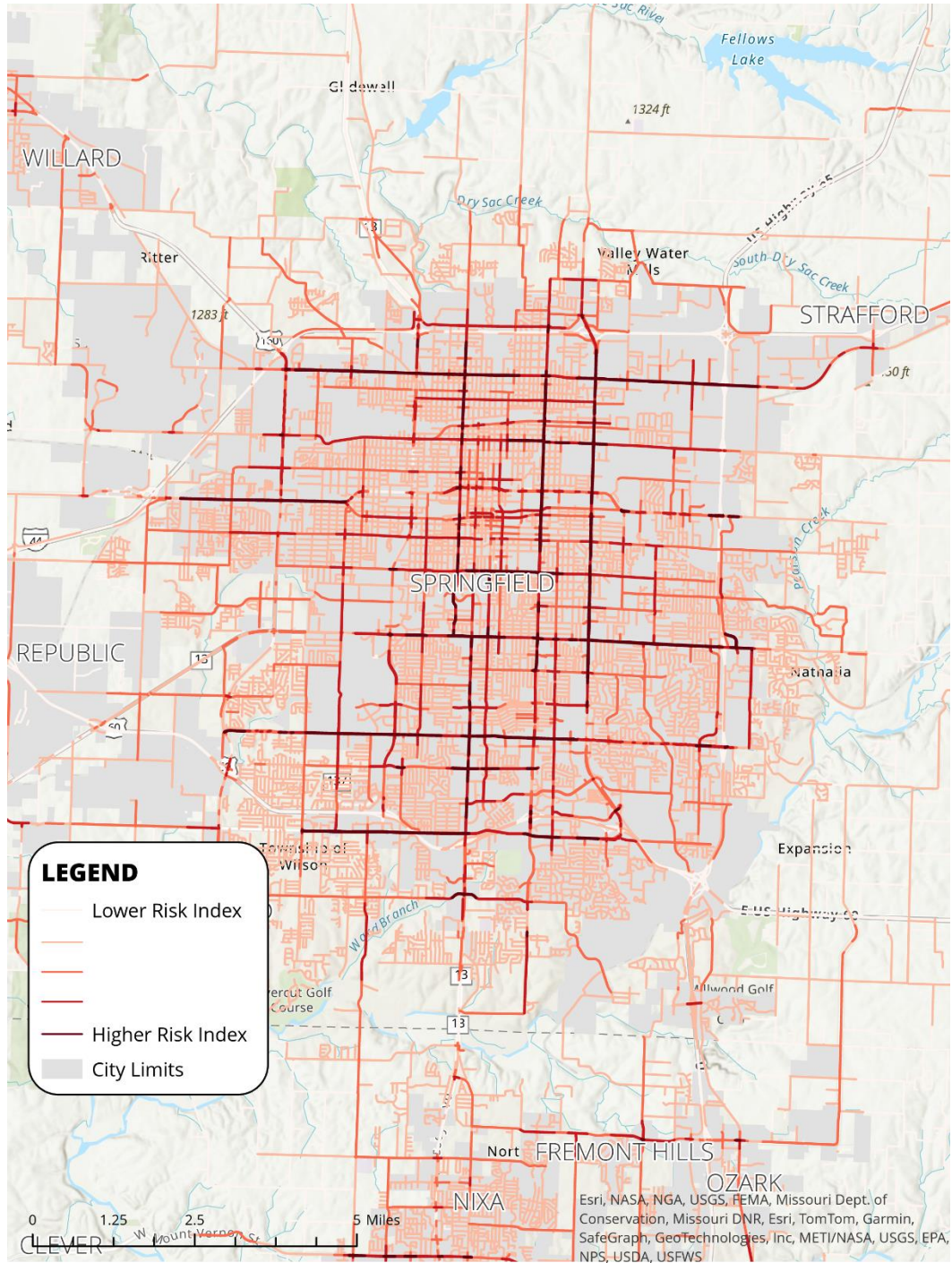


FIGURE 14: RISK