



Quantifying Roadside Assessment for Highway Safety

Kentucky Transportation Center Research Report – KTC-16-15/SPR14-482-1F

DOI: <https://doi.org/10.13023/KTC.RR.2016.15>



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Research Report
KTC-16-15/SPR14-482-1F

Quantifying Roadside Assessment for Highway Safety

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Commonwealth of Kentucky

and

Federal Highway Administration
U. S. Department of Transportation

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September 2017

| | | | |
|---|--|--|------------------|
| 1. Report No. KTC-16-15/SPR14-482-1F | 2. Government Accession No. | 3. Recipient's Catalog No | |
| 4. Title and Subtitle Quantifying Roadside Assessment for Highway Safety | | 5. Report Date September 2017 | |
| | | 6. Performing Organization Code | |
| 7. Author(s): Reginald R. Souleyrette, PhD, PE; Michael A. Fields; and Heather Hunt | | 8. Performing Organization Report No. KTC-16-15/SPR14-482-1F | |
| 9. Performing Organization Name and Address Kentucky Transportation Center College of Engineering University of Kentucky Lexington, Kentucky 40506-0281 | | 10. Work Unit No. (TRAIS) | |
| | | 11. Contract or Grant No. SPR 14-482 | |
| 12. Sponsoring Agency Name and Address Kentucky Transportation Cabinet 200 Mero Street Frankfort, Kentucky 40622 | | 13. Type of Report and Period Covered Final Year 3 | |
| | | 14. Sponsoring Agency Code | |
| 15. Supplementary Notes Prepared in cooperation with the Kentucky Transportation Cabinet and the Federal Highway Administration | | | |
| 16. Abstract Many of Kentucky's two-lane rural roads pose an above average risk for fixed object crashes. In Kentucky, run-off-road (ROR) collisions with fixed objects account for 18.9% of all crashes and 41.6% of fatal crashes. Accordingly, ROR crashes are a significant public safety hazard that must be addressed through judicious investments in safety improvements. Until recently, transportation engineers and planners have mostly leveraged qualitative metrics to prioritize safety investments, however, qualitative methodologies are problematic because they may rely excessively on subjective opinion and intuition. This study applied methodologies and software from the U.S. Road Assessment Program (usRAP) to develop quantitative, objective roadside safety ratings for rural two-lane roads in the state of Kentucky on which 20 or more crashes occurred from 2010 to 2015. Kentucky Transportation Center researchers generated usRAP star rating scores following standard protocols and, to validate the methodology, compared those scores to the number of ROR collisions over the specified interval. Analysis revealed robust correlations between star rating scores (and star ratings) and crash data, justifying their as an objective measure of roadside safety. Researchers also delivered a comprehensive database containing over 126,000 records to the Kentucky Transportation Cabinet, which can be used to examine roadside severity and potentially inform future highway investments. | | | |
| 17. Key Words roadside safety; run-off-road crashes; roadside rating; clear zone; quantifying roadside | | 18. Distribution Statement Unlimited, with approval of the Kentucky Transportation Cabinet | |
| 19. Security Classification (report) Unclassified | 20. Security Classification (this page) Unclassified | 21. No. of Pages 37 | 22. Price |

Table of Contents

| | |
|--|----|
| Executive Summary..... | 1 |
| 1 Introduction..... | 2 |
| 1.1 Background..... | 2 |
| 1.2 Problem Statement..... | 2 |
| 1.3 Objectives | 2 |
| 1.4 Approach..... | 2 |
| 2 Literature Review | 4 |
| 2.1 General..... | 4 |
| 2.2 Factors that Contribute to ROR Crashes | 5 |
| 2.2.1 Roadway Alignment | 5 |
| 2.2.2 Roadway Functional Classification | 5 |
| 2.2.3 Roadway Speed Limit..... | 5 |
| 2.2.4 Roadway Number of Lanes | 6 |
| 2.2.5 Measures to Reduce ROR Crashes | 6 |
| 3 Methodology/Approach..... | 7 |
| 3.1 usRAP | 7 |
| 3.2 Study Areas..... | 9 |
| 3.3 Sensitivity Analysis and Selection of Roadside Attributes | 10 |
| 3.3.1 Sensitivity Analysis Procedure | 10 |
| 3.3.2 Sensitivity Analysis Results | 10 |
| 3.4 Other Roadway Attributes Coded..... | 11 |
| 3.5 Data Coding | 12 |
| 3.6 Data Processing, Validation, and Analysis | 17 |
| 4 Results..... | 18 |
| 5 Conclusions/Recommendations..... | 24 |
| Appendix A: Route Summary Data and Average Star Rating Scores | 25 |
| Appendix B: Summary of “Accident Effects of Side Slopes and other Roadside Features on Two-Lane Roads (Zegeer et al., 1988)” | 26 |
| Bibliography | 32 |

List of Figures

| | |
|---|----|
| Figure 1: Zegeer’s 7 point rating method (Zegeer et al, 1988)..... | 3 |
| Figure 2: Overall usRAP process and general steps | 7 |
| Figure 3: Star Ratings and their associated Star Rating Scores | 8 |
| Figure 4: Roadway attributes to determine likelihood and severity for usRAP analysis | 9 |
| Figure 5: Rotation of attributes being tested in the sensitivity analysis | 10 |
| Figure 6: ROR score portion of overall usRAP processing..... | 11 |
| Figure 7: Data preprocessor – 19 roadway attributes coded for this project highlighted..... | 12 |
| Figure 8: Google Street View - data coder has options to pan, zoom, and move forwards or backwards along the roadway..... | 13 |
| Figure 9: Example of a completed form for data coding..... | 17 |
| Figure 10: Total Crash Rate vs. Star Rating Score - all relevant attributes..... | 18 |
| Figure 11: Total Crash Rate vs. Star Rating Score Range - all relevant attributes..... | 19 |
| Figure 12: K+A Crash Rate vs Star Rating Score - all relevant attributes | 19 |
| Figure 13: K+A Crash Rate vs Star Rating Score Range - all relevant attributes | 20 |
| Figure 14: Star Ratings - all relevant attributes | 20 |
| Figure 15: Total Crash Rate vs. Star Rating Score – non-roadside attributes held constant..... | 21 |
| Figure 16: Total Crash Rate vs. Star Rating Score Range..... | 22 |
| Figure 17: Star Ratings – non-roadside attributes held constant | 23 |

List of Tables

| | |
|--|----|
| Table 1. usRAP general recommendations for improving roadway safety | 6 |
| Table 2. Crash reduction related to roadside hazard rating | 28 |
| Table 3. Crash reduction related to increased roadside recovery distance | 28 |
| Table 4. Mean adjusted single-vehicle crashes per 100 MVM for lane width, shoulder width, and average roadside recovery distance using rural sections..... | 28 |
| Table 5. Summary of Expected Percent Reduction in Single-Vehicle Crashes Due to Sideslope Flattening | 29 |
| Table 6. Fixed-object crashes by ADT group and type of obstacle struck on urban and rural highways ... | 29 |
| Table 7. Severity of common crashes types in several databases..... | 30 |
| Table 8. Severity of common ROR fixed-object crash types in several databases | 31 |

Acknowledgements

The following individuals contributed to the successful completion of this project through their participation on the Study Advisory Committee:

| | |
|--------------------------|--------------------------------------|
| Tracy Lovell, Chair..... | KYTC Division of Traffic Operations |
| Jarrold Stanley | KYTC Division of Traffic Operations |
| Ed Harding..... | KYTC Division of Traffic Operations |
| Keith Dotson..... | KYTC Division of Planning |
| Jon Wilcoxson | KYTC Division of Planning |
| Diana Radcliff..... | KYTC Division of Planning |
| Jason Siwula | KYTC State Highway's Engineer Office |
| Ryan Tenges | FHWA, Kentucky Division |

Executive Summary

The National Highway Traffic Safety Administration defines a run-off-road (ROR) crash as one that “occurs when a vehicle in transit leaves the road and collides with a tree, a pole, other natural or artificial objects, or overturns on non-traversable terrain.” While 18% of crashes in the U.S. involve roadside collisions with fixed objects, they are responsible for 45% of all fatal crashes. Kentucky’s statistics are similar — collisions with fixed objects account for 18.9% of all crashes and 41.6% of all fatal crashes (Kentucky Transportation Cabinet and Kentucky State Police, 2014).

Many rural two-lane roadways in Kentucky pose a higher risk for fixed object crashes. However, until this project, this risk had not been systematically quantified. This project’s objective was to develop a method that could be used to evaluate the relative risk posed by Kentucky’s roadsides, and use that method to rate the safety of roads where ROR crashes are common — two-lane rural state highways on which 20 or more ROR crashes have been recorded during the last five years.

The method developed by the research team is based on the usRAP star rating scoring protocol. It calls for rating 100-meter roadway segments using imagery from Google Street View. Researchers examined this imagery and over 50 elements which influence the probability and outcome of crashes. Two critical attributes that influence the likelihood and outcome of ROR crashes are roadside severity and distance to hazard (transverse to the highway, measured from the outside of the traveled way). With the usRAP method, total risk of ROR crash hinges on other roadway attributes as well (e.g., speed, curvature, pavement marking). As such, the research team coded information on these elements for over 8,000 miles of Kentucky highways. A sensitivity analysis was conducted to determine whether coded data on these elements was necessary. Two measures of roadside rating were subsequently developed in this study. First, the usRAP software ViDA, was used to compute a relative Star Rating Score (SRS) for each 100-meter roadway segment based on all attributes the roadside component of Road Protection Scores (RPS) are sensitive to. In general, the higher the RPS, the higher the roadside crash risk.

To provide a second measure of roadside rating, and one that only depends on roadside character, only the roadside elements were allowed to vary in computation of RPSs. All other attributes were held constant to the mode of other attributes (e.g., most common speed, most common lane width.) This measure can be used to compare roadsides on a common scale, though the total risk of ROR crash is not approximated.

Crash analysis was performed to determine if and how roadside rating explains crash performance. It is recommended that the first measure of roadside rating (all attributes sensitive to ROR crash risk) be used to evaluate the need for and benefits from roadside improvement.

1 Introduction

1.1 Background

A significant portion of the fatalities and serious injuries which occur on Kentucky's highways are the result of run-off-road (ROR) crashes. Collisions with fixed objects account for 18% of all crashes in the U.S. and 45% of all fatal crashes (NTHSA, 2014). Kentucky's statistics are similar — collisions with fixed objects account for 18.9% of all crashes and 41.6% of all fatal crashes (Kentucky Transportation Cabinet and Kentucky State Police, 2014). In fact, Kentucky ranks in the top ten for states with the highest proportion of fatal crashes attributable to collisions with fixed objects. Because of this, the FHWA has designated Kentucky as a Roadway Departure *Focus State*.

Recent legislation (Moving Ahead Progress for the 21st Century, or MAP-21) mandates safety analysis for *all public roads*. Effective safety analysis is possible only if states have access to high-quality road, crash, driver, vehicle, medical, and enforcement data. Due to the high frequency of ROR crashes, it is critical for comprehensive road data to contain exhaustive information on roadside data. Specifications for roadside data and rating are outlined in the Federal Highway Administration's (FHWA) MIRE criteria (Model Inventory of Roadway Elements).

1.2 Problem Statement

ROR crashes are a serious problem in Kentucky. Despite accounting for approximately 19% of all crashes in 2012 and 2013, 42% of all fatal crashes in 2012 and 37% of all fatal crashes in 2013 were ROR crashes. The winding, unforgiving geometries of many rural two-lane roads contribute to the occurrence of ROR crashes and the high number of serious injuries and fatalities which result. Successfully mitigating these crashes requires understanding which roadway features increase their probability of occurring as well as the consequences of these crashes. But states face several hurdles in their efforts to address mitigation systematically, including the lack of quantitative data on roadside characteristics as well as the lack of a widely accepted methodology that can be used to assess how these features contribute to overall risk.

