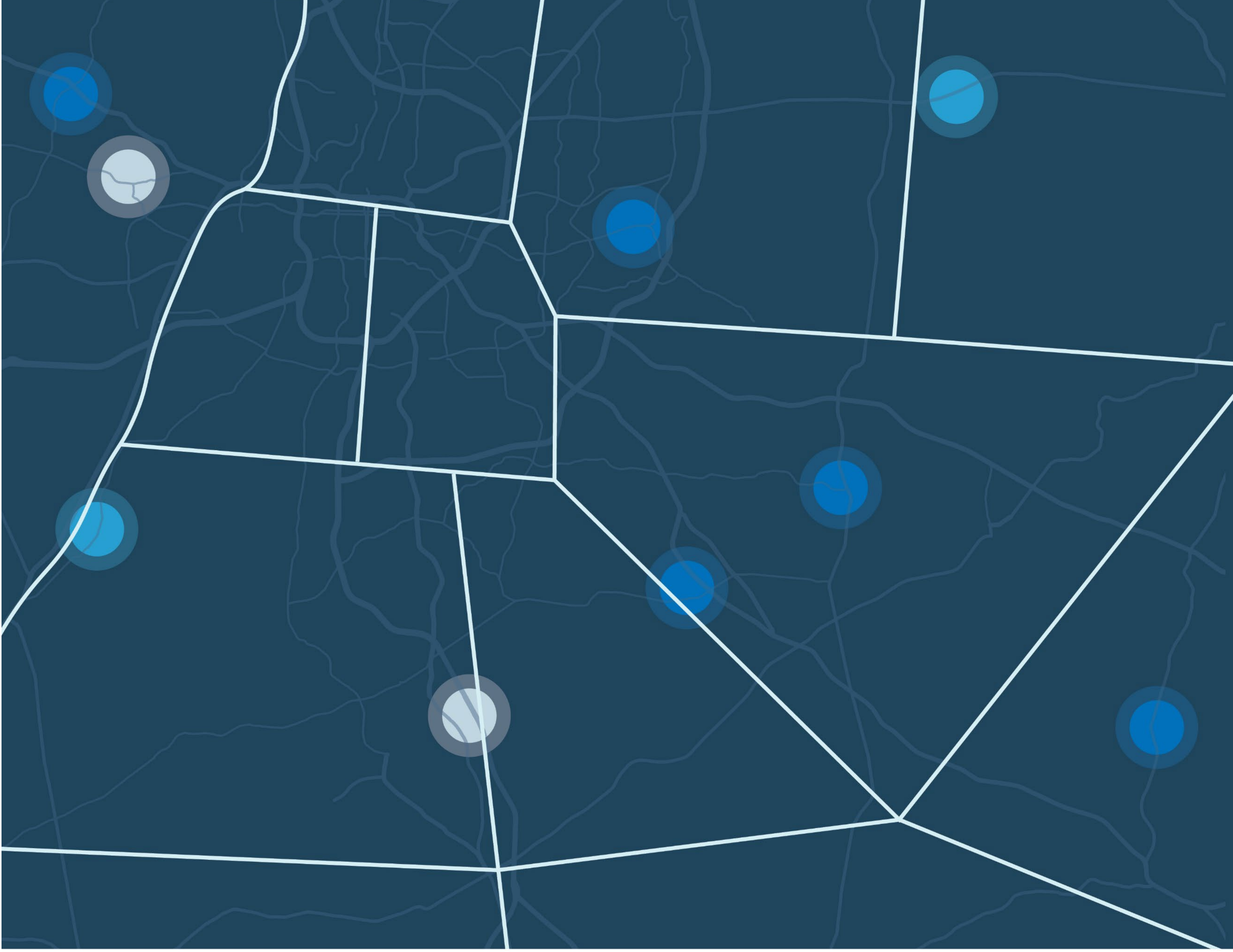

Application of DDSA for a Systemwide Safety Risk Assessment:

A How-To Guide

U.S. Department of Transportation
Federal Highway Administration

ZERO IS OUR GOAL
A SAFE SYSTEM IS HOW WE GET THERE

Introduction

Data-Driven Safety Analysis (DDSA) employs evidence-based models and methods that provide State and local agencies with the means to characterize safety performance. DDSA allows agencies to evaluate and assess safety performance similar to the way they evaluate and assess right-of-way and environmental impacts, traffic operations performance, and construction costs. DDSA seeks to provide reliable estimates of safety performance for existing and proposed conditions, helping agencies make more informed decisions, better targeted investments, and ultimately reduce the number of traffic fatalities and serious injuries occurring on their roadways. Figure 1 shows the benefits of applying DDSA. This guide demonstrates how transportation professionals can use DDSA to perform a systemwide safety risk assessment.

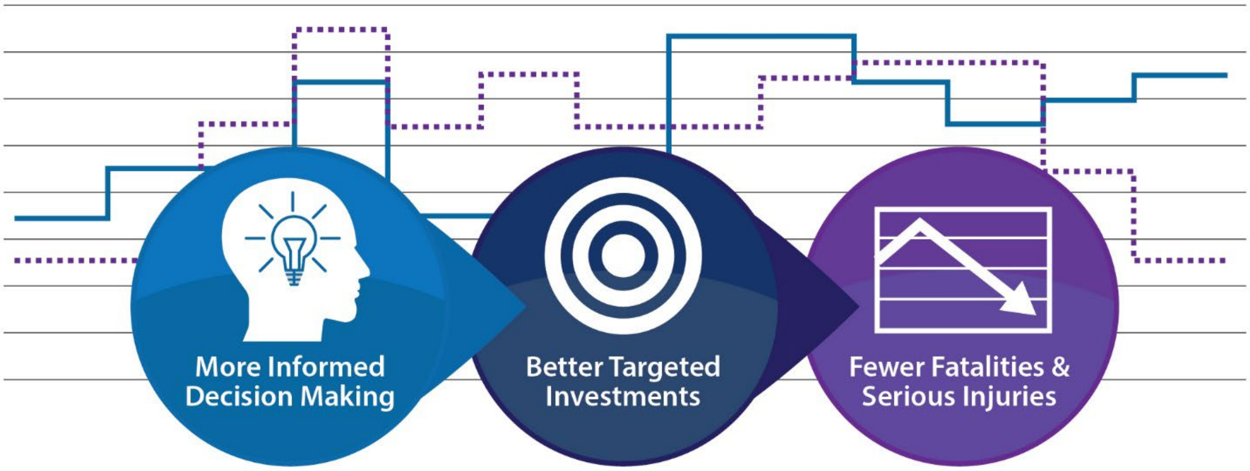

Figure 1. Graphic. Benefits of DDSA applications. Source: FHWA

In this guide, the Federal Highway Administration (FHWA) describes a scalable framework which transportation agencies can use to perform a systemwide safety risk assessment[1] of their roadway system. Such an approach is analogous to the traditional crash-based network screening methodology, with one clear distinction: whereas agencies traditionally assess roadways using crash-based measures (e.g., observed or expected crash frequency), this approach allows agencies to assess roadways using a risk-based approach (i.e., potential risk of a severe crash).

A notable example to follow for this procedure is European Union (EU) Directive 2019/1936, which requires a risk assessment of the roadway system in the EU. The International Road Assessment Programme (iRAP)[2], and its local variants, is a tool commonly used to perform such an assessment. This tool provides a level of service of safety using context-sensitive star ratings, where stars at a site are correlated with safer design features, such as wide lanes and wide shoulders. A version of iRAP was created for the United States, called the United States Road Assessment Program (usRAP)[3].

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[1] For this guide, FHWA is using the term "systemwide safety risk assessment" as a general term. Other potential terms used synonymously include systemwide risk assessment, risk-based network assessment, and risk-based system assessment. These terms are considered interchangeable and generally describe the relative rating of system components based on risk.