INDEX, NIXA

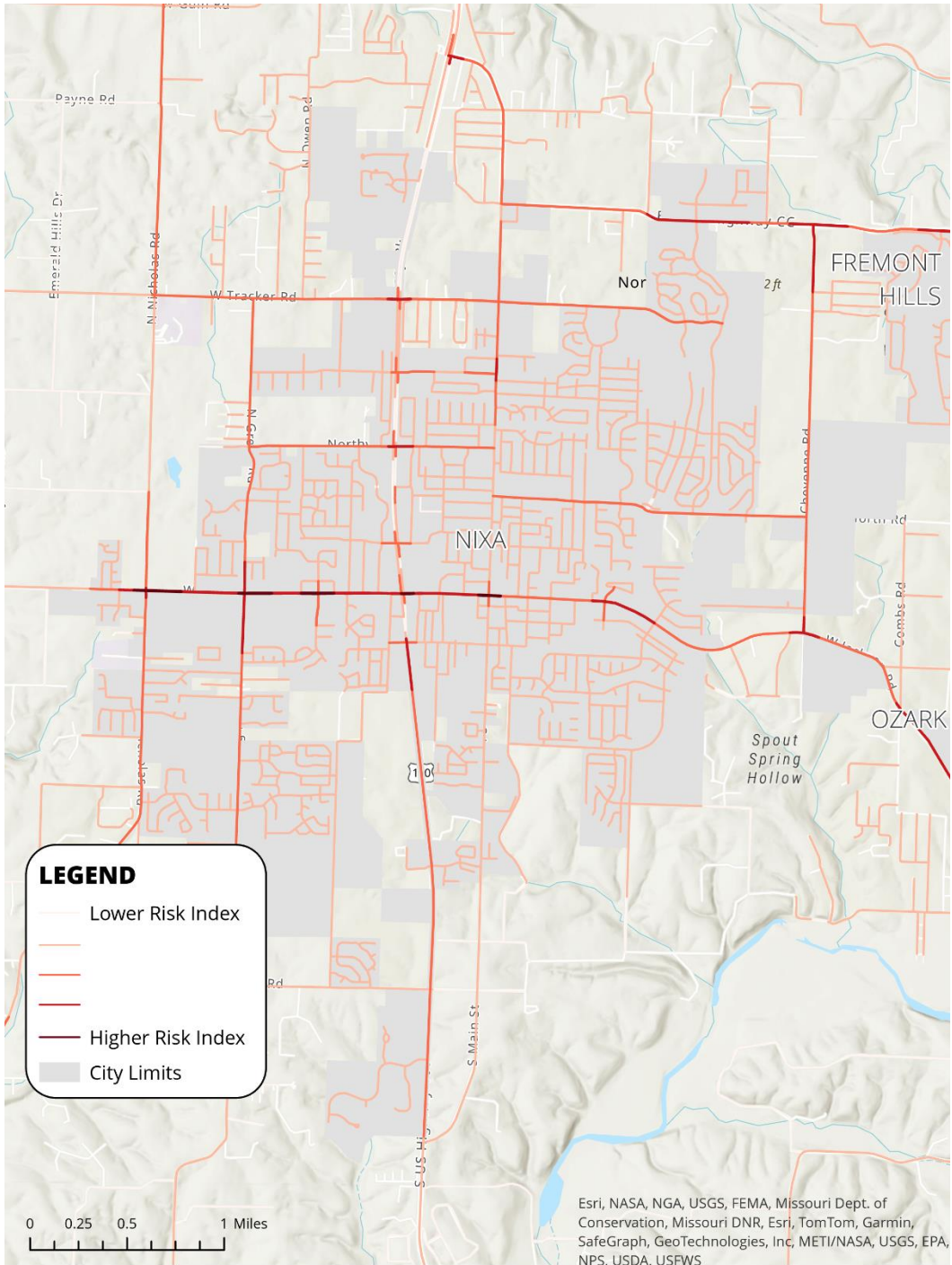