1.3 Objectives

Engineers can improve their ability to identify and prioritize sites for improvements that can reduce the severity of ROR crashes in a cost-effective manner by rating roadside safety. Roadside safety ratings can be used in conjunction with crash data to better prioritize safety investments and identify locations where additional cost-effective investments may be made. The main objective of rating roadside safety is to save lives and reduce the frequency serious injury crashes. To achieve this goal, this project's objective was to conduct a pilot test and evaluate quantitative methods for roadside assessment; design a database and procedures for collecting (coding) roadside data; and code roadside data which can be used to populate a roadside rating database.

1.4 Approach

Kentucky has approximately 18,000 miles of state-maintained two-lane rural roads, which comprise approximately 85 percent of state-maintained roadways. Given the variability of Kentucky's terrain and roadways, many miles of these roads may be at higher risk for ROR crashes.

Several factors affect the outcome of ROR crashes, including roadside slopes, fixed-objects adjacent to the roadway, and other roadside hazards. If roadside severity is rated at all, it is typically done with qualitative methodologies that rely on the subjective evaluations of researchers (e.g., Zegeer's 7-point rating method; Zegeer et al., 1988; Figure 1). The lack of an accepted quantitative methodology prevents transportation agencies from systematically identifying roadside hazards and designing appropriate mitigation plans or

countermeasures. However, new methods, such as the Road Safety Federation's U.S. Road Assessment Program (usRAP), can be used to quantify the safety impact of roadside environments. Both manual and automated (e.g., machine vision, LIDAR) methods for data collection have emerged recently as well.

We employed usRAP ViDA software to generate quantitative roadside safety ratings based on the assessment of specific roadway and roadside attributes. These ratings, in turn, can be used to determine the level of risk for Kentucky's rural two-lane roads. Once data have been coded and processed, ViDA computes Star Rating Scores (SRS), which measure the risk (likelihood multiplied by consequence) for ROR collisions. Roadside attributes are rated independently as well as in the context of the entire roadway.

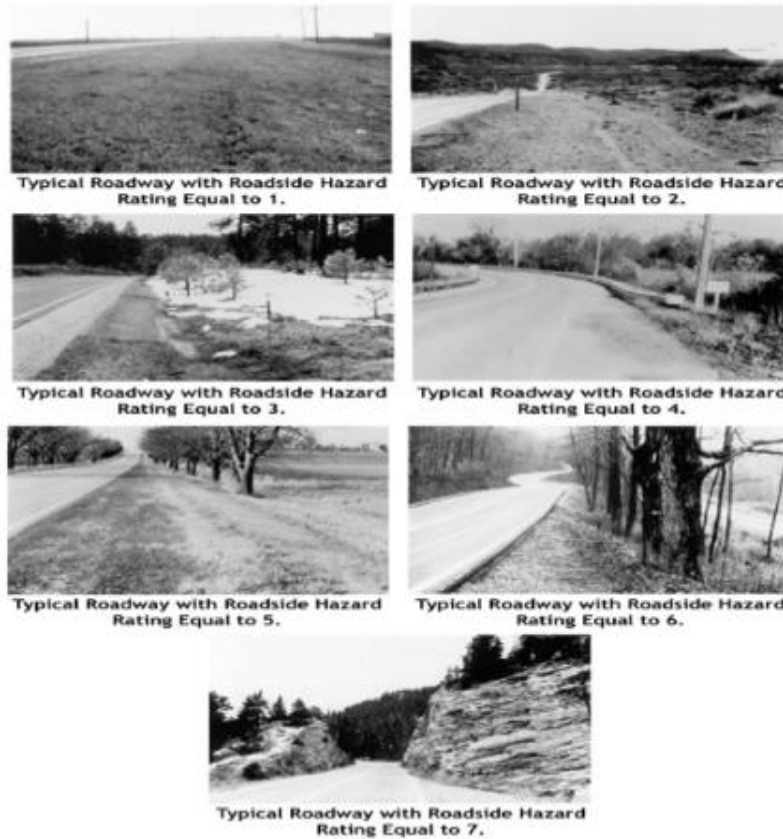


Figure 1: Zegeer's 7-point rating method (Zegeer et al, 1988)

2 Literature Review

2.1 General

Several studies have attempted to develop methodologies to rate crash severity and frequency based on the characteristics of certain roadside features. While many studies have focused on *roadway* features such as the travel lane and shoulders, there have been studies in which *roadside* features were the focal point. Two seminal papers detailed the relationship between crashes and roadside features and proposed strategies to quantify this relationship

Accident Effects of Sideslopes and Other Roadside Features on Two-Lane Roads (Zegeer et al., 1988)

Zegeer et al. observed that fixed object crashes are both more frequent and more severe compared to other crash types. In response, they developed a method to quantify roadside hazards and identify what factors influence the occurrence of ROR crashes. They introduced a method to estimate the benefits of making various roadside improvements, a rating system that is used to assign roadside hazard ratings on a scale from 1 to 7 (Figure 1). The system adopts an ordinal scale instead of a logarithmic scale — higher ratings indicate a greater likelihood for crashes. Zegeer et al. found that making a roadside improvement that reduces the roadside hazard rating by one point (e.g., from five to four) would reduce the number of roadside-related crashes by 19%.

This study was limited in terms of the number of roadway/roadside variables analyzed and modeled. Additionally, some of the variable categorization was excessively subjective. The method to assign ratings scores was somewhat ambiguous as well. Although it is easy to assign extreme ratings (e.g., 6 or 7), the subjective nature of the scale makes it challenging to differentiate among roads that fall in the middle of the spectrum. The study also failed to elaborate on the potential interactions among different variables. This was discussed briefly, but it can be assumed that there are many more relationships that indirectly affect roadside crash frequency and severity.

Safety Relationships Associated with Cross Sectional Roadway Elements (Zegeer and Council, 1995.)

This paper used previous studies to summarize the known relationships between cross-sectional roadway elements and crash data. Zegeer and Council sought to determine the anticipated reduction in crashes after implementation of cross-sectional roadway improvements. They found that cross-sectional roadway elements significantly influence the outcome of crashes. As such, modifying these elements can affect crash rates. Specifically, the study looked at roadside condition (e.g., roadside recovery, clear zone, sideslope) and objects along the roadways, and concluded that roadsides free of objects and without steep slopes afford vehicles the best chance to recover without experiencing a serious crash. Other key findings were:

- Increasing the roadside recovery distance by five feet reduces the chance of a “related¹” crash by 13%.
 - There is a consistent relationship between recovery distance and the probability of a crash occurring — increases in recovery are correlated with the reduced likelihood of a crash occurring.
- Flatter sideslopes reduce crash rates and rollovers.

¹ run-off-road (fixed object, rollover, and other run-off-road accidents), head-on, and opposite and same-direction sideswipe crashes

- Crash severity varies as a function of what objects are present on the roadside.
 - Higher-risk objects include trees, poles, culverts, and embankments.
- Roadside ditch characteristics also influence crash severity and frequency.

2.2 Factors that Contribute to ROR Crashes

Driver and environmental factors are the two main contributors to ROR crashes. Driver factors include operator characteristics, such as vision, response time, and cognitive function. Environmental factors include roadway features and surrounding elements such as weather and lighting. As driver factors are unpredictable and difficult to control, the current project focused on roadway infrastructure. Roadway factors, including alignment, functional classification, speed limit, and number of lanes, also contribute to ROR crashes. Several previous studies have examined the impact of these factors, using FARS data from 1999 (Neuman et al., 2003) and FARS data from 1991-2007 (Liu and Subramanian, 2009). The goal of these studies was to identify high-risk areas that warranted crash mitigation treatments.

2.2.1 Roadway Alignment

Roadway alignment is broken into two categories: curved roads and straight roads. Neuman et al. (2003) primarily looked at the overall crash distributions for both alignment types, while Liu and Subramanian provided more detail on the statistical distribution of crashes. Neuman et al. reported data for tangent (straight) roadway segments, finding that ROR crashes account for 58% of crashes on all roads and 50% of crashes on two-lane rural roads. Although this seems counterintuitive, they speculated that this may reflect the fact that most road sections are classified as tangent segments.

Liu and Subramanian compared curved and straight roadway segments by examining the proportion of ROR crashes out of all fatal single-vehicle crashes. They found that 90.2% of crashes on curved roads were ROR, while 62.1% of crashes on straight roads were ROR. Using a chi-squared analysis, Liu and Subramanian demonstrated there was a significant difference in crash rates between the two road types, leading them to conclude that ROR crashes are more likely to occur on curved roadway segments than straight roadway segments.

2.2.2 Roadway Functional Classification

For ROR crash analysis, roadway functional classification is divided into two primary categories — rural or urban. Liu and Subramanian found that approximately 80.6% of all crashes along rural roadways were ROR, while only 56.2% of crashes on urban roads were ROR. A chi-squared analysis test confirmed these rates significantly differ from one another (Liu and Subramanian, 2009). This demonstrated that ROR crashes are more likely to occur on rural roadways than on urban roadways. Neuman et al. (2003) arrived at a similar conclusion, finding that 82 percent of ROR crashes occur on rural roads while 18 percent occur on urban roads (Neuman et al., 2003).

2.2.3 Roadway Speed Limit

Liu and Subramanian (2009) compared single-vehicle crash rates on roads with posted speed limits greater than or equal to 60 mph to roads with posted speed limits less than 60 mph. On roads with speed limits greater than or equal to 60 mph, 81% of single-vehicle crashes were ROR. Conversely, on roads with a speed limit below 60 mph ROR crashes accounted for 69% of all crashes. A chi-squared analysis confirmed there was a significant difference between these percentages, indicating that ROR crashes are more likely to occur on roadways with a posted speed limit greater than or equal to 60 mph.

2.2.4 Roadway Number of Lanes

Liu and Subramanian (2009) also investigated the relationship between the number of lanes on a roadway and ROR crashes. They classified number of lanes into two groups — one or two lanes (divided and undivided), and three or more lanes (divided and undivided). For one- and two-lane roadways, 67.8% of fatal single-vehicle crashes on divided roads and 76.7% of fatal single-vehicle crashes on undivided roads were ROR crashes. Conversely, on roadways with three or more lanes, 40% of crashes on divided roads and 62% of crashes on undivided roads were ROR crashes. A chi-square confirmed statistical significance — ROR crashes are more likely to occur on roadways with fewer lanes.

2.2.5 Measures to Reduce ROR Crashes

A number of measures have been proposed to counteract the effects of roadway features that increase the frequency of ROR crashes. usRAP documentation lists some recommendations along with the average cost to implement each, along with the reduction in casualties each could viably produce (Table 1).

Table 1. usRAP general recommendations for improving roadway safety

| Safer Roads | Estimated Cost | Casualty Reduction |
|---------------------------------|----------------|--------------------|
| Delineation | Low | 10-25% |
| Rumble Strips | Low | 10-25% |
| Skid Resistance | Low to medium | 25-40% |
| Roadside Safety- Hazard Removal | Low to medium | 25-40% |
| Sideslope Improvement | Medium | 10-25% |
| Roadside Safety- Barriers | Medium | 40-60% |
| Shoulder Sealing | Medium | 25-40% |
| Speed Management | Medium | 25-40% |
| Traffic Calming | Medium to high | 25-40% |
| Lane Widening | Medium to high | 25-40% |
| Median Barrier | Medium to high | 60% or more |
| Realignment—Horizontal | High | 25-40% |
| Realignment—Vertical | High | 10-25% |

Neuman et al. (2003) made the following recommendations to reduce ROR crashes:

- Keep vehicles in the travel lane
- Minimize the likelihood of a crash if a vehicle travels beyond the shoulder
- Reduce the severity of crashes that occur

Although our ultimate goal should be the prevention of ROR crashes entirely, a more attainable and realistic goal is to identify strategies and countermeasures to reduce the severity of ROR crashes and prevent fatalities when they occur. Eliminating objects in the clear zone or installing preventative barriers are two methods to accomplish this. Neuman et al. (2003) catalogued methods to prevent or reduce the severity of ROR crashes. However, transportation officials recognize that only a very limited number of strategies can be used on rural two-lane roadways to reduce crashes. As such, not every measure they proposed is appropriate for mitigating ROR crashes on rural two-lane roadways.