[2] https://irap.org/

[3] http://www.usrap.org/

The purpose of this How-To Guide is to describe a framework, guided by DDSA, which agencies can follow to perform a systemwide safety risk assessment. The framework is intentionally generic, allowing for flexibility and scalability within an agency's application. The first section describes the data which agencies should consider for their assessment. The second section describes the assessment framework itself. The third section discusses how agencies can implement an assessment, particularly how agencies can consider incremental implementation and pilot efforts if it is infeasible to implement in full. Finally, the last section describes how an assessment is scalable based on the size of the agency and the resources available, including three examples. This Guide also includes an appendix which describes typical features agencies may consider for their assessment. Note that this Guide is considered a companion to FHWA's *Systemic Safety User Guide*[4].

Systemwide Safety Risk Assessment Data Needs

To assess the safety performance of the roadway system, agencies would benefit from an integrated safety dataset, including crash, roadway, intersection, and traffic data. The National Highway Traffic Safety Administration (NHTSA) describes desired crash data elements in the Model Minimum Uniform Crash Criteria (MMUCC)[5]. Additionally, agencies would benefit from geolocating the crashes to the appropriate system elements (segment, intersection, or ramp) to understand what characteristics were present at the time of the crash.

Roadway, intersection, and traffic data are key to defining site characteristics for performing the safety risk assessment. FHWA describes the desired roadway, intersection, and traffic elements in the Model Inventory of Roadway Elements (MIRE) 2.1[6]. Within MIRE, the Fundamental Data Elements (FDEs) provide a starting point for advanced safety analysis. The MIRE FDE are required for collection by States [23 U.S.C. 148(f)(2)] and provide agencies with basic data to identify the location and characteristics of each segment and intersection (e.g., divided or undivided, number of lanes, number of legs, traffic control). While agencies can also use the MIRE FDE as potential risk factors, they should consider which characteristics are most useful to assess risk within their system and collect additional data for those features, if necessary.

Finally, agencies would benefit from integrating other available data, such as socioeconomic, demographic, and equity data, that may provide additional insights. Several equity-related metrics are publicly available, including:

- The Environmental Protection Agency (EPA) Environmental Justice (EJ) Screening tool, available at https://www.epa.gov/ejscreen.
- The Center for Disease Control (CDC) and Agency for Toxic Substances and Disease Registry (ATSDR) Social Vulnerability Index, available at https://www.atsdr.cdc.gov/placeandhealth/svi/index.html.
- The FHWA Planning, Environment, Realty Geographic Information System (HEPGIS) Census and Equity Analysis data, available at https://hepgis.fhwa.dot.gov/fhwagis/.

The absence of any of these data sources should not be viewed as an impediment to completing a systemwide safety risk assessment. The *Systemic Safety User Guide* provides several scalable methods based on available data and analysis capabilities, including examples of data that may act as a surrogate for recommended data elements. Table 1 summarizes several types, sources, and data elements recommended for systemic safety

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[4] Gooch, J., Gross, F., Dunn, M., Kersavage, K., Sanders, R., Schoner, J., Himes, S., Albee, M., & Boller, N. (2024, August). Systemic Safety User Guide. Federal Highway Administration, Washington, D.C. FHWA-SA-23-008. https://highways.dot.gov/safety/data-analysis-tools/systemic/systemic-safety-user-guide

[5] https://www.nhtsa.gov/traffic-records/model-minimum-uniform-crash-criteria

[6] Hamilton, I., Richey, D., Himes, S., & Chestnutt, C. (2024, August). Model Inventory of Roadway Elements – MIRE 2.1. Federal Highway Administration, Washington, D.C. FHWA-SA-24-052.

analysis. A Federal Lands Highway (FLH) project also created a user manual for a risk data framework which can guide the data collection and integration for systemic safety analysis.[7]

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[7] Hamilton, I., Cohen, T., Amoabeng, M., Spear, M., Chestnutt, C. (2022, December). Development of Safety and Traffic Data Collection System and Analysis Framework for Federal Lands: Final Report. Federal Highway Administration, Washington, D.C. FHWA-FLH-23-006. https://rosap.ntl.bts.gov/view/dot/74639

Table 1. Recommended data, sources, and elements for systemic analysis.

Data type	Potential data sources	Recommended data elements
Crash data	» State or local crash database. » Police reports. » FARS. » Hospital records.	» Crash date and time. » Manner of collision. » First harmful event. » Injury severity. » Area type. » Relation to junction. » Roadway type.
Roadway data	» State road inventory (MIRE). » Asset management datasets. » As-built plans. » Aerial and street-level imagery.	» Jurisdiction. » Trafficway type. » Number of lanes. » Median type. » Functional class. » Area type. » Speed limit. » Cross-section dimensions. » Horizontal geometry. » Vertical geometry. » Roadside conditions.
Traffic and operational data	» Roadway inventories. » Statewide count data. » Pedestrian and bicycle surveys. » Probe data sources.	» Annual average daily traffic (AADT). » Pedestrian volume. » Bicycle volume. » Peak hour demand. » Truck volume. » Operating speeds.
Socioeconomic data	» United States Census. » American Community Survey (ACS). » EPA Environmental Justice Screening Tool. » CDC/ATSDR Social Vulnerability Index. » FHWA HEPGIS Census and Equity Analysis data. » State vehicle licensure and ownership data.	» Population. » Median income. » EJ indicators. » Vehicle ownership. » Commuting behaviors. » Health indices.

Systemwide Safety Risk Assessment Framework

A systemwide safety risk assessment is simply network screening with a crash-informed, risk-based metric rather than a crash-based metric. Agencies can take several approaches to assessing risk. FHWA's *Systemic Safety User Guide* documents the following approaches:

- Statistical modeling.
- Overrepresentation analysis.
- Established findings.
- Local knowledge.

These methods produce some measure of risk of a severe crash occurring at a given site. Ideally, agencies would use local data and results to inform the assessment, whether through statistical modeling or overrepresentation analysis. Another option is to use established findings, where agencies use local data to identify sites with higher risk based on risk factors identified in literature (e.g., national research results). The local knowledge approach is not feasible for a statewide safety risk assessment but may be appropriate for relatively small geographical areas in a data-limited environment (e.g., a rural county) or to supplement the other approaches.

To perform the systemwide safety risk assessment, agencies should use safety data to develop a risk-based score for each site (e.g., segment and intersection) across the system. This can be done for all severe crashes or separately for focus crash types.

Focus Crash Types

While all forms of crashes may result in severe outcomes, a safety risk-based assessment may focus on those that are most likely to result in a severe injury (i.e., fatality or suspected serious injury). A review of fatal crash data in NHTSA's Fatality Analysis Reporting System (FARS)[8] using the Fatality and Injury Reporting System Tool (FIRST)[9] suggests several crash types that could be considered as focus crash types for segments and intersections. Table 2 shows that a substantial proportion of fatalities in the United States between 2018 and 2022 can be attributed to a few specific types of crashes, including lane departure crashes on segments, angle crashes at intersections, and crashes involving pedestrians, motorcycles, and bicycles both on segments and at intersections. While this does not encompass all fatal crashes, these crash types account for a significant portion of highway fatalities in the United States and can present opportunities for infrastructure solutions.

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[8] https://www.nhtsa.gov/research-data/fatality-analysis-reporting-system-fars

[9] https://cdan.dot.gov/query

Table 2. Summary of fatal crashes for segments and intersections.

Facility level	**Notable fatal crash results, 2018-2022**
Segment	» 61 percent of non-intersection fatalities involved a roadway departure. Additionally, 26 percent involve a rollover. » 17 percent of non-intersection fatalities were pedestrians. An additional 2 percent of fatalities involved a cyclist. » 12 percent of non-intersection fatalities involved a motorcycle. » 14 percent of non-intersection fatalities involved a head-on collision. » 29 percent of non-intersection fatalities involved speeding.
Intersection	» 53 percent of intersection fatalities involved an angle collision, while 34 percent were not a collision with a motor vehicle in transport.[10] An additional 6 percent involved a rear end collision, and another 6 percent involved a head-on collision. » 21 percent of intersection fatalities involved a motorcycle. » 17 percent of intersection fatalities were pedestrians and 4 percent were cyclists.