FIGURE 15: RISK INDEX, OZARK

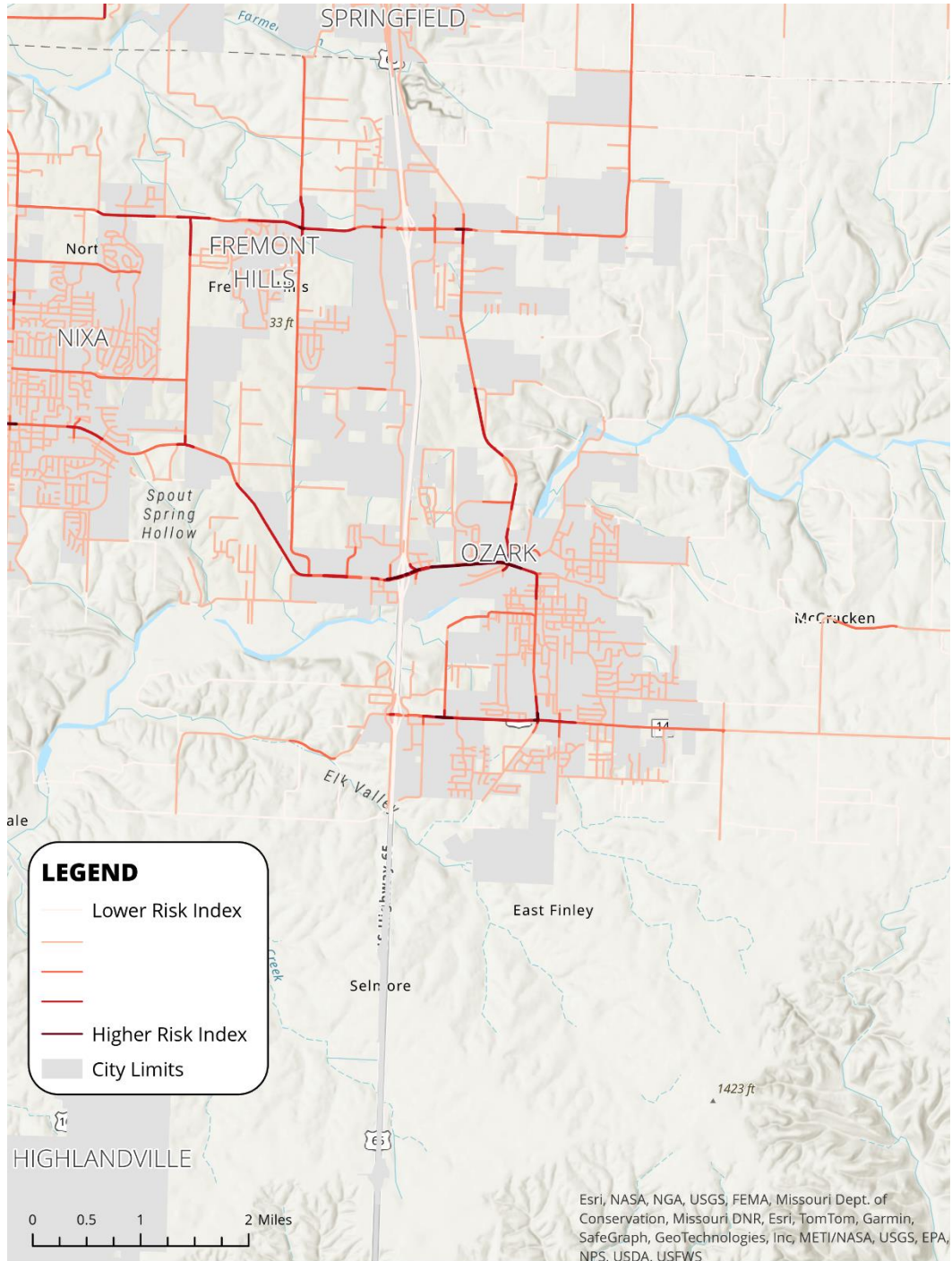