3 Methodology/Approach

3.1 usRAP

The Roadway Safety Foundation sponsors usRAP, which offers protocols to identify high-risk roadways and develop risk-based recommendations for improving roadway safety. The goal of usRAP is to reduce the likelihood of roadway crashes and minimize their impact.

usRAP's software, ViDA, processes data on roadside attributes — coded at 100-m intervals — using equations that have been developed and refined over the course of numerous roadway research studies. Results can be used to develop a plan to create safer roadways. Figure 2 illustrates the usRAP process and general steps. Note that iRAP is the international *parent* of usRAP, and some graphics use the term iRAP.

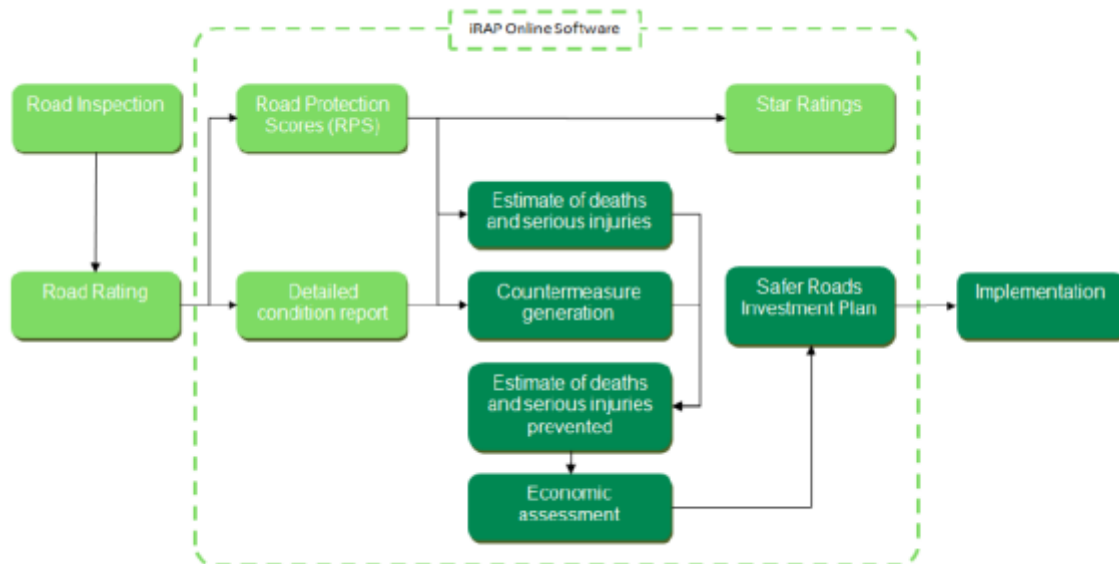


Figure 2: Overall usRAP process and general steps

The primary output of usRAP analysis is a star rating, which rates an existing roadway's safety. Higher star ratings indicate less risk. Star ratings are based on Star Rating Scores (SRS), also known as Road Protection Scores (RPS), which are generated by the usRAP ViDA software. Star Ratings are inversely proportional to SRS — higher SRS = lower star rating = greater risk (Figure 3).

Star Rating bands and colours

| Star Rating | Star Rating Score | | | | |
|-------------|-------------------------------------|------------|-------------|-------------|--------------|
| | Vehicle occupants and motorcyclists | Bicyclists | Pedestrians | | |
| | | | Total | Along | Crossing |
| 5 | 0 to < 2.5 | 0 to < 5 | 0 to < 5 | 0 to < 0.2 | 0 to < 4.8 |
| 4 | 2.5 to < 5 | 5 to < 10 | 5 to < 15 | 0.2 to < 1 | 4.8 to < 14 |
| 3 | 5 to < 12.5 | 10 to < 30 | 15 to < 40 | 1 to < 7.5 | 14 to < 32.5 |
| 2 | 12.5 to < 22.5 | 30 to < 60 | 40 to < 90 | 7.5 to < 15 | 32.5 to < 75 |
| 1 | 22.5 + | 60+ | 90 + | 15 + | 75 + |

Figure 3: Star Ratings and their associated Star Rating Scores

Figure 4 presents the computational method and data requirements for star rating analysis.

x – Factors (to the right) are multiplied

+ - Factors (to the right) are added

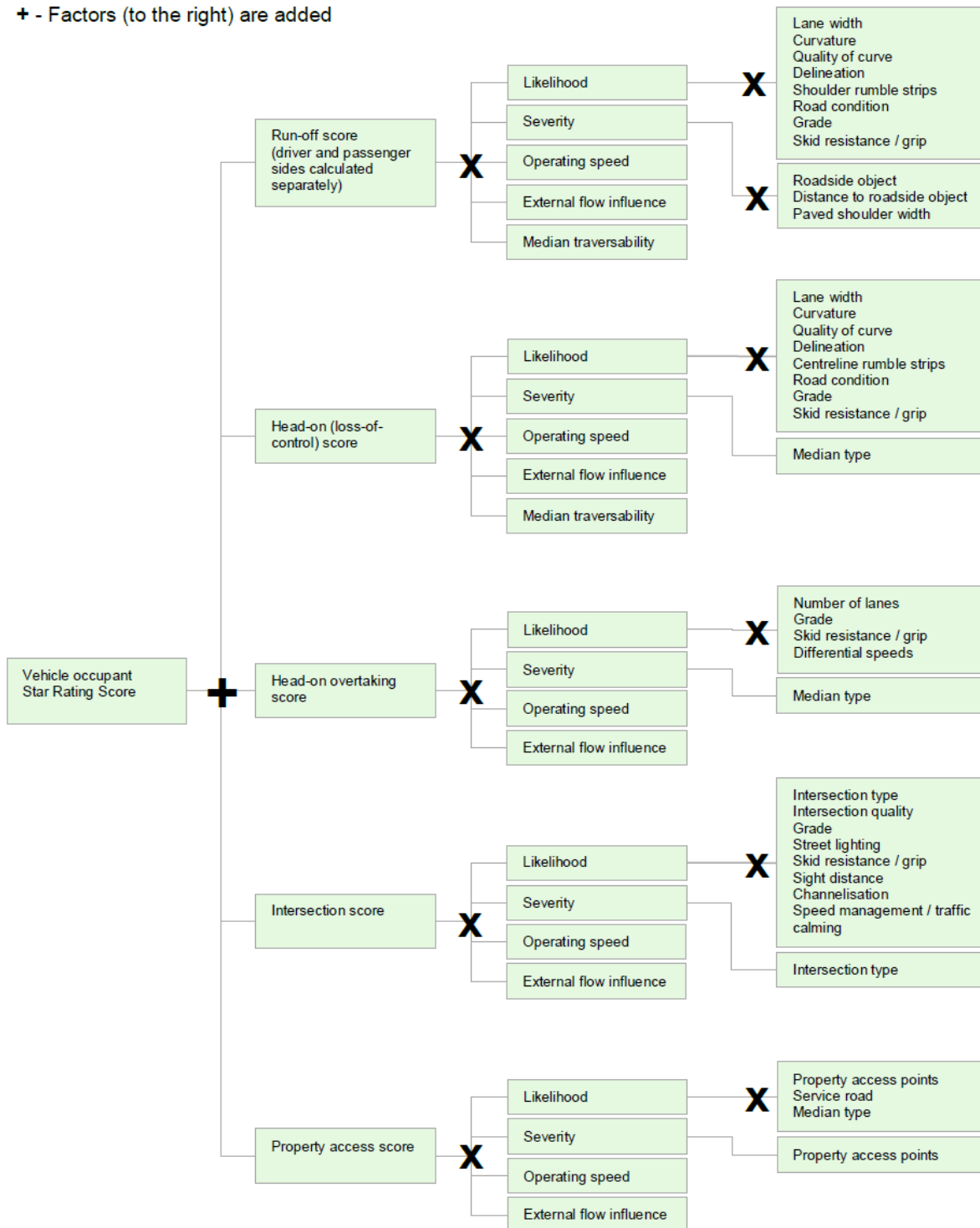


Figure 4: Roadway attributes to determine likelihood and severity for usRAP analysis

3.2 Study Areas

There are approximately 18,000 miles of two-lane undivided roadways in Kentucky. Studying all two-lane undivided roadways would have proven analytically intractable. Thus, this project's focus was on roads

where 20 or more crashes were recorded from 2010–2015. This resulted in a study area of approximately 8,000 miles, a number that could be reasonably coded with the resources available to the Kentucky Transportation Center (KTC).

3.3 Sensitivity Analysis and Selection of Roadside Attributes

ViDA software normally requires the coding of over 60 data elements to perform risk analysis. While only two data elements explicitly address roadside elements (roadside severity and distance to hazard), a number of other elements influence the overall usRAP risk rating for ROR crashes. Other elements may not affect roadside risk rating. A sensitivity analysis was performed to determine the effects each of 60+ elements have on ROR rating, thereby eliminating the need to code certain elements and conserving project resources.

3.3.1 Sensitivity Analysis Procedure

At the outset of the sensitivity analysis, sets of four hypothetical 100-meter segments were specified for each roadway element (i.e., *subject*; see Figure 5) that would be tested. Researchers defined extreme values (both forgiving and unforgiving) for the roadside hazard, including type of object and distance to object, for each segment. This value was combined with the extreme values for the test (i.e., *subject*) element (e.g., lowest and highest speed limits). We classified the most hazardous roadsides as those with rigid (infrangible) objects less than one meter away from the edge of the traveled way. For each of the four subject/roadside combinations, all other elements (i.e., *others*) were held constant at a default value. We selected a typical value for the study area’s roads. Sets of hypothetical segments (four times the number of subject elements to be tested) were then input into the ViDA program. We evaluated the output for each segment, which took the form of either ROR risk or SRS). If varying the level of a particular test element from one extreme to the other did not affect ROR risk for either the most or least severe roadside, the test element was classified as “not-required” for the project. Figure 5 illustrates this process.

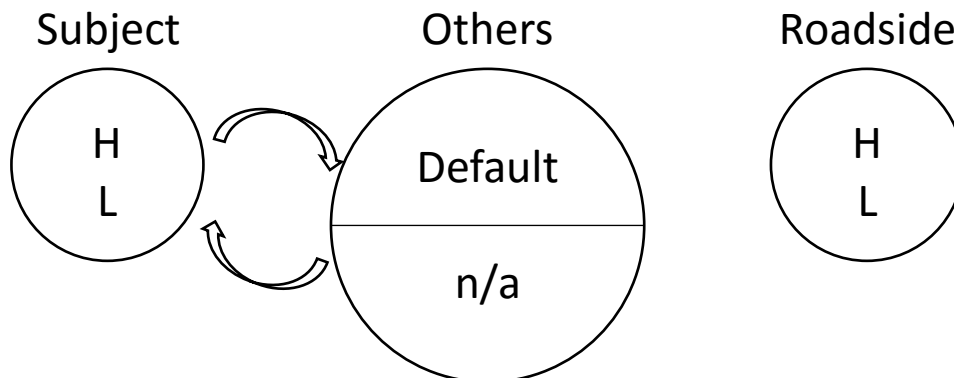


Figure 5: Rotation of attributes being tested in the sensitivity analysis

3.3.2 Sensitivity Analysis Results

Along with the original four roadside attributes, sensitivity analysis indicated that the following attributes were necessary to accurately calculate the roadside star rating:

- Speed limit
- Lane width
- Grade
- Road condition

- Curvature
- Quality of curve
- Skid resistance/grip

Figure 6 illustrates that the sensitivity analysis results compared favorably to those indicated in the usRAP manual as contributing to the likelihood of ROR crashes.