These findings are in line with the methodology used in iRAP, which focuses on road users by crash type, as summarized in Table 3. While national data present certain types of crashes as accounting for a significant portion of fatal crashes in the United States, agencies should focus on crash problems specific to their roadways. Additionally, agencies may benefit from creating more specific crash types (e.g., collision between pedestrian crossing and driver going straight, angle collision between two through moving vehicles) to better understand the nuances of systemic risk for those modes. Safety plans such as the State Strategic Highway Safety Plan, Vulnerable Road User Safety Assessment, Comprehensive Safety Action Plan, local road safety plan, and Vision Zero plan can help to guide the focus crash types.

Table 3. Summary of focus crashes in iRAP.[11]

Motor vehicle occupants	Motorcyclists	Bicyclists	Pedestrians
» Run-off-road. » Head-on. » Intersections.	» Run-off-road. » Head-on. » Intersections. » Moving along road.	» Traveling along road. » Intersections. » Run-off-road.	» Walking along road. » Crossing road.

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[10] The plurality of these fatalities involve a collision with pedestrians (49 percent of those not involving a motor vehicle in transport), collision with a pedalcyclist (10 percent of those not involving a motor vehicle in transport), or a rollover or overturn (6 percent of those not involving a motor vehicle in transport).

[11] https://irap.org/methodology/

Focus Facility Types

In a systemwide safety risk assessment, agencies should consider screening their entire system. However, agencies may also refine the focus facility types—the facility types which account for a substantial number of severe focus crashes. If data or resources are insufficient to screen the full system, agencies can identify focus facilities (e.g. Federal-aid system) for their assessment. Refer to the later section, titled *Scalability of Systemwide Safety Risk Assessment*, for further discussion.

Risk Scores

Risk scores reflect the relative risk of a crash at a given site based on the presence or absence of certain factors. Risk scores should be based on correlations between crash likelihood and factors such as geometric design, traffic, equity, and other site- or area-level characteristics. Appendix A summarizes a list of features that have been found to be correlated with each focus crash type at the segment level. This list is not all-inclusive but is guided by the *Highway Safety Manual*[12], iRAP, other safety management models, and research. Agencies can revise these lists to include any risk factors correlated with increased severe crash probability. While volumes are included, agencies should use an approach that accounts for potential bias towards high-volume facilities. Additionally, lack of pedestrian or bicycle volume data should not exclude a facility from systemic risk assessment for non-motorists.

After assigning risk scores to each individual factor considered in the analysis, agencies can combine these scores across a site for a total risk score. In some cases, an agency may use different risk factors for different types of sites (e.g., segments vs. intersections) or a different number of risk factors based on data availability (e.g., State vs. local roads). In these cases, agencies can normalize the risk scores for comparison across the entire system. This is done by dividing the risk score for each site by the maximum potential score for that site.

Agencies can assign scores based on the presence of risk factors or safer roadway features. The iRAP methodology assigns stars based on the presence of safety features, such as wider lanes, wider shoulders, and presence of lighting. Priority sites are those with the fewest stars (i.e., fewest safety features). Alternatively, as described in the *Systemic Safety User Guide*, agencies can assign scores based on the presence of risk factors, such as narrow lanes, narrow shoulders, or the presence of skew at an intersection. Priority sites in this case are those with a relatively high number of risk factors or risk score.

Agencies with crash and roadway data are beginning to use more reliable safety performance measures, such as expected crash frequency, for network screening. Expected crash frequency combines historical crash data and the predicted average crash frequency to estimate the long-term safety performance for a site. Similarly, agencies can combine historical crash data in a risk-based analysis. While a safety risk-based assessment should be guided primarily by site characteristics, there is an opportunity to include site-specific crash history as one of the risk factors. While it is often the case that the same roadways that are a higher risk for pedestrians and bicyclists are also a higher risk for motorists, this is not universal. Therefore, pedestrian and bicyclist risk should be assessed separately from motorist risk to better understand the safety risk for each mode, potentially including separate implementation programs as well, as described in more detail below.

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[12] American Association of State Highway and Transportation Officials. (2010). Highway Safety Manual. https://www.highwaysafetymanual.org/Pages/default.aspx

Implementation of Systemwide Safety Risk Assessment

Agencies should consider implementing a systemwide safety risk assessment framework as part of a comprehensive approach to safety management. For an implementation model, consider mimicking the crash-based network screening approach where risk is assessed and prioritized at all sites across the system. When this is not possible due to limited data or resources, consider scaling the assessment as discussed in the next section and then prioritizing sites within the area of interest.

Once the sites are scored within the area of interest (e.g., entire system or subset), agencies should stratify the sites by risk level (or level of safety) and roadway type. If the assessment applies to only a subset of the system, this should be made clear in the results and stratification. There are several methods agencies can use to classify by risk. One example from iRAP includes six categories for sites:

- Primary risk.
- High risk.
- Medium risk.
- Low risk.
- Minimal risk.
- Not a focus facility.

Agencies can use the stratified categories to inform the development and prioritization of their safety programs. For instance, agencies may develop higher-cost and more impactful countermeasure packages for the highest priority sites, and then program lower-cost improvements for lower-risk sites. Agencies may develop a road safety audit program for detailed diagnosis of safety issues at the highest priority sites. Further classifying sites by roadway category or into groups with similar characteristics can simplify countermeasure selection and project identification. If a team is tasked with identifying improvements for all primary risk sites, it can be difficult to identify an improvement that is appropriate for all sites. For example, it may not be appropriate to implement the same improvements for a high-speed two-lane rural highway, an urban freeway segment, and a signalized intersection along a suburban arterial. Breaking these into individual categories can make it easier to develop targeted projects.

As described in the *Systemic Safety User Guide*, agencies can bundle improvements geographically with similar or identical countermeasures. Such an effort should be done in conjunction with the more traditional implementation of site-specific projects from the crash-based network screening approach. Agencies should create a library of site-specific and systemic projects from these assessments and prioritize them based on benefit-cost ratio (BCR). This mixed approach, prioritized using BCR, can increase the efficiency of a highway safety program. If an agency cannot calculate BCR, but one is reported in the literature, agencies can use those. In the event an agency is not able to use BCR, they can instead consider the CMF, countermeasure score, or other metrics described in FHWA's *Selecting Projects and Strategies to Maximize HSIP Performance*[13].

The results can also be used outside of dedicated safety projects. For example, agencies can cross reference their paving program against the safety risk assessment results and identify overlap between higher priority risk

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[13] Gross, F., Harmon, T., Cynecki, M., Dittberner, R., & Chestnutt, C. (2021, March 5). Selecting Projects and Strategies to Maximize Highway Safety Improvement Program Performance. Federal Highway Administration, FHWA-SA-20-001. Washington, D.C. https://safety.fhwa.dot.gov/hsip/docs/FHWA-SA-20-001_Maximizing_HSI_Performance_508.pdf.

sites and sites with planned paving projects. Where a paving project overlaps with a high-risk location, agencies can consider adding safety improvements to that project.

Another use of these results is for establishing key performance indicators or selecting performance measures for a safety program. For instance, one key performance indicator may be the average risk rating for the system or average risk rating by functional class or ownership. In terms of performance measures, an agency could track the average risk level by year and compare it to the number of projects and overall dollar value of investments. In a similar manner, agencies can establish goals or targets of having a certain proportion of their system meet a minimum safety score in a given timeframe. For example, an agency may set a goal that in 10 years, 80 percent of their system is rated as 3 stars or better. Again, this could be done for the entire system or some subset (e.g., by functional class or ownership).