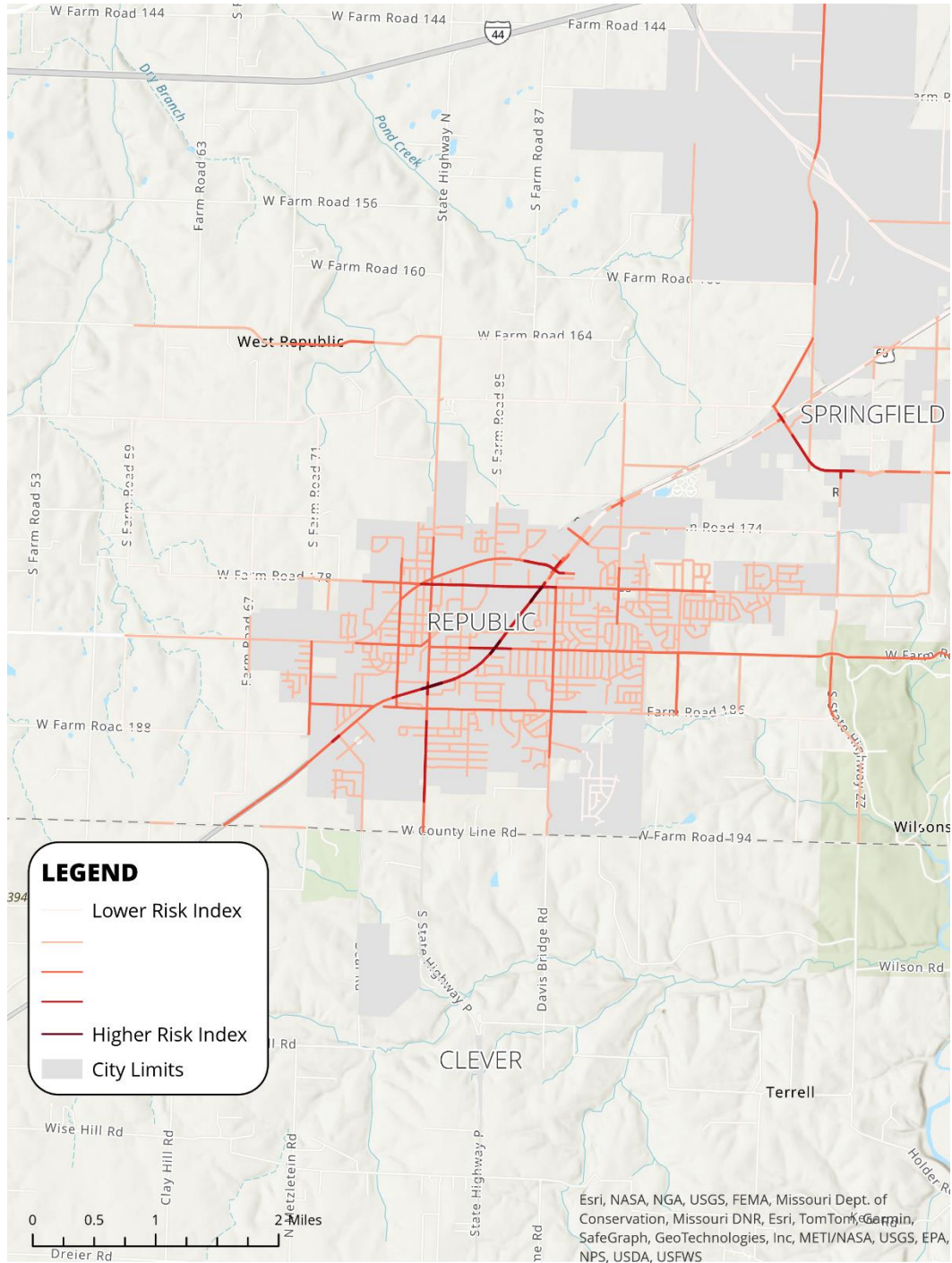