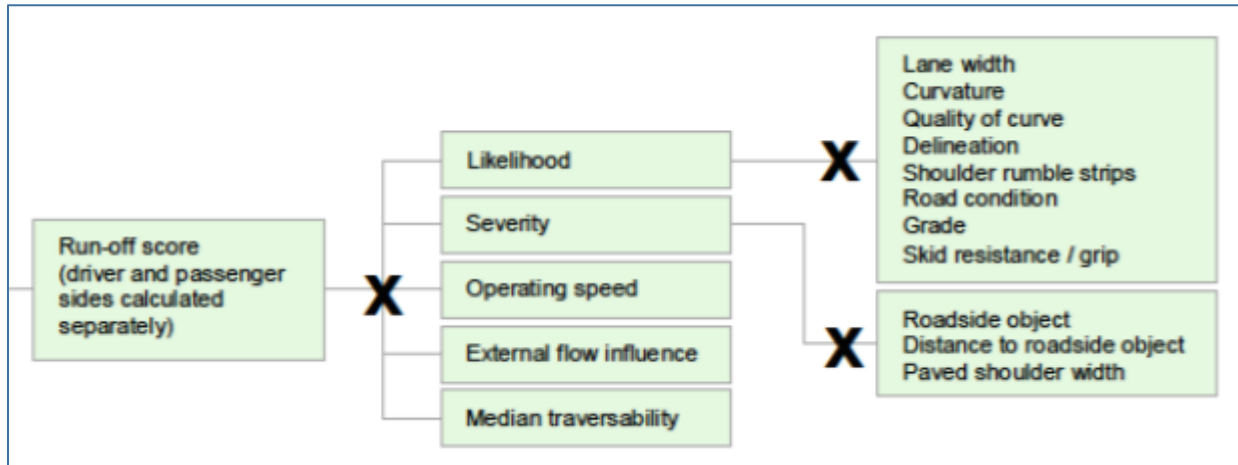


Figure 6: ROR score portion of overall usRAP processing

3.4 Other Roadway Attributes Coded

Originally, the goal of this project was to characterize the roadsides of Kentucky state highways with the aim of providing data which could be used to inform future decisions about safety improvements. However, early in the project researchers determined that the Kentucky Transportation Cabinet (KYTC) could be interested in and use other data elements. For example, additional elements could potentially be used to facilitate quality checks of existing HIS data elements. We established that the most cost-effective solution would be to gather those elements as data were manually coded from imagery. Originally, just four roadside attributes and seven other attributes (identified using sensitivity analysis) were included in the data requirements. These are listed below.

- Roadside
 - Roadside Severity — Driver’s Side
 - Roadside Severity — Driver’s Side Object
 - Roadside Severity — Passenger’s Side
 - Roadside Severity — Passenger’s Side Object
- Sensitivity Considerations
 - Speed Limit
 - Lane Width
 - Curvature
 - Quality of Curve
 - Grade
 - Road Condition
 - Skid Resistance/Grip

KYTC’s Planning Division, in cooperation with the Office of Traffic Safety and Project Advisory Committee agreed to add on the following elements for other uses:

- Centerline Rumble Strips
- Shoulder Rumble Strips
- Street Lighting
- Pedestrian Crossing — Inspected Road
- Pedestrian Crossing — Side Road
- Sidewalk — Driver’s Side
- Sidewalk — Passenger’s Side
- Bicycle Facility

3.5 Data Coding

Data coding occurred between January 2015 and April 2016. Figure 7 illustrates the form that was used to record information for each 100-meter segment of roadway.

The screenshot shows the 'iRAP Star Rating Input Review' form. It contains several sections for data entry:

- Header Information:** Road Name (002-KY-0121-000), Length (0.1), Landmark, Section (8), Latitude (36.7532801347), Vehicle flow (AADT) (0), Distance (0), Longitude (-86.190466697), Image reference.
- Main Attribute Grid:** A grid of 48 items, each with a 'Category' dropdown and a 'Hold' checkbox. 19 items are highlighted in yellow:
 - Shoulder rumble strips
 - Paved shoulder - drivers side
 - Paved shoulder - passenger side
 - Intersection type
 - Intersection channelisation
 - Intersecting road volume
 - Intersection quality
 - Property access points
 - Number of lanes
 - Lane width
 - Curvature
 - Quality of curve
 - Grade
 - Road condition
 - Skid resistance / grip
 - Delineation
 - Street lighting
 - Pedestrian crossing - inspected road
 - Pedestrian crossing quality
 - Pedestrian crossing facilities - side
- Other Attributes:** Carriageway, Upgrade coat, Motorcycle observed flow, Bicycle observed flow, Pedestrian observed flow across the, Pedestrian observed flow along the, Pedestrian observed flow along the, Land use - passenger side, Land use - drivers side, Area type, Speed limit, Motorcycle speed limit, Truck speed limit, Differential speed limits, Median type, Centreline rumble strips, Roadside severity - drivers side, Roadside severity - drivers side object, Roadside severity - passenger side, Roadside severity - passenger side, Pedestrian fencing, Speed management / traffic calming, Vehicle parking, Sidewalk - drivers side, Sidewalk - passenger side, Service road, Facilities for motorized two wheelers, Bicycle facility, Roadworks, Sight distance, Motorcycle %.
- Footer:** Coder name, Coding date, Road survey date, Sheet Name (Sheet1), Row Number (2), Previous Row, Next Row, Update Input File, Hold all - on/off, Show StreetView, Show Image, Save Input File, Exit.

Figure 7: Data preprocessor – 19 roadway attributes coded for this project highlighted

The preprocessor form was used to input data into a corresponding Excel spreadsheet, which had a column for each field to be filled. The Excel spreadsheet was input into the ViDA program to determine the SRS. The desired fields were highlighted to streamline the process of data coding and focus data entry on the desired roadway attributes (Figure 7).



Figure 8: Google Street View — data coder has options to pan, zoom, and move forwards or backwards along the roadway

We inspected the roadways and recorded data on the following attributes:

Posted Speed Limit

- If there was no speed limit sign, or no changes were observed upstream of a location, researchers assumed the speed limit was 55 mph. Researchers were instructed not to record temporary speed limits or speed limits posted in conjunction with road work.

Median Type

- If no median was present, *None* was entered on the preprocessor form.

Presence/Absence of Centerline Rumble Strips

- KYTC informed KTC that all centerline rumble strips are milled in. Thus, if rumble strips were present, this was noted on the preprocessor form.

Roadside Severity — Driver's Side Distance

- We estimated, using visual clues, the distance between the left edge of a roadway and the closest object that would pose a threat to a vehicle were it to depart the roadway.
- After estimating the distance between the roadway and object, we assigned it to one of the following intervals: 0 to < 1m, 1 to < 5m, 5 to < 10m, and $\geq 10m$.

Roadside Severity — Driver’s Side Object

We identified the most severe object on the driver’s side of the roadway. Options included:

- Cliff
- Tree $\geq 10\text{cm}$
- Non-frangible sign/ post./pole $\geq 10\text{cm}$
- Unprotected safety barrier end
- Aggressive vertical face
- Upwards slope - (15° to 75°)
- Deep drainage ditch
- Downwards slope ($> -15^\circ$)
- Large boulders $\geq 20\text{cm}$ high
- Non-frangible structure/bridge or building
- Frangible structure or building
- Safety barrier - concrete
- Safety barrier - metal
- Safety barrier - wire rope
- Safety barrier - motorcycle friendly
- Upwards slope - ($\geq 75^\circ$)
- No object

Roadside Severity — Passenger Side

Same as the Roadside Severity — Driver’s Side, but with distance coded from the right edge of the road to the hazardous object.

Roadside Severity — Passenger Side Object

Same procedure as described above for Roadside Severity — Driver’s Side Object.

Shoulder Rumble Strips:

- We determined if rumble strips were present by specifying rumble strip location (edge line or shoulder) and rumble strip type (milled or rolled).
- Because the majority of rumble strips on Kentucky rural roads were rolled at the time of this study, they were coded as *Rolled*.

Paved Shoulder — Driver’s Side

- We estimated shoulder width on the driver’s side of the road using visual clues or the linear measurement tool in Google Street View.
- The measured width was recorded to the nearest 1-foot interval, between 0 and 9 feet.

Paved Shoulder — Passenger Side

- We estimated shoulder width on the passenger’s side of the road using the same method described for Paved Shoulder — Driver’s Side.

Lane Width

- We estimated lane width based on visual clues or using the linear measurement tool in Google Street View.
- The measured width was recorded to the nearest 1-foot interval, between 7 feet to 14 feet.

Curvature

- The preprocessing form lets users select from a number of qualitative descriptions to characterize how quickly a driver can approach a curved segment. Options include *very sharp*, *sharp*, *moderate*, and *straight or gently curving*.
- We used visual clues, such as advisory speed signs, to make these characterizations.

- If no visual clues were present, we determined the magnitude of curvature based on our existing knowledge.

Quality of Curve

- We characterized the quality of curves using the preprocessing form’s options of *poor*, *not applicable*, or *adequate*. If there was no curve, *not applicable* was selected. Otherwise, the condition of the curve was identified and listed as such.
- We judged whether the curve could be accurately evaluated and whether the driver can safely make a decision on how to approach the curve.
- Factors that informed the rating included quality of the road surface, road width, and distance to nearest roadside hazard.

Grade

- We measured road grade by visually analyzing the focal segment’s steepness. It was then assigned to one of the following bins:
 - $\geq 10\%$
 - $\geq 7.5\%$ to $<10\%$
 - $\geq 5\%$ to $<7.5\%$
 - $\geq 4\%$ to $<5\%$
 - $\geq 0\%$ to $<4\%$

Road Condition

- We evaluated roadway condition based on the frequency of bumps, potholes, and a vehicle’s ability to maintain grip on the roadway. Condition was rated as *poor*, *medium*, or *good*.

Skid Resistance/Grip

- We determined whether appropriate treatments had been applied to roadways to provide adequate skid resistance/grip. Roadways were assigned to one of the following categories:
 - Unsealed — Poor
 - Unsealed — Adequate
 - Sealed — Poor
 - Sealed — Medium
 - Sealed — Adequate
- Generally, we assumed that the roadways in the study had been properly treated, so we usually defaulted to the *Sealed — Adequate* option.

Street Lighting

- We noted the presence or absence of street lighting.

Pedestrian Crossing — Inspected Road:

- We examined roadways to evaluate the availability of pedestrian crossing facilities. Roads were then assigned to one of the following categories:
 - Refuge only
 - Signalized with refuge
 - Unsignalized raised marked crossing without refuge

- Unsignalized marked crossing without a refuge
- Unsignalized marked crossing with refuge
- Signalized without refuge
- Grade separated facility
- No facility
- Unsignalized raised marked crossing with refuge
- Raised unmarked crossing with refuge
- Raised unmarked crossing without refuge

Pedestrian Crossing Facilities — Side Road

- We indicated whether there were pedestrian crossing facilities crossing any visible side roads. Options were the same as for Pedestrian Crossing — Inspected Road.

Vehicle Parking

- We classified the availability of parking facilities along the roadway as *high, medium, or low*.

Sidewalk — Driver’s Side

- We inspected roadways to determine whether a sidewalk was located along the driver’s side of the road. Sidewalk type was classified into one of the following categories:
 - Non-physical separation 0m to <1.0m
 - Non-physical separation 1.0m to <3.0m
 - Non-physical separation $\geq 3.0m$
 - Physical barrier
 - Informal path 0m to <1.0m
 - Informal path $\geq 1.0m$
 - None

Sidewalk — Passenger Side

- We inspected roadways to determine whether a sidewalk was located along the driver’s side of the road. Options were the same as for Sidewalk — Driver’s Side

Bicycle facility

- We recorded the presence or absence of bicycle facilities. If present, the facilities were classified into one of the following categories:
 - None
 - Extra wide outside ($\geq 4.2m$)
 - On-road lane
 - Off-road path
 - Off-road path with barrier
 - Signed shared roadway
 - Shared use path

The screenshot shows the 'iRAP Star Rating Input Review' interface. It contains several input fields at the top for basic road information. Below these are three columns of dropdown menus, each with a 'Hold' checkbox. The first column covers items like Carriageway, Upgrade coat, Motorcycle observed flow, Bicycle observed flow, Pedestrian observed flow, Land use, Area type, Speed limit, Motorcycle speed limit, Truck speed limit, Differential speed limits, Median type, Centreline rumble strips, Roadside severity, Pedestrian crossing, and School zone crossing. The second column covers items like Shoulder rumble strips, Paved shoulder, Intersection type, Intersection channelisation, Intersecting road volume, Intersection quality, Property access points, Number of lanes, Lane width, Curvature, Quality of curve, Grade, Road condition, Skid resistance, Delineation, Street lighting, Pedestrian crossing, and Pedestrian crossing facilities. The third column covers items like Pedestrian fencing, Speed management, Vehicle parking, Sidewalk, Service road, Facilities for motorized two wheelers, Bicycle facility, Roadworks, Sight distance, Motorcycle %, Pedestrian peak hour flow, Bicycle peak hourly flow, Operating Speed, and School zone crossing supervisor. At the bottom, there are fields for Coding date and Road survey date, a Comments field, a Sheet Name dropdown, a Row Number field, and buttons for navigation and saving.