Scalability of Systemwide Safety Risk Assessment

Systemwide safety risk assessments can be performed by Federal, State, regional, local, and Tribal agencies and scaled based on available resources. In terms of the focus crash type(s), agencies can scale the assessment to one or more focus crash types. For instance, agencies without a reliable intersection inventory may scale the assessment to focus on segment-related crashes (e.g., roadway departure). However, agencies should make a concerted effort to examine the crashes contributing most to fatalities and serious injuries (both by magnitude and overrepresentation of crash types), including pedestrian and bicyclist crashes.

Agencies can also scale the assessment to one or more focus facility types. For instance, local agencies may focus on their High Injury Network (HIN)—a small percentage of roadway facilities, including segments and intersections, which account for a large percentage of severe crashes or fatalities within a jurisdiction. Focusing on this small percentage of mileage allows local agencies with limited resources to make a significant impact on reducing the risk of severe injuries on public roadways. Alternatively, local agencies can look for common site characteristics across the HIN (to identify these as risk factors) and include all similar roads in the systemwide safety risk assessment. Agencies should create separate HINs for pedestrians, bicyclists, and motorists to capture potentially varying risk factors for each mode. Agencies may wish to separate motorcyclists from other motorists for the purpose of creating HINs. This can provide insights into motorist-motorcyclist crashes and risk factors that would not be available otherwise.

Larger agencies that are unable to perform the assessment for the entire system within the jurisdiction may conduct the analysis incrementally. For example, State agencies could start with a district or region, metropolitan planning organizations could start with a county or city, and counties could start with a facility type. Using this incremental approach, agencies can perform the assessment, prioritize locations based on risk, and develop systemic projects for that area. For each of these examples, separate analyses should be conducted to assess pedestrian, bicyclist, and motorist risk (again, motorcyclist risk may be assessed separately as well). This exercise can serve as a demonstration for the agency, clarifying which data are available and most relevant for the assessment, identifying potential challenges for the analysis, determining an appropriate scoring method for the assessment, and developing procedures for managing and delivering systemic projects. The agency can then bring the noteworthy practices and lessons learned for application in other areas or facility types within the jurisdiction. These initial efforts can also help to justify expenditures and requests for additional funds to continue and expand the assessment over time. Below are three examples at separate scales and within different contexts which highlight how this method can be applied at various complexities and data levels. Note that the “Bringing It All Together” chapter of the *Systemic Safety User Guide* also describes an example systemwide safety risk assessment.

Example 1 – State Systemwide Safety Risk Assessment

A State Department of Transportation (DOT) wants to perform a systemwide safety risk assessment of their State highway system. The State DOT begins by reviewing the severe crash data along the State highway system. The State DOT queried and analyzed crash data for the previous five years using their crash database tool. Table 4 summarizes the fatalities and serious injuries by first harmful event, as reported in the crash data. The State DOT found that five first harmful events—run-off-road, head on, right angle, collisions with pedestrians, and collisions with bicyclists—accounted for 96 percent of fatalities and serious injuries on the State system. As such, the State DOT decided to focus the assessment on these individual crash types.

Table 4. Summary of fatalities and serious injuries by first harmful event.

First harmful event	Percent of fatalities and serious injuries
RUN-OFF-ROAD	54%
COLLISION WITH MOTOR VEHICLE – RIGHT ANGLE	18%
COLLISION WITH PEDESTRIAN	14%
COLLISION WITH MOTOR VEHICLE – HEAD ON	8%
COLLISION WITH BICYCLIST	2%
OTHER	4%

Reviewing the system, the State DOT elected to analyze the following focus crash types for segments and intersections:

- Segments – run-off-road, head-on, pedestrian, bicyclist.
- Intersections – right angle, pedestrian, bicyclist.

To identify risk factors, the State DOT classified their roadway system into groups (facility types) with similar characteristics. Table 5 summarizes the facility types selected by the State DOT. This resulted in 28 sets of risk factors—one for each combination of crash type and facility type[14].

Table 5. Summary of facility types for risk analysis.

Segments	Intersections
Access-controlled freeways and expressways	Urban and suburban signalized intersections
Divided highways with no or partial access control	Rural signalized intersections
Rural undivided highways	Urban and suburban stop-controlled intersections
Urban arterials and collectors	Rural stop-controlled intersections

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[14] There are 4 crash types and 4 facility types for segments, which leads to 16 segment combinations. Additionally, there are 3 crash types and 4 facility types for intersections, which leads to 12 intersection combinations. Combined this leads to the total of 28 combinations.

The State DOT has an extensive set of roadway, traffic, and crash data, so they elected to use statistical modeling to identify risk factors. The State DOT used statistical regression to identify risk factors for severe focus crashes on the system. Table 6 summarizes the risk factors identified for run-off-road crashes on the four different segment-related facility types. The State DOT also established risk factors for head-on, pedestrian, and bicyclist crashes on the four different segment-related facility types.

*Table 6. Risk factors for the agency's run-off-road crashes on segments.**

Access-controlled freeways and expressways	**Divided highways with no or partial access control**	**Rural undivided highway**	**Urban arterials and collectors**
» Median width. » Right shoulder width. » Left shoulder width. » Lane width. » Lack of shoulder rumble strips. » Horizontal curve radius. » Grade. » Clear zone width.	» Median width. » Shoulder width. » Lane width. » Lack of shoulder rumble strips. » Horizontal curve radius. » Grade. » Clear zone width. » Access density. » Posted speed limit.	» Lane width. » Shoulder width. » Lack of shoulder rumble strips. » Curve radius. » Side friction demand on a horizontal curve. » Clear zone width. » Presence of drainage issues. » Fixed object density. » Edgeline presence.	» Lane width. » Median presence. » Horizontal curve radius. » Fixed object density. » Clear zone width. » Posted speed limit. » Lighting presence.

***** This table contains a non-exhaustive list of risk factors. Other agencies may identify additional or different variables.

In a similar manner, the State DOT identified risk factors for the focus intersection crash types on each of the individual intersection facility types. Table 7 summarizes the selected risk factors for pedestrian crashes at the four intersection-related facility types. The State DOT also established risk factors for right angle and bicyclist crashes at the four intersection-related facility types.

*Table 7. Risk factors for the agency's pedestrian crashes at intersections.**

Urban and suburban signalized intersections	Rural signalized intersections	Urban and suburban stop-controlled intersections	Rural stop-controlled intersections
» Pedestrian signal presence and type. » Crosswalk presence. » Crossing distance. » Adjacent alcohol sales. » Adjacent schools. » Adjacent transit stops. » Vehicle approach speed. » Vehicle approach demand. » Presence of lighting. » Pedestrian commuting behavior in area of intersection. » Environmental justice indicators in area of intersection.	» Pedestrian signal presence and type. » Crosswalk presence. » Crossing distance. » Adjacent land use. » Vehicle approach speed. » Vehicle approach demand. » Presence of lighting. » Presence of sidewalk on approaches. » Environmental justice indicators in area of intersection.	» Crossing distance. » Crosswalk presence. » Intersection skew angle. » Adjacent alcohol sales. » Adjacent schools. » Adjacent transit stops. » Vehicle approach speed. » Vehicle approach demand. » Presence of lighting. » Pedestrian commuting behavior in area of intersection. » Environmental justice indicators in area of intersection.	» Crossing distance. » Crosswalk presence. » Intersection skew angle. » Adjacent land use. » Vehicle approach speed. » Vehicle approach demand. » Presence of lighting. » Presence of sidewalk on approaches. » Environmental justice indicators in area of intersection.

***** This table contains a non-exhaustive list of risk factors. Other agencies may identify additional or different variables.