FIGURE 16: HIGH-RISK NETWORK, REPUBLIC



Systemic Strategies

To mitigate the effects of high-risk features along roadways throughout the OTO region, a systemic application of safety countermeasures is recommended. Each of the high-risk roadway features established in the risk factor analysis is listed along with the most frequently occurring crash types resulting in fatal and/or serious injuries. Finally, a set of recommended strategies is listed to mitigate risk and address the most frequently occurring KSI crash types. Recommended systemic strategies are shown in

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Table 2. Table 3 lists the mitigated high-risk features for each systemic strategy. All recommended strategies are proven safety countermeasures and consider risk factors and prevailing crash types. Each recommendation is linked to a source for more information on effectiveness, applicability, and/or other considerations.

TABLE 2: RECOMMENDED SYSTEMIC STRATEGIES

Roadway Characteristic	High-Risk Feature	Top KSI Crash Types	Recommended Systemic Strategies
Intersection Type	Signalized Intersection	Left Turn (34%) Left Turn Right Angle (12%) Out of Control (11%) Head On (11%) Pedestrian/Bicyclist (11%)	<u>Retroreflective Backplates</u> <u>Roundabouts</u> <u>Yellow Change Intervals</u> <u>Leading Pedestrian Intervals</u> <u>Crosswalk Enhancements</u> <u>Pedestrian Refuge Islands</u> <u>Permissive to Protected Left Turn</u> <u>Improved Channelized Right Turn Angle</u> <u>Dilemma Zone Detection</u> <u>Left Turn Offset Improvement</u>
Functional Class	Minor/Principal Arterial	Out of Control (18%) Left Turn (16%) Pedestrian/Bicyclist (14%) Rear End (12%) Right Angle (11%)	<u>Road Diets</u> <u>Corridor Access Management</u> <u>Dilemma Zone Detection</u> <u>Median Barriers</u> <u>Sidewalks</u> <u>Shared Use Paths</u> <u>Left or Right Turn</u>
Shoulder Type	Aggregate	Left Turn Right Angle (23%) Left Turn (23%) Pedestrian/Bicyclist (23%)	<u>Enhanced Delineation</u> <u>Curve Improvements</u> <u>High Friction Surface Treatment</u>
	Asphalt	Out of Control (26%) Rear End (21%)	<u>Enhanced Delineation</u> <u>Curve Improvements</u> <u>High Friction Surface Treatment</u> <u>Rumble Strips</u>
	Curb and Gutter	Out of Control (17%) Left Turn (17%) Pedestrian/Bicyclist (16%)	<u>Enhanced Delineation</u> <u>Bicycle Lanes</u> <u>Pedestrian Hybrid Beacons (PHBs)</u> <u>Rectangular Rapid Flashing Beacons (RRFBs)</u>
	Earth	Out of Control (28%) Pedestrian/Bicyclist (15%) Head On (13%)	<u>Enhanced Delineation</u> <u>Curve Improvements</u> <u>Shared Use Paths</u>
Shoulder Width	1ft – 4ft	Out of Control (26%) Left Turn (14%) Pedestrian/Bicyclist (13%) Right Angle (11%)	<u>Enhanced Delineation</u> <u>Curve Improvements</u> <u>Rumble Strips</u> <u>High Friction Surface Treatment</u>

Roadway Characteristic	High-Risk Feature	Top KSI Crash Types	Recommended Systemic Strategies
Number of Lanes	3+ lanes	Out of Control (17%) Pedestrian/Bicyclist (15%) Left Turn (15%) Rear End (14%)	Road Diets Corridor Access Management Median Barriers Sidewalks Shared Use Paths
Undivided	Undivided	Out of Control (26%) Pedestrian/Bicyclist (13%) Left Turn (12%) Right Angle (12%) Head On (10%)	Enhanced Delineation Rumble Strips High Friction Surface Treatment Intersection Conflict Warning
Horizontal Curvature	Class 4	Out of Control (31%) Left Turn (19%) Rear End (13%)	Enhanced Delineation Curve Improvements Rumble Strips High Friction Surface Treatment Guardrail, Clear Zone
Multimodal Activity	Yes	Out of Control (26%) Pedestrian/Bicyclist (14%) Right Angle (14%) Left Turn (12%)	Road Diets Corridor Access Management Dynamic Speed Displays Intersection Conflict Warning Shared Use Paths Pedestrian Refuge Islands Sidewalks Yellow Change Intervals Leading Pedestrian Intervals Crosswalk Enhancements Pedestrian Hybrid Beacons (PHBs) Rectangular Rapid Flashing Beacons (RRFBs) Roadway Lighting
Area Type	Urban	Out of Control (25%) Pedestrian/Bicyclist (14%) Left Turn (13%) Right Angle (11%) Rear End (11%)	Road Diets Corridor Access Management Sidewalks Shared Use Paths Pedestrian Refuge Islands Permissive to Protected Left Turn Pedestrian Hybrid Beacons (PHBs) Rectangular Rapid Flashing Beacons (RRFBs) Roadway Lighting