Figure 9: Example of a completed form for data coding

3.6 Data Processing, Validation, and Analysis

ViDA software validates data to ensure the results are logical and accurate, and that users have not forgotten to input required information. The software requires post-processing information on speed limit and traffic volume, which cannot be accurately evaluated with a still image. As such, the data must be entered manually. Values come from existing information available through the Highway Information System and other available databases. Following data coding, we uploaded the spreadsheet to the ViDA online software to generate SRSs, Five Star Ratings and recommendations. This produced an ROR SRS for each 100-meter roadway segment.

Once the star ratings were generated, we reviewed a small sample of roadways to verify the software accurately evaluated their severity by manually comparing the results with roadway images. If, for instance, a roadway's results suggest that the risk is low, yet Google Street View of that roadway shows some roadside objects that obviously increase the risk of crash, it would be apparent that the methods used to determine that star rating should be reviewed.

Although the manual method is accurate, it is both time-consuming and reliant on subjective opinion. A less subjective option for data validation is to compare a roadway's SRS with its crash history. Crash history is a reliable indicator of roadway safety. Because the results from usRAP are intended to indicate the relative risk of roadways, a roadway's star rating or SRS should be proportional to the documented crash history. Plots can be used to display these relationships and validate the ViDA results.

4 Results

Figure 10 compares total crash rate to the SRS for the 615 roadways included in the study (7,864 total miles) using *all relevant attributes*. Recall that a higher star rating indicates a higher risk of crashes. The plot shows a positive correlation between ROR crash rate and ROR SRSs, with increases in ROR tracking increases in SRSs, thus validating the chosen methodology.

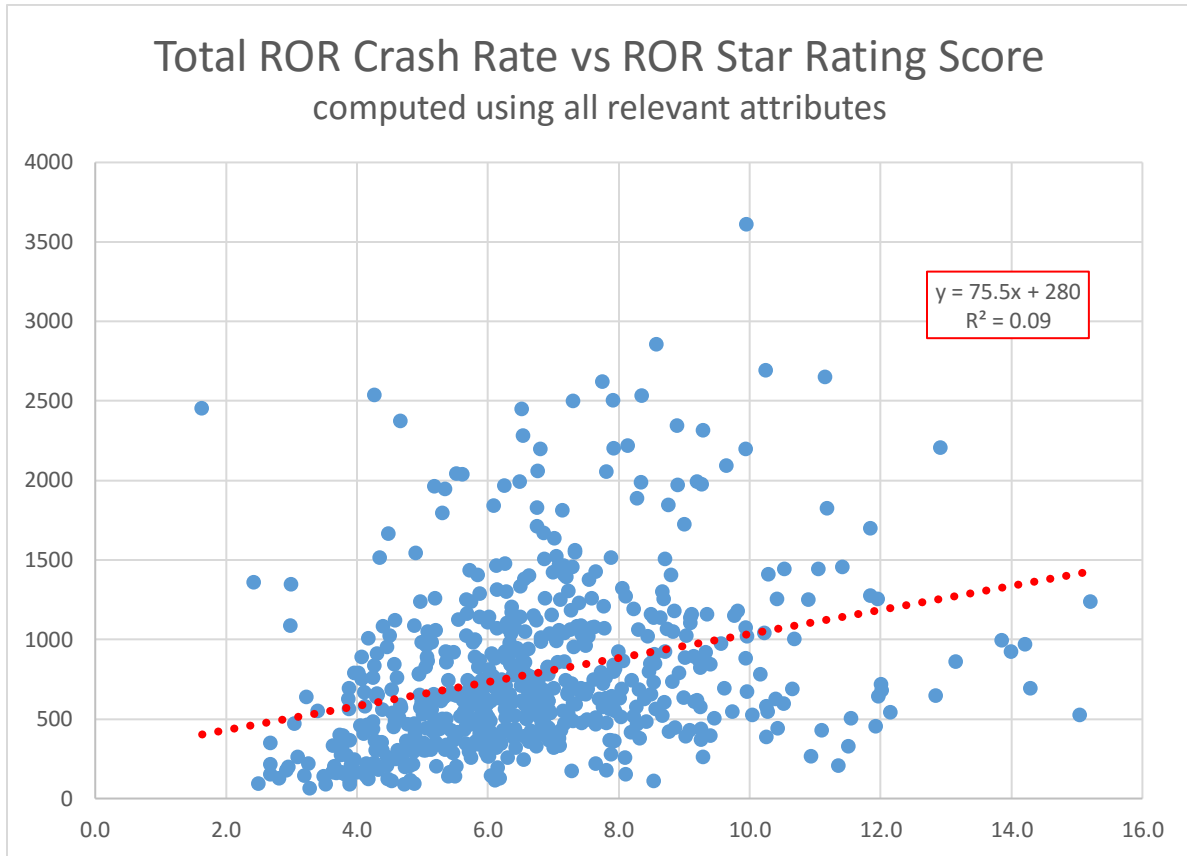


Figure 10: Total Crash Rate vs. Star Rating Score — all relevant attributes

Figure 11 plots ROR crash rates against binned SRSs. The trend line clearly indicates the strength of relationship between SRSs and ROR crash risk in Kentucky — bins with higher SRS values have higher total ROR crash rates. Note the very high correlation coefficient of nearly 0.95.

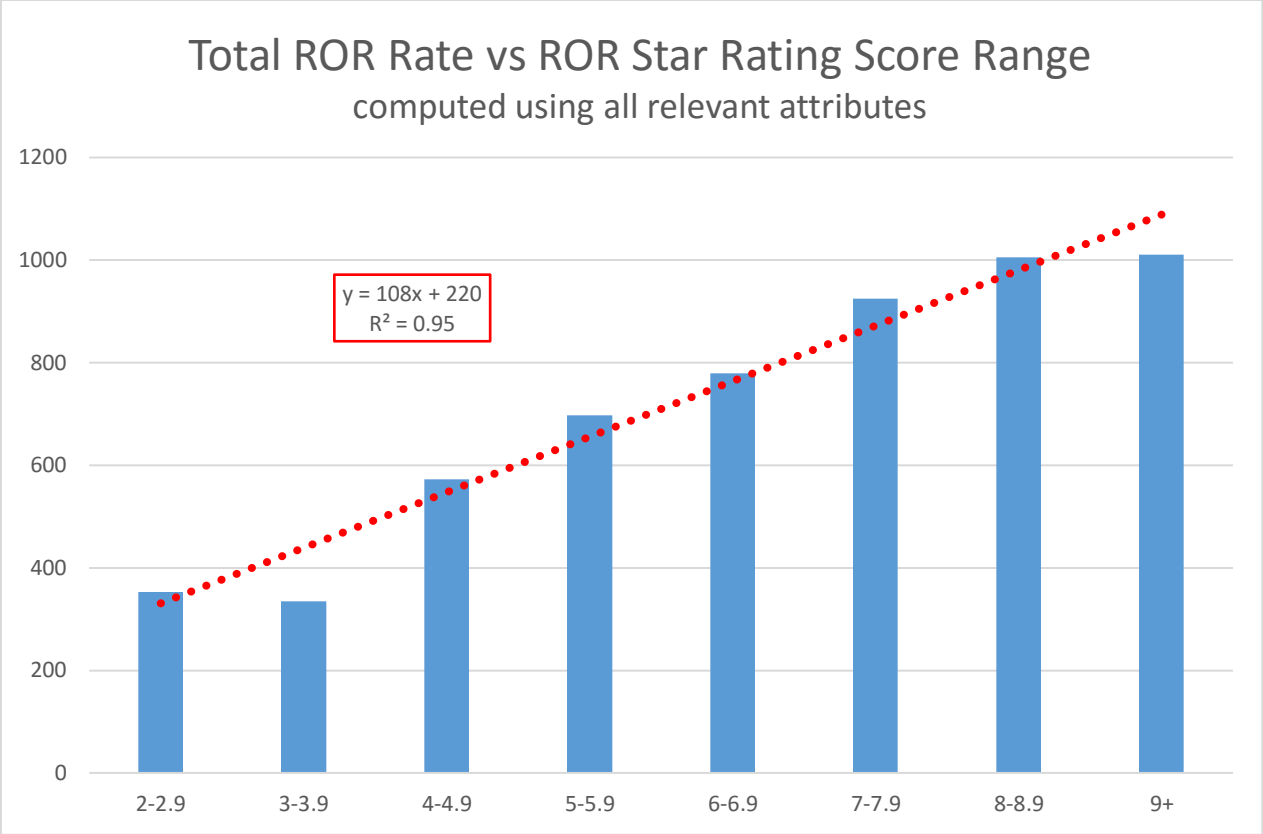


Figure 11: Total Crash Rate vs. Star Rating Score Range — all relevant attributes

Figures 12 and 13 show similar well-fitting trends between SRSs and serious injury crash rates.

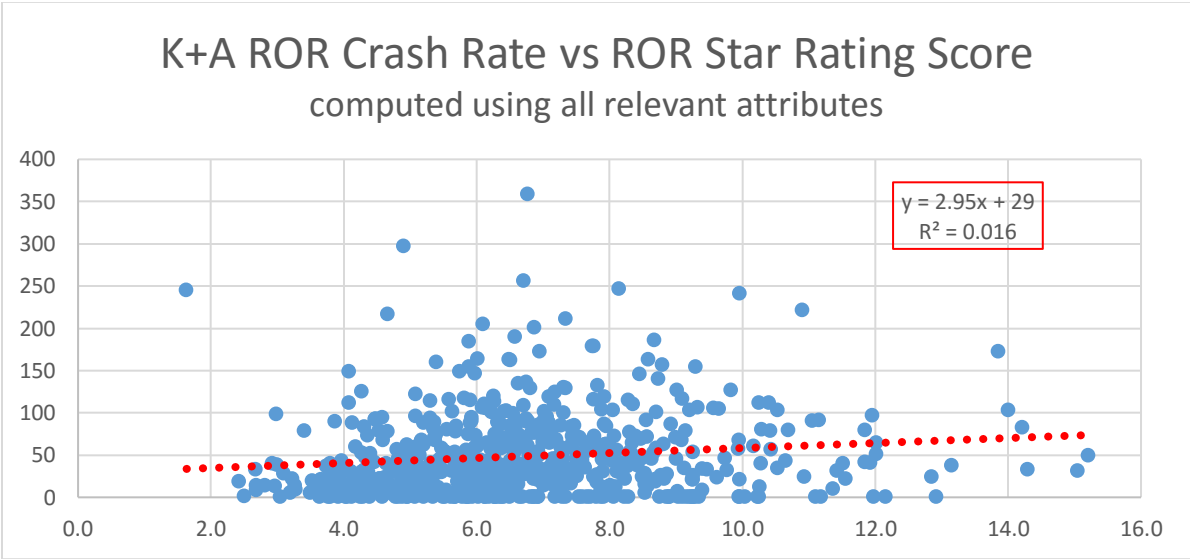


Figure 12: K+A Crash Rate vs Star Rating Score — all relevant attributes

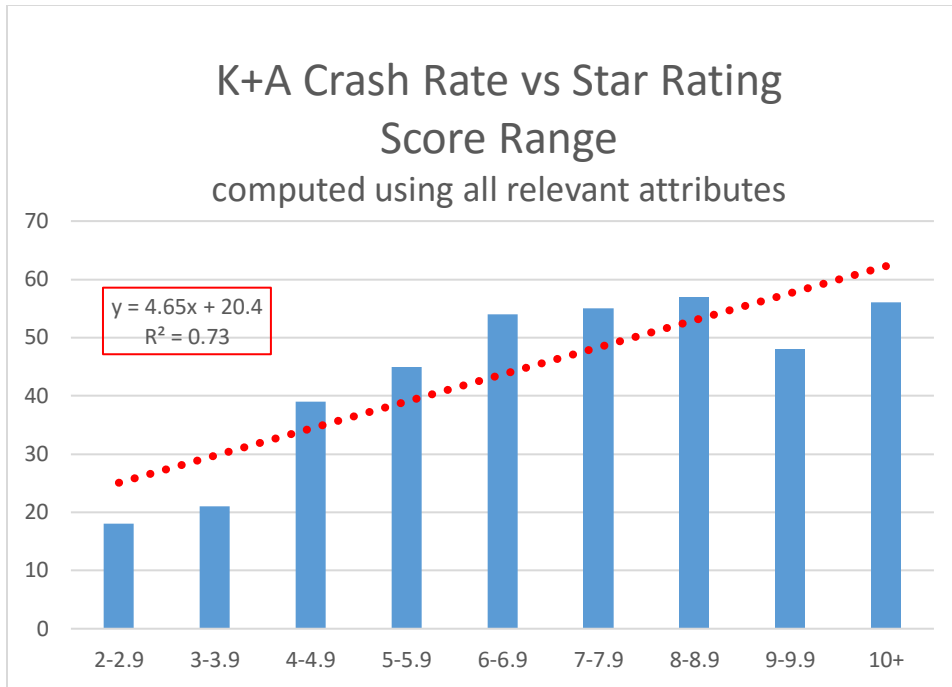


Figure 13: K+A Crash Rate vs Star Rating Score Range — all relevant attributes

Figure 14 is a map of Kentucky that plots overall star ratings (ROR and other crash types combined) for all roads analyzed as part of this project.