To calculate risk scores, the State DOT elected to assign categorical risk for each risk factor—high risk (3), medium risk (2), and low risk (1). For instance, when scoring the risk of adjacent alcohol sales for pedestrian crashes at urban and suburban signalized intersections, an intersection was considered high risk if there were at least 4 establishments with a license to sell alcohol within 0.25 miles of the intersection, medium risk if there were between 1 and 4 establishments within 0.25 miles, and low risk if there were no establishments within 0.25 miles. Table 8 summarizes the number of risk factors, and thus the total potential risk score, for each combination of crash type and facility type.

Table 8. Number of risk factors and total potential risk score for each crash type and facility type combination.

Facility type	Run-off-road	Head-on	Pedestrian	Bicyclist	Right angle
Access-controlled freeways and expressways	8 risk factors 24 risk points	7 risk factors 21 risk points	Not applicable	Not applicable	Not applicable
Divided highways with no or partial access control	9 risk factors 27 risk points	9 risk factors 27 risk points	6 risk factors 18 risk points	5 risk factors 15 risk points	Not applicable
Rural undivided highways	9 risk factors 27 risk points	10 risk factors 30 risk points	8 risk factors 24 risk points	5 risk factors 15 risk points	Not applicable
Urban arterials and collectors	9 risk factors 21 risk points	8 risk factors 24 risk points	12 risk factors 36 risk points	10 risk factors 30 risk points	Not applicable
Urban and suburban signalized intersections	Not applicable	Not applicable	11 risk factors 33 risk points	8 risk factors 24 risk points	10 risk factors 30 risk points
Rural signalized intersections	Not applicable	Not applicable	11 risk factors 33 risk points	6 risk factors 18 risk points	8 risk factors 24 risk points
Urban and suburban stop-controlled intersections	Not applicable	Not applicable	11 risk factors 33 risk points	11 risk factors 33 risk points	9 risk factors 27 risk points
Rural stop-controlled intersections	Not applicable	Not applicable	11 risk factors 33 risk points	7 risk factors 21 risk points	11 risk factors 33 risk points

The State DOT calculated risk scores for each crash type and facility type and then combined the crash type risk scores for a total risk score for each site (segment or intersection). For instance, if the individual risk scores for a rural, undivided highway are 20 for run-off-road, 25 for head-on, 15 for pedestrian, and 10 for bicyclist, then the total risk score is 70 for the site. The difference in total potential risk score presented an issue when comparing sites across the system. For instance, a rural undivided highway segment has a total potential risk score of 96 (27 + 30 + 24 + 15), while an urban arterial segment has a total potential risk score of 111 (21 + 24 + 36 + 30). To address the issue, the State DOT normalized against the total potential risk score for the site by dividing the actual risk score by the total potential risk score for a given site. For instance, if a rural undivided highway segment had a risk score of 70 out of a total of 96, the normalized score assigned would be 72.9 (70/96 * 100), while a score of 98 out of 111 for an urban arterial segment resulted in a normalized risk score of 88.3 (98/111 * 100). This normalization allowed the State DOT to compare these two segments, despite being scored differently—the urban segment with a normalized score of 88.3 would be prioritized over the rural segment with a normalized score of 72.9.

Using the normalized risk score, the State DOT proceeded to prioritize and categorize the sites into risk categories. The State DOT used the categories from usRAP. Table 9 summarizes the risk categories, including the range of risk scores, percentage of segment mileage, and percentage of intersections which fall within each risk category. The State DOT also visualized these results using maps in GIS (see Figure 1).

Table 9. Summary of risk categories for the example systemwide safety risk assessment.

Risk category	Normalized risk score range	Percentage of segment mileage in risk category	Percentage of intersections in risk category
Risk tier 1	95-100	4%	3%
Risk tier 2	85-95	7%	6%
Risk tier 3	75-85	11%	21%
Risk tier 4	50-75	23%	28%
Risk tier 5	0-50	39%	25%
Not a focus facility	N/a	16%	17%

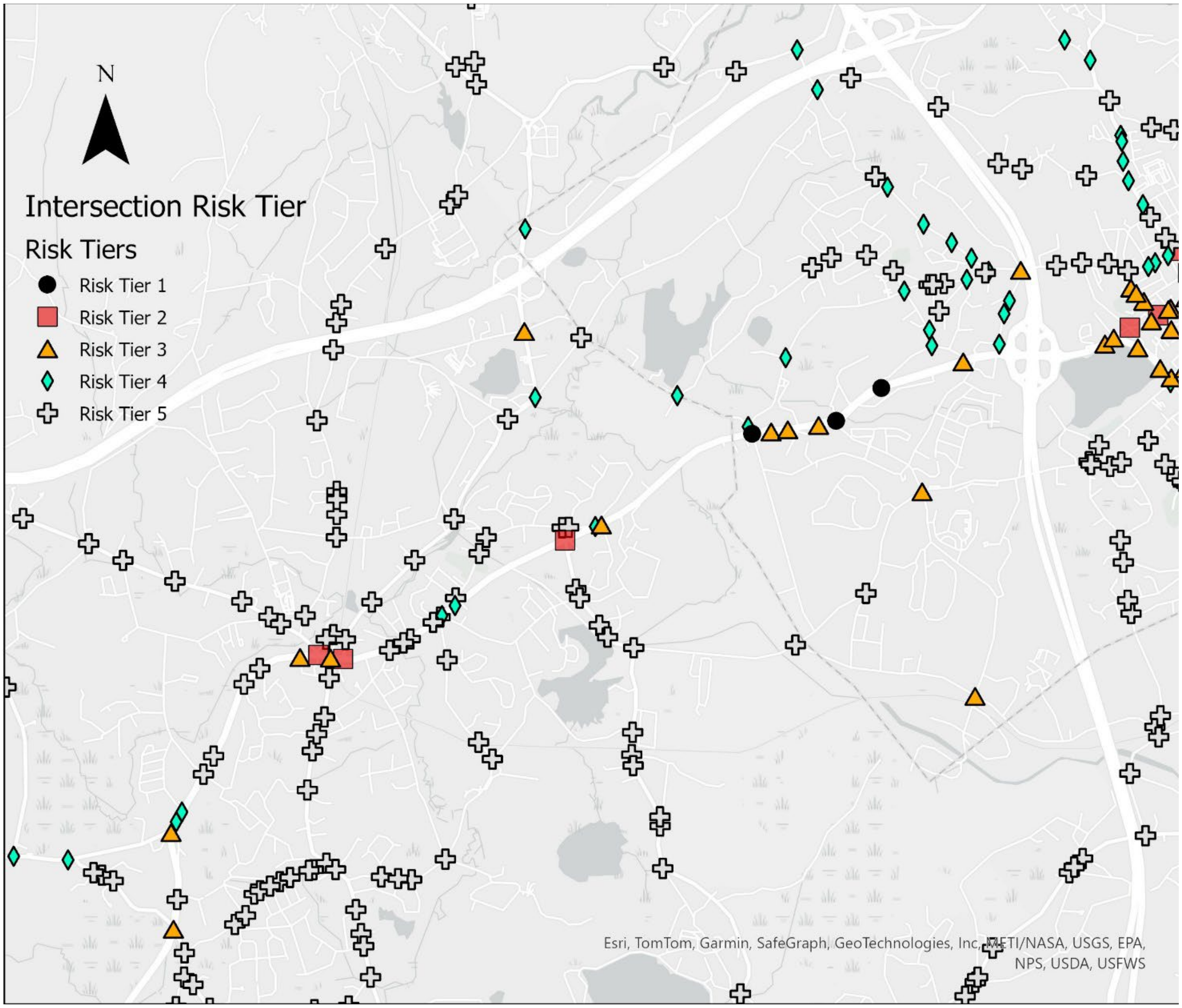

Figure 2. Graphic. Systemwide safety risk assessment map of intersections for the example State, categorized by risk of a pedestrian crash.

Example 2 – Tribal Roadway Systemwide Safety Risk Assessment

A Tribe was interested in performing a safety risk assessment of the roadway system within their boundaries. The Tribal land abutted several counties and a National Forest, so the Tribe began working with safety partners including the State DOT, Bureau of Indian Affairs (BIA), FHWA's Federal Lands Highway (FLH) division, and adjacent county governments to assess the data environment.