Roadway Characteristic	High-Risk Feature	Top KSI Crash Types	Recommended Systemic Strategies
Roadway Type	Two-Lane	Out of Control (38%) Pedestrian/Bicyclist (11%) Right Angle (10%)	Enhanced Delineation Curve Improvements Rumble Strips High Friction Surface Treatment Intersection Conflict Warning Dynamic Speed Displays Guardrail, Clear Zone Pedestrian Hybrid Beacons (PHBs)
	3-Lane Section	Out of Control (31%) Pedestrian/Bicyclist (17%) Right Angle (12%) Left Turn (12%)	Road Diets Corridor Access Management Dilemma Zone Detection Median Barriers Sidewalks Shared Use Paths Pedestrian Refuge Islands Permissive to Protected Left Turn Pedestrian Hybrid Beacons (PHBs)
	5-Lane Section	Left Turn (20%) Pedestrian/Bicyclist (16%) Out of Control (12%)	Road Diets Corridor Access Management Dilemma Zone Detection Median Barriers Sidewalks Shared Use Paths Pedestrian Refuge Islands Permissive to Protected Left Turn Rectangular Rapid Flashing Beacons (RRFBs)
	Expressway	Out of Control (26%) Rear End (14%) Left Turn (14%) Right Angle (14%)	Wider Edge Lines Dynamic Speed Displays Intersection Conflict Warning Roadway Lighting Median Barriers High Friction Surface Treatment

TABLE 3: MITIGATED HIGH-RISK FEATURES

Recommended Systemic Strategies	Mitigated High-Risk Features
Bicycle Lanes	Curb and Gutter Shoulder Types
Corridor Access Management	3+ lanes 3-Lane Sections 5-Lane Sections Minor/Principal Arterials Multimodal Activity Urban Areas
Crosswalk Enhancements	Multimodal Activity Signalized Intersections
Curve Improvements	1ft – 4ft Shoulder Widths Aggregate Shoulder Types Asphalt Shoulder Types Earth Shoulder Types Class 4 Curves Two-Lane Sections
Dilemma Zone Detection	3-Lane Sections 5-Lane Sections Minor/Principal Arterials Signalized Intersections
Dynamic Speed Displays	Expressways Two-Lane Sections Multimodal Activity
Enhanced Delineation	1ft – 4ft Shoulder Widths Aggregate Shoulder Types Asphalt Shoulder Types Curb and Gutter Shoulder Types Earth Shoulder Types Class 4 Curves Two-Lane Sections Undivided Roadways
Guardrail, Clear Zone	Class 4 Curves Two-Lane Sections
High Friction Surface Treatment	1ft – 4ft Shoulder Widths Aggregate Shoulder Types Asphalt Shoulder Types Class 4 Curves Expressways Two-Lane Sections Undivided Roadways
Improved Channelized Right Turn Angle	Signalized Intersections

Recommended Systemic Strategies	Mitigated High-Risk Features
Intersection Conflict Warning	Multimodal Activity Expressways Two-Lane Sections Undivided Roadways
Leading Pedestrian Intervals	Multimodal Activity Signalized Intersections
Left or Right Turn	Minor/Principal Arterials
Left Turn Offset Improvement	Signalized Intersections
Median Barriers	3+ lanes 3-Lane Sections 5-Lane Sections Expressways Minor/Principal Arterials
Pedestrian Hybrid Beacons (PHBs)	Curb and Gutter Shoulder Types Multimodal Activity Two-Lane Sections 3-Lane Sections Urban Areas
Pedestrian Refuge Islands	3-Lane Sections 5-Lane Sections Multimodal Activity Signalized Intersections Urban Areas
Permissive to Protected Left Turn	3-Lane Sections 5-Lane Sections Signalized Intersections Urban Areas
Rectangular Rapid Flashing Beacons (RRFBs)	Curb and Gutter Shoulder Types Multimodal Activity 5-Lane Sections Urban Areas
Retroreflective Backplates	Signalized Intersections
Road Diets	3+ lanes 3-Lane Sections 5-Lane Sections Minor/Principal Arterials Multimodal Activity Urban Areas
Roadway Lighting	Expressways Multimodal Activity Urban Areas

Recommended Systemic Strategies	Mitigated High-Risk Features
Roundabouts	Signalized Intersections
Rumble Strips	1ft – 4ft Shoulder Widths Asphalt Shoulder Types Class 4 Curves Two-Lane Sections Undivided Roadways
Shared Use Paths	Earth Shoulder Types 3+ lanes 3-Lane Sections 5-Lane Sections Minor/Principal Arterials Multimodal Activity Urban Areas
Sidewalks	3+ lanes 3-Lane Sections 5-Lane Sections Minor/Principal Arterials Multimodal Activity Urban Areas
Wider Edge Lines	Expressways
Yellow Change Intervals	Multimodal Activity Signalized Intersections