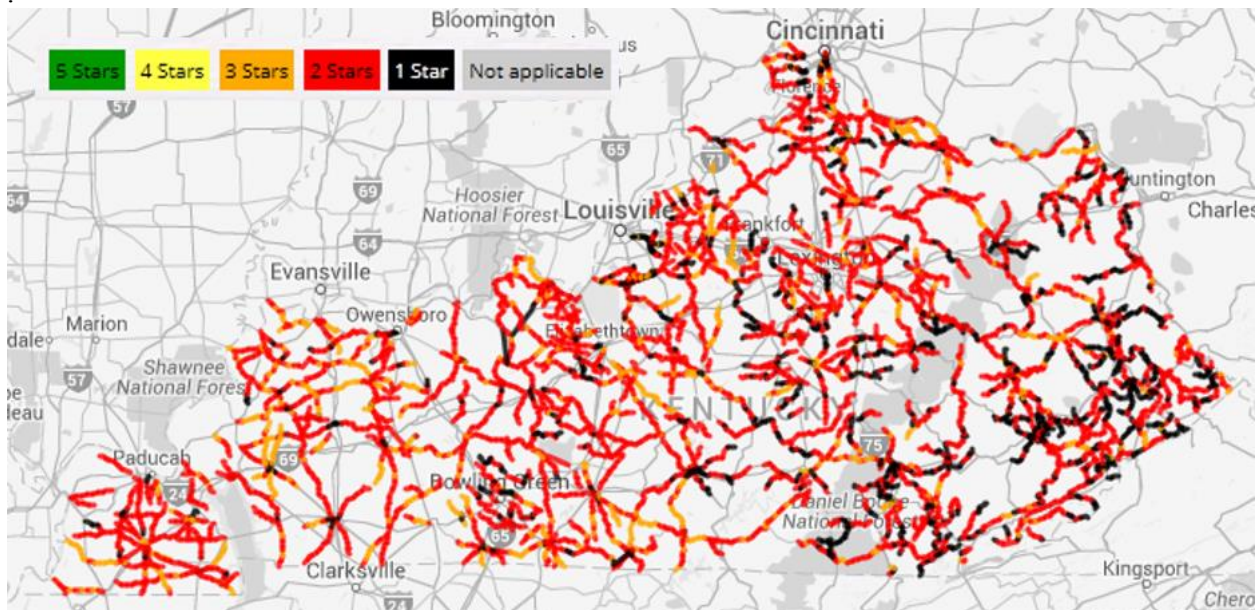


Figure 14: Star Ratings — all relevant attributes

We performed a second analysis to measure roadside severity based only on the differences in roadside attributes. For this analysis, attributes were coded and used for roadside severity and distance to objects, but all other roadway and traffic attributes were held constant at typical values. It is critical to note that as other values will affect the overall ROR SRS, the measures developed with this approach only reflect the roadside values.

There is little correlation between crash rates and *roadside element only* scores (Figures 15 to 18). In fact, the plots of crash rate vs. SRS range reveal counterintuitive relationships. However, these are not surprising because other non-roadside factors that greatly affect the likelihood (e.g., curves, delineation, rumble strips) and severity (e.g., speed) of ROR crashes were held constant for the calculations. Figure 19 shows that there is relatively little variation in star rating when only the roadside attributes vary. This demonstrates that it is only in the context of all roadway attributes that ROR safety is most sensitive to the severity of the roadside.

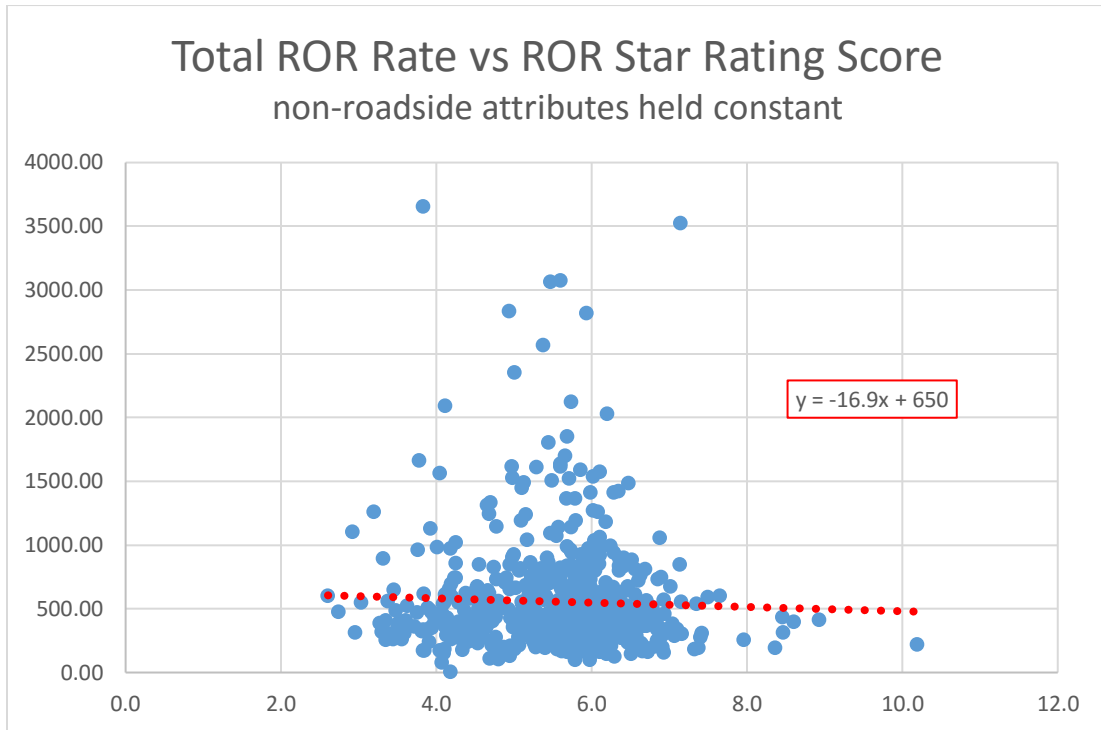


Figure 15: Total Crash Rate vs. Star Rating Score — non-roadside attributes held constant

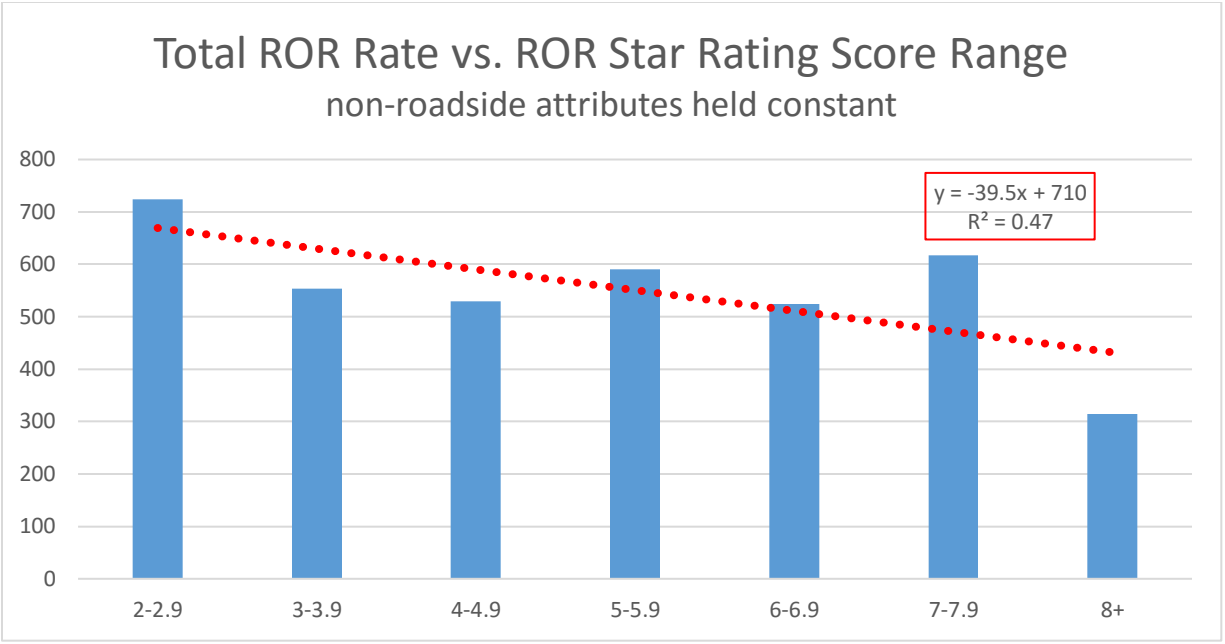


Figure 16: Total Crash Rate vs. Star Rating Score Range — non-roadside attributes held constant

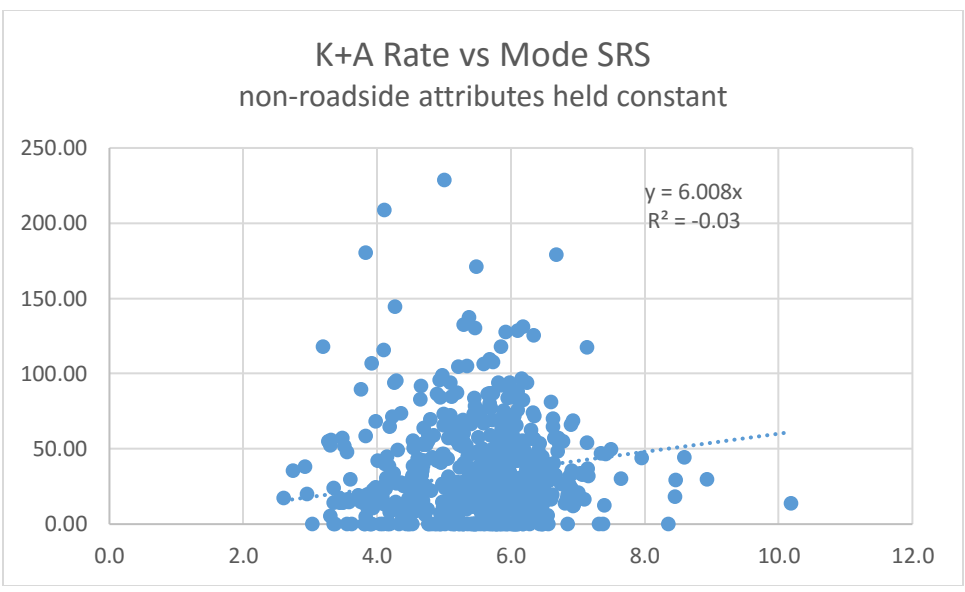


Figure 17: K+A Crash Rate vs. Star Rating Score — non-roadside attributes held constant