The discussions yielded an assortment of data—some agencies had extensive data for their roads in the boundary, while others had limited data. This presented a challenge to the Tribe—how could they assess the system consistently with inconsistent data? After consideration, the Tribe elected to use a combination of the available data, primarily crash data, and local knowledge to perform their assessment.

The Tribe began by reviewing ten years of fatal crash data within their boundaries. As shown in Table 10, the vast majority of fatalities within Tribal land occurred in run-off-road crashes. As a result, the Tribe elected to focus primarily on run-off-road crashes, and then on intersection right-angle crashes and pedestrian crashes.

Table 10. Summary of fatalities by first harmful event from FARS.

First harmful event	Number of fatalities
Run-off-road	26
Collision with motor vehicle – right angle	4
Collision with pedestrian	2
Collision with motor vehicle – head on	1
Other	1

The Tribe summarized these data in briefing packets to distribute to all risk assessors. These packets included information about the key crash types—run-off-road, intersection right angle, and pedestrian crashes—to inform the assessors of potential issues associated with those crashes. The Tribe cast a wide net when selecting risk assessors. The goal was to identify individuals who are familiar with the roadway system, committed to the mission of roadway safety, and contribute to the well-being of the Tribe. Assessors included:

- Tribal elders.
- Tribal law enforcement.
- Tribal highway department staff.
- Tribal planning staff.
- Tribal maintenance staff.
- State law enforcement.
- Adjacent government law enforcement.
- Partner highway department staff (e.g., State DOT, County, and city).
- Local Technical Assistance Program staff.
- School district transportation staff.
- Transit and paratransit staff.

- Emergency services, including emergency medical technician and fire department representatives.
- FLH staff.
- BIA representatives.
- State Highway Safety Office personnel.

To encourage a consistent, quantitative approach to the assessment, the Tribe reviewed national research publications related to the focus crash types and selected six risk factors for each crash type. Table 11 summarizes the risk factors selected for each crash type. For each risk factor, the assessors assigned a score from 1 to 5—1 meaning the roadway is considered low risk for that risk factor, and 5 meaning the roadway is considered high risk for that risk factor. For instance, an assessor could score shoulder width as a 5 for a roadway with no shoulder, 3 for a roadway with a 2-foot shoulder, and 1 for a roadway with a 4-foot shoulder. However, the scoring is not standardized for these features, so the qualitative assessment by another may produce a score of 5 for no shoulder, 4 for a 2-foot shoulder, and 3 for a 4-foot shoulder. The Tribe was not concerned with differences in assessments between reviewers, as the qualitative differences would average out across all assessors.

*Table 11. Summary of selected risk factors by focus crash type.**

Run-off-road – segments	**Pedestrian – segments**	**Right angle – intersections**	**Pedestrian – intersections**
Shoulder width	Walking desirability	Traffic control for left-turns	Maximum number of lanes crossed
Roadside rating	Pedestrian facility presence	Intersection skew angle	Pedestrian crossing treatments
Lane width	Traffic speed	Sight distance	Complexity of the pedestrian crossings
Horizontal curvature	Traffic volume	Speed of conflicting traffic	Traffic speed
Roadway departure countermeasure presence	Crossing opportunities and facilities	Left turn volume	Traffic volume
Pavement quality, including edge drop-off	Adjacent trip generators, including schools, transit stops, and alcohol sales establishments	Awareness of intersection	Adjacent trip generators, including schools, transit stops, and alcohol sales establishments

***** This table contains a non-exhaustive list of risk factors. Other agencies may identify additional or different variables.

The Tribe asked the assessors to score each route within the Tribal boundaries. For longer routes, segmentation was created at intersections or where notable changes in the roadway character occurred. Given the rural nature of the Tribal land, few intersections needed to be assessed. In all, the assessment team reviewed 826 miles of roadway, broken into 826 1-mile segments and 113 intersections. The review was done using publicly available street-level and aerial imagery; the data were collected using spreadsheets. To calculate the risk score for each site, the Tribe summed the individual scores for each risk factor across the assessors. The Tribe then ranked all assessed sites by the total risk score. Those with the highest risk score were prioritized for improvements. The Tribe published a map highlighting the highest priority sites for distribution, similar in appearance to Figure 1.

Example 3 – Systemwide Safety Risk Assessment for Roadside Barrier

A State DOT is interested in performing a safety risk assessment of their rural, two-lane highway system to prioritize roadside barrier installation[15]. The assessment analyzes various factors such as crash data, roadway geometrics, roadside slopes, and traffic volume on two priority corridors. The agency began by integrating safety data, which are summarized in Table 12.

Table 12. Data elements for collection and integration.

Data type	Data source(s)	Data elements
Crash data	Spatial data from the Department of Motor Vehicles.	» Crash year. » Crash severity. » Crash type. » Lighting condition. » Intersection-related. » Surface condition. » Weather. » Off Roadway flag.[16]
Roadway data	Spatial road inventory and asset management data.	» Route identification information. » Cross-section details and dimensions. » Functional classification. » Posted speed limit. » Pavement type and condition. » Barrier presence.
Terrain data	Spatial digital elevation models (DEMs) at 3 feet by 3 feet pixels, including a bare Earth model and a tree canopy model.	» Vertical alignment. » Roadside slope. » Distance between tree canopies. » Clear zone. » Sight distance.
Traffic data	State traffic volume database.	» Annual Average Daily Traffic (AADT). » Truck AADT. » Peak truck traffic.

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[15] This case study was derived from the following source: Tanzen, R., Hamilton, I., Spear, M., & Himes, S. (2024). A Practical Analysis of Risk Factors for Roadside Barrier Need in Rural Oregon. Presented at the 103rd Annual Meeting of the Transportation Research Board. Washington, D.C.

[16] The Off Roadway flag indicates a vehicle ran off the road and applies to crashes where the first harmful event occurs in a location outside of the travel way; this is specific to the State's crash data structure.

After collecting the data, the State DOT processed the data to classify their roadway system and assign risk factors. Table 13 summarizes the process used to create the risk factor identification database. The data were organized at the segment level; the segments were created by breaking the roadway inventory data into 0.1-mile-long segments. The State DOT separated their crashes into two aggregated crash severity categories: 1) KAB which includes fatal injury, suspected serious injury, and suspected minor injury crashes, and 2) CO, which includes possible injury (C) and property damage only (O) crashes.

Table 13. Data processing steps.

Data element(s)	Processing
Focus crash groupings	The following four focus crash groupings were developed to explore during the analysis: **High-Severity Run Off Road**: KAB Off Roadway crashes only. **Low-Severity Run Off Road**: Possible injury (C) and property damage only (O) Off Roadway crashes only. **High-Severity Roadway Departure**: KAB Off Roadway, head-on, and sideswipe-opposite direction crashes combined. **Low-Severity Roadway Departure**: CO Off Roadway, head-on, and sideswipe-opposite direction crashes combined. The State DOT used spatial analysis to tally the number of crashes present along the segment.
Horizontal curvature and tangent sections	Horizontal curve information was generated using a GIS-based tool which derives curve type, radius, length, and degree of curvature using roadway centerline information. The State DOT used the features at the midpoint of the segment to represent the segment as a whole. The State DOT also calculated the length of tangent at the start and end of the curve.
Vertical grade	The State DOT used a GIS tool to calculate the absolute value of the minimum, maximum, and average slope of each segment in percent grade – this was applied as the vertical grade for the analysis.
Clear zone	In addition to the data indicating roadside object presence and offset, the State DOT employed two methods for assessing potential clear zone: 1) distance between non-traversable slopes derived from the bare Earth DEM (1V:3H or greater) at the midpoint of the segment; and 2) distance between tree canopies calculated from the highest hit LiDAR from the surface model at the start, end, and midpoint of the segment. These results were averaged to create a general estimate of the roadside.
Roadside slope and topographic risk factor	The State DOT also used the DEM to assess the presence of a roadside of higher risk. The State DOT calculated the average slope as the difference in elevation of the centerline and the elevation of a point projected 10 feet from the edge of the roadway; the State DOT also noted whether this was a cut slope (i.e., the centerline is lower than the roadside elevation) or a fill slope (i.e., the centerline is higher than the roadside elevation). This provides insight into the potential risk factors present in the case that a slope is non-traversable.
Sight distance	The State DOT combined the bare earth DEM and the canopy height data to assess available sight distance through a spatial analysis tool.