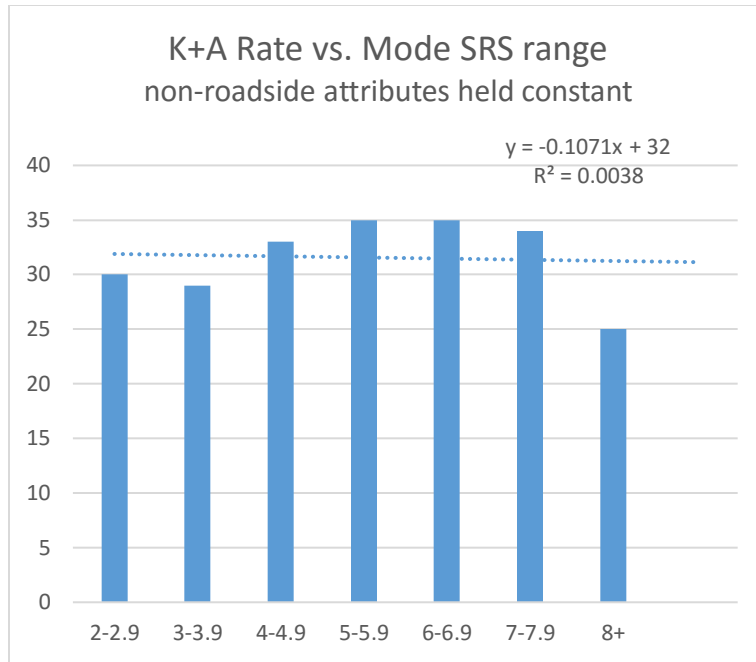


Figure 18: K+A Crash Rate vs. Star Rating Score Range — non-roadside attributes held constant



Figure 19: Star Ratings — non-roadside attributes held constant

5 Conclusions/Recommendations

Analysis indicated significant correlations between SRSs/Star Ratings and crash data, validating the use of ROR SRSs as a practical and robust quantification of roadside safety in Kentucky. As emphasized earlier, it is important to note that while roadside features (slope, distance to objects) greatly affects the roadside SRS, other factors, principally speed and curves, also significantly influence it.

Each of the computed databases (all relevant attributes and roadside only) may have their own use in transportation planning, policy, and safety applications. For example, the first computation including all relevant usRAP elements provides the best estimate of the current risk for roadside crashes, enabling the identification of locations where improvements may have the most benefits. The second database (roadside attributes only) is more useful for examining roadside severity. A third dataset which contains ratings of roadside elements could also be useful in some circumstances (e.g., for plotting the variation in roadside severity on a thematic map.) Appendix A summarizes the crash data — by route — used to validate the analysis and SRSs for all attributes as well as for roadside attributes only. A comprehensive database of data inputs and ROR SRS for each 100-meter segment (126,000 records, 123,000 of which are two-lane roads) has been provided to KYTC separately.

Appendix A: Route Summary Data and Average Star Rating Scores

| Route ID | Average ROR SRS - all relevant attributes | Average ROR SRS – roadside attributes only | Total Length (km) | Total Crashes Last 5 Years | K | A | B | C | O |
|-----------------|--|---|--------------------------|-----------------------------------|----------|----------|----------|----------|----------|
| 001-KY-0055 | 6.5 | 7.0 | 34.3 | 61 | 1 | 2 | 9 | 6 | 43 |
| 001-KY-0061 | 4.8 | 5.9 | 31.8 | 46 | 0 | 3 | 1 | 6 | 36 |
| 001-KY-0080 | 7.9 | 7.3 | 36.8 | 59 | 3 | 6 | 8 | 11 | 31 |
| 001-KY-0206 | 10.3 | 8.9 | 25.3 | 55 | 2 | 2 | 4 | 8 | 39 |
| 001-KY-2971 | 5.4 | 4.6 | 6.7 | 10 | 1 | 0 | 2 | 2 | 5 |
| 002-KY-0098 | 5.9 | 5.4 | 21.8 | 66 | 2 | 2 | 9 | 7 | 46 |
| 002-KY-0100 | 5.8 | 4.7 | 47.7 | 185 | 3 | 11 | 25 | 25 | 121 |
| 002-KY-0101 | 5.4 | 5.6 | 21.5 | 50 | 1 | 2 | 7 | 6 | 34 |
| 002-KY-0980 | 3.8 | 5.1 | 2.1 | 10 | 0 | 0 | 2 | 2 | 6 |
| 002-KY-1332 | 5.4 | 4.1 | 26 | 25 | 2 | 0 | 5 | 5 | 13 |
| 002-KY-1421 | 5.8 | 5.2 | 12.3 | 23 | 0 | 1 | 2 | 5 | 15 |
| 002-KY-1578 | 4.1 | 3.3 | 7.2 | 12 | 1 | 1 | 2 | 1 | 7 |
| 002-KY-2160 | 5.2 | 3.9 | 15.3 | 41 | 0 | 0 | 10 | 5 | 26 |
| 002-KY-3499 | 6.5 | 5.4 | 5.5 | 23 | 1 | 0 | 1 | 1 | 20 |
| 003-KY-0044 | 5.1 | 4.4 | 22.4 | 35 | 0 | 2 | 2 | 6 | 25 |
| 003-KY-0053 | 9.2 | 5.3 | 13.8 | 16 | 0 | 0 | 3 | 5 | 8 |
| 003-KY-0151 | 3.9 | 4.8 | 7.4 | 26 | 0 | 1 | 4 | 3 | 18 |
| 003-KY-0512 | 9.0 | 5.2 | 14.6 | 24 | 0 | 0 | 3 | 5 | 16 |
| 004-KY-0121 | 6.1 | 6.1 | 14 | 12 | 0 | 0 | 2 | 2 | 8 |
| 004-KY-0286 | 6.4 | 6.5 | 23.1 | 50 | 2 | 1 | 8 | 10 | 29 |
| 005-KY-0063 | 7.6 | 6.5 | 23.5 | 110 | 5 | 0 | 7 | 17 | 81 |
| 005-KY-0087 | 5.7 | 4.8 | 19.8 | 16 | 0 | 1 | 2 | 3 | 10 |
| 005-KY-0090 | 3.0 | 3.5 | 35.4 | 169 | 9 | 7 | 18 | 40 | 95 |
| 005-KY-0249 | 5.0 | 5.0 | 26.2 | 64 | 2 | 0 | 8 | 19 | 35 |
| 005-KY-0740 | 6.4 | 5.5 | 22.3 | 37 | 2 | 2 | 1 | 12 | 20 |
| 005-KY-0839 | 3.0 | 2.6 | 11 | 35 | 1 | 0 | 4 | 9 | 21 |
| 005-KY-1297 | 6.4 | 6.0 | 20.6 | 66 | 0 | 3 | 6 | 17 | 40 |
| 005-KY-2189 | 7.8 | 6.0 | 9.7 | 43 | 0 | 3 | 7 | 6 | 27 |
| 006-KY-0036 | 7.8 | 6.2 | 38.4 | 29 | 0 | 3 | 3 | 2 | 21 |
| 007-KY-0066 | 8.0 | 5.3 | 29.7 | 48 | 1 | 3 | 10 | 4 | 30 |
| 007-KY-0092 | 6.4 | 5.3 | 18 | 38 | 1 | 4 | 6 | 5 | 22 |

Appendix B: Summary of “Accident Effects of Side Slopes and other Roadside Features on Two-Lane Roads” (Zegeer et al., 1988)

This appendix summarizes Zegeer et al.’s (1988) seminal study on roadside severity rating. The study was conducted to develop methods for quantifying roadside hazards and factors that influence ROR crashes. The methods were also used to estimate the potential benefits of various roadside improvements. Based on a review of previous studies, Zegeer et al. concluded that:

- Fixed objects are associated with the most severe crashes.
- Of the various types of fixed objects, utility poles are the most frequently involved in roadside crashes.
- In ROR collisions with fixed objects, there is a (positive?) relationship between vehicle speed and crash severity.
- The number and placement of fixed objects influence crash frequency.
- Degree of sideslope influences roadside crash frequency.
- Previous studies attempted to develop roadside crash prediction models involving various factors and roadside objects.

Zegeer et al. concluded that there was a need for a better method to quantify roadside hazards and the predict ROR crashes based on traffic, roadside, and roadway variables. To develop the roadside crash prediction model, Zegeer et al. asked the following questions:

1. What methods or scales can be used to define and quantify roadside hazards?
2. What is the effect of various traffic, roadway, and roadside factors on ROR crashes?
3. What is the expected crash reduction that will result from improvements to the roadside?
4. What is the effect of sideslope on the rate of single-vehicle rollover crashes?
5. What types of roadside obstacles are most often struck, and what crash severities are associated with each obstacle type?

A random sample 4,951 miles of rural two-lane roadway in seven different states, and their crash data, was used to develop the hazard rating methodology. Roadways were assigned roadside hazard ratings, and the roadside recovery distances were measured using grid overlays on photos of 0.1 mile intervals of the selected roadways. Zegeer et al. developed a 7-point scale based on the input of 13 professionals reviewing hundreds of photos of roadsides to determine potential frequency, potential severity, and overall severity (combining the frequency and severity ratings.) Roadside hazards were recorded on both sides of the road for every tenth of a mile.

Other data used to develop the model included ADT, horizontal and vertical curvature, sideslope length and ratio, width of lanes and shoulders and shoulder type, number of bridges and intersecting features (intersections, driveways, train tracks, etc.), and individual obstacles within 30 feet of the road (as measured from the edge line). Statistical tests were used to determine which variables have the greatest influence on the frequency of crashes on rural two-way roadways. The predictive model included the use of these variables and the interactions between the variables.

Using roadside hazard as the roadway variable, the model equation was:

$$\frac{AO}{M/Y} = 0.0019(ADT)^{0.8824}(0.8786)^W(0.9192)^{PA}(0.9316)^{UP}(1.2365)^H(0.8822)^{TER1}(1.3221)^{TER2}$$

where $AO/(M/Y)$ = related crashes (single-vehicle, head-on, opposite direction sideswipe, and same-direction sideswipe crashes) per mile, per year

ADT = average daily traffic

W = lane width

PA = average paved shoulder width

UP = average unpaved (gravel, stabilized, earth, or grass) shoulder width

H = median roadside hazard rating

$TER1$ = 1 if flat terrain, zero otherwise

$TER2$ = 1 if mountainous terrain, zero otherwise

The R^2 value was 0.456, meaning that 45.6% of the variation in AO crashes was explained by the traffic and roadway variables included in the model. Of the 45.6%, the following list summarizes each variable's relative contribution:

$ADT = 70.2\%$

$W = 8.6\%$

$PA = 1.7\%$

$UP = 10.5\%$

$H = 7.2\%$

$TER = 1.8\%$

A similar model was developed using average roadside recovery distance ($RECC$) in place of roadside hazard rating:

$$\frac{AO}{M/Y} = 0.0076(ADT)^{0.8545}(0.8867)^W(0.8927)^{PA}(0.9098)^{UP}(0.9715)^{RECC}(0.8182)^{TER1}(1.2770)^{TER2}$$

where $RECC$ = average roadside recovery distance as measured from the outside edge of the shoulder

This R^2 value was 0.461. Of that value, the following list summarizes each variable's relative contribution:

$ADT = 69.4\%$

$W = 8.5\%$

$PA = 1.7\%$

$UP = 10.4\%$

$RECC = 7.5\%$

$TER = 2.5\%$

The paper found that crash reduction can be predicted by a reduction in roadside hazard rating. Table 2 shows this relationship. Larger reductions in roadside hazard rating correlate with more significant declines in related crashes.

Table 2. Crash reduction related to roadside hazard rating

| Reduction in roadside hazard rating (number of levels) | Reduction in related crashes (%) |
|--|----------------------------------|
| 1 | 19 |
| 2 | 34 |
| 3 | 47 |
| 4 | 52 |
| 5 | 65 |

Table 3 shows another relationship that is likely to affect crash rate. As the amount of roadside recovery distance increases, a marked reduction in related crashes is apparent.

Table 3. Crash reduction related to increased roadside recovery distance

| Amount of increased roadside recovery distance (feet) | Reduction in related crashes (%) |
|---|----------------------------------|
| 1 | 19 |
| 2 | 34 |
| 3 | 47 |
| 4 | 52 |
| 5 | 65 |

Single-vehicle crash rates were studied to understand how various combinations of lane width, shoulder width, and average roadside recovery distance influence them. Table 4 summarizes the relationship between these variables and number of crashes.

Table 4. Mean adjusted single-vehicle crashes per 100 MVM for lane width, shoulder width, and average roadside recovery distance using rural sections

| Lane width (ft) | Shoulder width (ft) | Average roadside recovery distance (ft) | | |
|-----------------|---------------------|---|------------|-----------|
| | | 0-8 | 9-16 | 17-30 |
| 8-10 | 0-3 | 203 | 183 | 87 |
| | 4-5 | 140 | 119 | 70 |
| | 6-13 | 144 | 85 | 43 |
| 11-14 | 0-3 | 146 | 133 | 58 |
| | 4-5 | 122 | 77 | 46 |
| | 6-13 | 96 | 74 | 45 |

Another model was developed to discern the effect of sideslopes on single-vehicle and rollover crashes. Almost 600 rural highway sections were measured for sideslope angles. Log-linear regression models were fitted to two dependent variables: rollover crash rate and single-vehicle crash rate (including fixed object, rollover, and other ROR crashes). Sideslopes were classified in one of six sideslope categories, which included 2:1 or steeper, 3:1, 4:1, 5:1, 6:1, 7:1 and flatter. Log-linear models were developed, initially using sideslope as an independent variable. Other relevant variables were included in later iterations. In each model, sideslope was found to have a statistically significant effect. Segments with steeper sideslopes have higher rates of single-vehicle crashes than segments with flatter sideslopes. The following equation captures the relationship between crash rate and sideslope:

$$AS = 793.58(1.91)^{SS} (0.845)^W (0.974)^{RECC} (0.99994)^{ADT} (0.908)^{SW}$$

$$R^2 = 0.18$$

where AS = the rate of single-vehicle crashes (in crashes/ 100 MVM)
 SS = median (50th percentile) sideslope measure, where $SS = 1$ if sideslope is 3:1 or steeper, or zero otherwise
 ADT = average daily traffic (50 to 10,000)
 W = lane width in feet (8 to 13)
 SW = total shoulder width (paved plus unpaved) in feet (0 to 12)
 $RECC$ = median (50th percentile) roadside recovery distance from the outside edge of the shoulder to the nearest roadside obstacle or hazard (0 to 30 feet)

Each variable significantly affected single-vehicle crash rates. Steep slopes (3:1 or higher) were associated with a 19% higher rate of single-vehicle crashes than a flatter slope. The model was further refined to include more sideslope categories, when relevant:

$$AS = 731.16(0.839)^W(0.99995)^{ADT}(0.975)^{RECC}(0.909)^{SW}(1.373)^{SS1}(1.349)^{SS2}(1.238)^{SS3}(1.164)^{SS4}(1.091)^{SS5}$$

where $SS1 = 1$ if sideslope = 2:1 or steeper, or zero otherwise
 $SS2 = 1$ if sideslope = 3:1, or zero otherwise
 $SS3 = 1$ if sideslope = 4:1, or zero otherwise
 $SS4 = 1$ if sideslope = 5:1, or zero otherwise
 $SS5 = 1$ if sideslope = 6:1, or zero otherwise

The completed model indicated that single-vehicle crash rates decrease steadily as the sideslope flattens. The only outstanding anomaly in the trend was the small difference between 2:1 and 3:1, indicating that this change would not significantly reduce single-vehicle crashes. Table 5 summarizes this information:

Table 5. Summary of Expected Percent Reduction in Single-Vehicle Crashes Due to Sideslope Flattening

| Sideslope ratio in before condition | Sideslope ratio in after condition | | | | |
|-------------------------------------|------------------------------------|-----------|-----------|-----------|----------------|
| | 3:1 | 4:1 | 5:1 | 6:1 | 7:1 or flatter |
| 2:1 | 2 | 10 | 15 | 21 | 27 |
| 3:1 | 0 | 8 | 14 | 19 | 26 |
| 4:1 | - | 0 | 6 | 12 | 19 |
| 5:1 | - | - | 0 | 6 | 14 |
| 6:1 | - | - | - | 0 | 8 |

Lastly, Zegeer et al. analyzed the available crash data to detect relationships between roadside objects and historical crash rates. Table 6 outlines their findings. It shows various roadside objects compared to traffic density and the number of crashes for each category.

Table 6. Fixed-object crashes by ADT group and type of obstacle struck on urban and rural highways

| ADT Group | Number of crashes (percent of crashes by ADT class) | | | | | | | |
|-----------|---|----------------|----------------|----------------|----------------|----------------|------------------|--------------------|
| | Trees | Signs | Utility Poles | Mail Boxes | Bridge Ends | Guard Rail | Other Obstacles | Total FO Accs. |
| 50-400 | 31 (24.0) | 6 (4.7) | 2 (1.6) | 2 (1.6) | 1 (0.8) | 5 (3.9) | 82 (63.6) | 129 (100.0) |

| | | | | | | | | |
|-------------|--------------|-----------|--------------|-----------|-----------|-------------|--------------|----------------|
| 401-750 | 92 (23.7) | 20 (5.2) | 24 (6.2) | 10 (2.6) | 5 (1.3) | 20 (5.2) | 217 (55.9) | 388 (100.0) |
| 751-1,000 | 107 (22.4) | 9 (1.9) | 26 (5.4) | 6 (1.3) | 2 (0.4) | 33 (6.9) | 295 (61.7) | 478 (100.0) |
| 1,001-2,000 | 278 (15.8) | 95 (5.4) | 118 (6.7) | 46 (2.6) | 33 (1.9) | 192 (10.9) | 997 (56.7) | 1,759 (100.0) |
| 2,001-4,000 | 467 (15.8) | 200 (6.8) | 319 (10.8) | 144 (4.9) | 29 (1.0) | 319 (10.8) | 1,475 (49.9) | 2,953 (100.0) |
| 4,001-7,500 | 483 (13.8) | 235 (6.7) | 611 (17.5) | 198 (5.7) | 31 (0.9) | 323 (9.3) | 1,609 (46.1) | 3,490 (100.0) |
| >7,500 | 275 (10.9) | 198 (7.9) | 556 (22.1) | 145 (5.8) | 31 (1.2) | 239 (9.5) | 1,070 (42.6) | 2,514 (100.0) |
| Total | 1,173 (14.8) | 763 (6.5) | 1,656 (14.1) | 551 (4.7) | 132 (1.1) | 1,131 (9.6) | 5,745 (49.1) | 11,711 (100.0) |

The most frequently struck objects were trees (14.8%) and utility poles (14.1%). In the groups with ADTs of 4,000 or less, trees were the object most often struck. This may be due to trees being more common than other fixed objects along low-volume rural roads. For the ADT groupings of 4,000 and above, utility poles were the most frequently struck object. This makes sense given that utility poles are more ubiquitous in suburban and urban areas.

Preliminary data were examined at the state level. Table 7 shows the distribution of crashes in three states by crash type. This dataset was compiled before more detailed analysis of ROR fixed object crashes was conducted.

Table 7. Severity of common crashes types in several databases

| Crash Type | Crash Severity | Percent of crashes within type resulting in injury or fatality | | | | | |
|--------------------------|----------------|--|---------|------|--------|------------|---------|
| | | State | | | | | |
| | | Michigan | | Utah | | Washington | |
| ROR fixed object | Injury | 35 | (10137) | 36 | (827) | 44 | (15902) |
| | Fatal | 0.8 | (228) | 2.0 | (46) | 1.5 | (532) |
| ROR rollover | Injury | 55 | (6587) | 55 | (1076) | 56 | (6488) |
| | Fatal | 1.1 | (73) | 3.2 | (63) | 2.1 | (245) |
| Head on | Injury | 41 | (1922) | 50 | (237) | 60 | (803) |
| | Fatal | 2.7 | (127) | 11.9 | (56) | 20.4 | (272) |
| Sideswipe, opposite dir. | Injury | 21 | (27) | 30 | (162) | 41 | (1118) |
| | Fatal | 2.4 | (3) | 1.9 | (10) | 2.0 | (54) |
| Sideswipe, same dir. | Injury | 13 | (42) | 11 | (87) | 20 | (2012) |
| | Fatal | 1.6 | (5) | 0.2 | (2) | 0.2 | (20) |
| Rear End | Injury | 27 | (2228) | 33 | (2320) | 43 | (21239) |
| | Fatal | 0.3 | (27) | 0.2 | (11) | 0.2 | (96) |
| Pedestrian or bicycle | Injury | 86 | (1769) | 84 | (654) | 90 | (2007) |
| | Fatal | 7.0 | (144) | 7.8 | (61) | 9.8 | (218) |
| Angle | Injury | 46 | (3145) | 31 | (2768) | 37 | (13272) |
| | Fatal | 1.1 | (78) | 0.1 | (55) | 0.5 | (174) |

Table 8 breaks down ROR collisions with fixed objects into various categories at the state level.

Table 8. Severity of common ROR fixed-object crash types in several databases

| Crash Type | Crash Severity | Percent of crashes within type resulting in injury or fatality | | | | | |
|--------------------|----------------|--|--------|------|-------|------------|--------|
| | | State | | | | | |
| | | Michigan | | Utah | | Washington | |
| Utility/Light Pole | Injury | 45 | (3385) | 39 | (163) | 47 | (2282) |
| | Fatal | 0.8 | (58) | 1.2 | (5) | 1.6 | (75) |
| Guardrail | Injury | 35 | (1392) | 42 | (130) | 41 | (3403) |
| | Fatal | 0.7 | (28) | 4.2 | (13) | 1.7 | (144) |
| Sign | Injury | 25 | (1397) | 24 | (74) | 40 | (700) |
| | Fatal | 0.4 | (22) | 1.3 | (4) | 1.4 | (25) |
| Fence | Injury | 28 | (851) | 35 | (139) | 40 | (594) |
| | Fatal | 0.2 | (7) | 1.0 | (4) | 1.7 | (26) |
| Tree | Injury | 47 | (4419) | | | 53 | (984) |
| | Fatal | 1.8 | (171) | | | 3.4 | (64) |
| Culvert | Injury | 49 | (250) | | | 64 | (277) |
| | Fatal | 3.3 | (17) | | | 2.1 | (9) |
| Bridge Rail | Injury | 41 | (178) | | | 41 | (1060) |
| | Fatal | 0.7 | (3) | | | 1.6 | (42) |
| Bridge Column | Injury | | | | | 54 | (53) |
| | Fatal | | | | | 6.1 | (6) |
| Bridge End | Injury | | | | | 53 | (72) |
| | Fatal | | | | | 5.2 | (7) |
| Barrier Wall | Injury | | | | | 41 | (908) |
| | Fatal | | | | | 0.5 | (10) |
| Earth Embankment | Injury | | | | | 53 | (1793) |
| | Fatal | | | | | 1.6 | (55) |
| Rock | Injury | | | | | 49 | (891) |
| | Fatal | | | | | 1.1 | (21) |
| Mailbox | Injury | | | | | 40 | (132) |
| | Fatal | | | | | 0.0 | (0) |
| Fire Hydrant | Injury | | | | | 30 | (44) |
| | Fatal | | | | | 0.7 | (1) |

This study found that fixed object crashes are both more frequent and more severe than other types of crashes. Zegeer et al. developed a model to predict crash frequency and severity based on various factors. Their effort was moderately successful. However, this study was constrained by the small number of roadway/roadside variables analyzed and modeled. In addition, some of the variable categorization was very subjective. The method used to assign ratings scores was somewhat problematic also: roadsides with extreme ratings are easy to identify and quantify, but those in the middle of the spectrum pose greater challenges, and thus introduces greater subjectivity. Zegeer et al. did not elaborate on the potential interactions among variables — it was discussed briefly, but there are likely many more relationships among variables that indirectly influence on roadside accident frequency and severity.

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