Ultimately, the State DOT created an integrated safety risk factor assessment database with the following data elements:

- Traffic volume.
- Number of lanes.
- Posted speed limit.
- Pavement condition (i.e., fair, good, and very good).
- Average vertical slope (i.e., grade).
- Average shoulder width (i.e., average of right and left shoulder, both paved and unpaved).
- Average paved shoulder width (i.e., average of right and left paved shoulder).
- Average lane width.
- Presence of barrier indicator (i.e., left, right, or both).
- Percentage of road covered by barrier.
- Presence of centerline rumble strips indicator.
- Presence of roadside rumble strips indicator.
- Presence of bridge indicator.
- Presence of curve indicator.
- Degree of curvature.
- Divided road indicator (i.e., presence of a median).
- Curve visibility indicator (i.e., visibility assessment based on surface elevation without considering the canopy data).
- Curve visibility indicator with canopy height (i.e., visibility assessment based on surface elevation and canopy/vegetation height).
- Percentage of the roadside within 100 feet of the centerline with a sideslope greater than 14 degrees.
- Percentage of the roadside within 100 feet of the centerline with a sideslope greater than 19 degrees.
- Distance between non-traversable slopes (i.e., the distance between nearest non-traversable slopes – 1V:3H – from segment midpoint with maximum search distance of 100 feet).
- Distance between roadside vegetation (i.e., the average distance between derived canopy tops at the beginning, midpoint, and end of each segment’s centerline).
- Assumed traversable distance (i.e., minimum of the distance between “Distance between roadside vegetation” and “Distance between non-traversable slopes variables”).

The State DOT employed negative binomial regression to produce crash prediction models for high-severity (KAB) roadway departure and run off road crashes. Independent variables were included in the model if they were shown to have a statistical relationship and produced logical relationships – positive coefficients indicate the presence of the risk factor is associated with an increase in severe crash frequency, while negative coefficients indicate the presence of the risk factor is associated with a decrease in severe crash frequency. Table 14 summarizes the risk factors identified through the modeling process. Note that most risk factors identified through the modeling effort are associated with an increase in severe crash frequency – pavement condition as good or fair (as opposed to very good), 3 or 4 travel lanes (as opposed to 2), an average vertical grade of 5 percent or larger, average shoulder width of 6 feet or less, the presence of a horizontal curve within the segment, and horizontal curvature is 5 degrees or sharper. Two variables were associated with a decrease in severe crash frequency – curve visibility (indicating whether a driver can see the end of the curve from the start of the curve; a surrogate for stopping sight distance) and the presence of a barrier.

Table 14. Risk factor summary (+ indicates an increase in crash frequency, - indicates a decrease).

Variables	Run off road (KAB)	Roadway departure (KAB)
Good or fair pavement condition indicator (baseline pavement condition is very good)	+	+
Number of lanes 3 and 4 indicator (baseline number of lanes is 2)	+	+
Average slope 5 percent or above indicator	+	+
Average shoulder width 6 feet or less indicator	+	+
Presence of a curve indicator	+	+
Degree of curvature 5 or above indicator	+	+
Curve visibility indicator with canopy height	-	-
Presence of a barrier indicator	-	-

Ultimately, this model does three things. First, it provides evidence for the assertion that the presence of roadside barrier reduces the frequency of severe roadway departure and run off road crashes. Second, it establishes a list of risk factors which the State DOT used to assess the risk of a severe roadway departure crash on their two-lane rural roads. Third, it demonstrates how readily available planning-level LiDAR data can be used to inform various aspects of traffic safety modeling.

The State DOT proposed a risk scoring procedure for all segments without roadside barriers present. Given both crash models produced the same list of risk factors, the agency elected to use binary scoring for risk prioritization, assigning 1 point for every risk factor present, summing to a total of 6 points. An additional point is assigned if the curve visibility indicator is false (i.e., the spatial analysis indicates drivers cannot see the other end of the horizontal curve from the start of the curve). As a result, the maximum potential score for a segment is 7 points.

Finally, the State DOT deployed the safety risk assessment results by calculating risk scores for each 0.1-mile segment. Segments in which a roadside barrier is already present were removed from the prioritization dataset. The agency then reviewed all segments with 7 risk factors present to determine whether installation of a roadside barrier is appropriate, and which barrier system should be deployed to reduce focus crash types.

Conclusion

The purpose of this guide is to describe a framework for performing a systemwide safety risk assessment. Such an assessment would be used as a network screening approach – identifying sites with potential for safety improvement based on the presence of risk factors associated with severe crashes, as opposed to the presence of excess crashes. The framework described is scalable to the analysis and data capabilities available to the performing agency. The “Bringing it All Together” section of the *Systemic Safety User Guide* provides an additional example of a systemwide safety risk assessment framework and a practical application of the results.

Relevant Resources

Additional resources available to support systemwide safety risk assessments include:

- FHWA *Systemic Safety User Guide*.
- NCHRP Research Report 955 – *Guide for Quantitative Approaches to Systemic Safety Analysis*[17].
- NCHRP Research Report 893 – *Systemic Pedestrian Safety Analysis*[18].

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[17] National Academies of Sciences, Engineering, and Medicine. (2020). Guide for Quantitative Approaches to Systemic Safety Analysis. Washington, DC: The National Academies Press. https://doi.org/10.17226/26032.

[18] National Academies of Sciences, Engineering, and Medicine. (2018). Systemic Pedestrian Safety Analysis. Washington, DC: The National Academies Press. https://doi.org/10.17226/25255.

Appendix A – Example Features for Systemwide Safety Risk Assessment

Table 15 lists several features agencies may consider when assessing segment-level risk. Table 16 lists several features agencies may consider when assessing intersection-level risk. FHWA[19] developed a short-form user manual for agencies to create a safety risk assessment database which can be used as a guide for such an application.

Table 15. Summary of features for segment-level systemwide safety risk assessment.

Focus crash	Characteristics to consider when assessing risk
Lane departure	» One-way or two-way travel. » Lane width. » Shoulder width and type. » Rumble strip presence. » Median type and width. » Median and outside barrier presence and offset. » Horizontal curve radius and superelevation. » Pavement friction and condition. » Signage and delineation. » Clear zone, side slope, and fixed object presence and offset. » Earthwork, including ditches and embankments. » Vehicle volume. » Number of lanes. » Lighting presence. » Severe lane departure crash history.
Motorcycle	» Functional classification. » One-way or two-way travel. » Lane width. » Shoulder width and type. » Median type and width. » Median and outside barrier presence and offset. » Horizontal curve radius and superelevation. » Pavement friction and condition. » Signage and delineation. » Clear zone, side slope and fixed object presence and offset. » Driveway density and type. » Lighting presence. » Presence of curbing. » Rumble strip presence. » Vehicle volume. » Number of lanes. » Severe motorcycle crash history.

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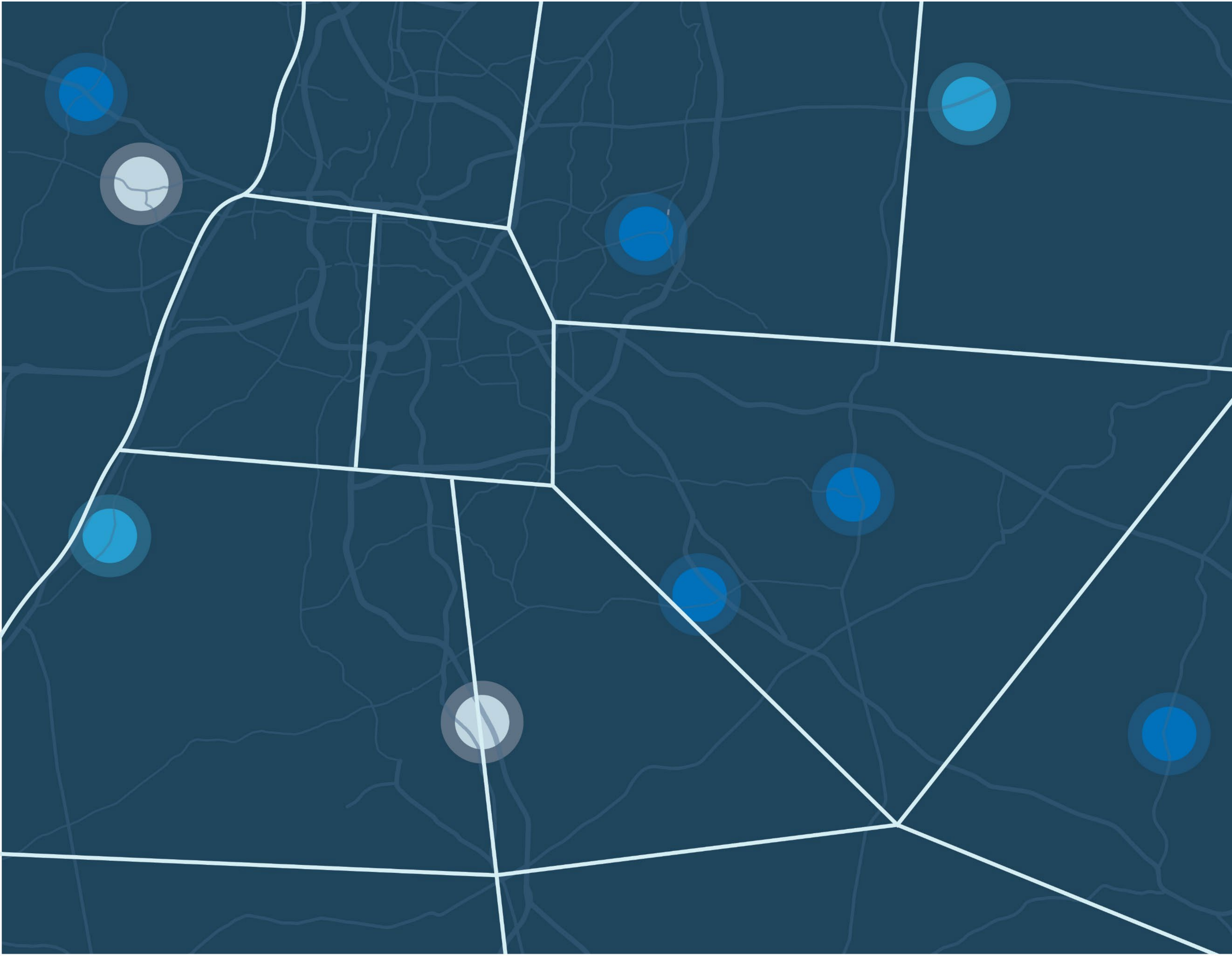
[19] Hamilton, I., Cohen, T., Amoabeng, M., Spear, M., Chestnutt, C. (2022, December). Development of Safety and Traffic Data Collection System and Analysis Framework for Federal Lands: Final Report. Federal Highway Administration, Washington, D.C. https://rosap.ntl.bts.gov/view/dot/74639

Focus crash	Characteristics to consider when assessing risk
Pedestrian	» Functional classification. » One-way or two-way travel. » Lane width. » Shoulder width. » Median presence. » Lighting presence. » Sidewalk presence and width. » Presence and width of sidewalk offset or furniture zone. » Mid-block crossing delineation (crosswalk, signage, pavement markings). » Number of lanes. » Posted speed limit. » Pedestrian volume and demand. » Vehicle volume. » Transit stops. » Adjacent land use. » Demographic factors (e.g., population, social vulnerability index and other equity indicators, income, commuting behavior, vehicle ownership). » Severe pedestrian crash history.
Bicycle	» Functional classification. » One-way or two-way travel. » Lane width. » Shoulder width. » Shoulder or edgeline rumble strip presence. » Median presence. » Presence of lighting. » Bicycle facility presence, type, and width. » Presence and type of bicycle lane separation. » Number of lanes. » Posted speed limit. » Bicycle volume and demand. » Vehicle volume. » Adjacent land use. » Demographic factors. » Transit stop presence. » Severe bicycle crash history.

Table 16. Summary of features for intersection-level safety risk assessment.

Focus crash	Characteristics to consider when assessing risk
Angle	» Highest functional class at the intersection. » One-way or two-way travel. » Left-turn lane offset. » Vehicle volume (particularly left-turn and opposing through volumes). » Sight distance. » Posted speed limit. » Approach geometry. » Angle crash history. » Skew angle. » Left-turn phasing. » Turn prohibitions. » Approach grades. » Presence of dedicated left turn lanes. » Presence of dedicated right turn lanes. » Presence of high-speed conflicts. » Presence of lighting. » Intersection traffic control.
Motorcycle	» Highest functional class at the intersection. » One-way or two-way travel. » Left-turn lane offset. » Sight distance. » Posted speed limit. » Approach geometry. » Angle crash history. » Skew angle. » Left-turn phasing. » Turn prohibitions. » Approach grades. » Presence of dedicated left turn lanes. » Presence of dedicated right turn lanes. » Presence of high-speed conflicts. » Presence of lighting. » Presence of curbing. » Pavement friction. » Intersection traffic control.
Pedestrian	» Highest functional class at the intersection. » One-way or two-way travel. » Pedestrian volume and demand. » Vehicle volume, ideally turning movement volumes. » Presence of adjacent schools and other pedestrian trip generators. » Presence of adjacent transit stops and transit ridership. » Presence of adjacent alcohol sales establishments. » Pedestrian crossing distance. » Number of lanes to be crossed. » Presence and type of crosswalk (by intersection approach).

Focus crash	Characteristics to consider when assessing risk
	» Presence and type of pedestrian traffic control device. » Intersection traffic control. » Presence of pedestrian warning signs. » Presence of pedestrian pavement markings. » Turn prohibitions. » Posted speed limit on approaches. » Adjacent population density and demographics, including vulnerable populations and income. » Approach geometry. » Pedestrian accessibility (i.e., presence of curb ramps). » Adjacent land use. » Approach grades. » Lighting presence. » Demographic factors. » Severe pedestrian crash history.
Bicycle	» Highest functional class at the intersection. » One-way or two-way travel. » Bicycle volume and demand. » Vehicle volume, ideally turning movement volumes. » Presence of adjacent schools and other bicycle trip generators. » Presence of adjacent transit stops and transit ridership. » Presence of adjacent alcohol sales establishments. » Presence of high-speed conflict points. » Presence and type of bicycle facilities (by approach and direction). » Type of bicycle facility separation. » Presence of bicycle traffic control device. » Intersection traffic control. » Presence of bicycle pavement markings. » Turn prohibitions. » Posted speed limit on approaches. » Adjacent population density and demographics, including vulnerable populations and income. » Approach geometry. » Pedestrian accessibility (i.e., presence of curb ramps). » Adjacent land use. » Approach grades. » Lighting presence. » Demographic factors. » Severe bicycle crash history.



U.S. Department of Transportation
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Contact

OFFICE OF SAFETY
https://highways.dot.gov/safety

Matt Hinshaw
360.619.7677
matthew.hinshaw@dot.gov

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