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Demonstration and Implementation Recommendations to Integrate the United States Road Assessment Program into Existing Kansas Highway Safety Programs

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Vehicle crashes on rural roadways in Kansas continue to be a serious safety concern. Many state agencies are utilizing systemic safety tools to identify, prioritize, and implement countermeasures based on numerous data sources. The United States Road Assessment Program (usRAP) is one such systemic tool which relies on determining areas of risk along a roadway without the need of localized crash data, which can sometimes be hard to obtain depending on the roadway. Three rural two-lane corridors were selected, including a US highway, Kansas highway, and a rural secondary road. Data collection for the usRAP software included manual speed data collection, system-wide centerline miles and crashes, crash costs, countermeasure costs, and manual roadway coding data every 100 m. The usRAP software evaluated each corridor and developed a star rating for each 100-m segment indicating areas of potential risk to vehicles, motorcycles, pedestrians, and bicyclists. Safer Roads Investment Plans were developed for each corridor based on the coded information. These plans included recommended countermeasures which mainly targeted run-off-road crashes, such as removing fixed objects in the clear zone, enhancing horizontal curves through delineation, and side slope improvements. Additionally, a benefit-cost ratio was provided for each countermeasure and also a program benefit-cost ratio. Output from usRAP for the rural secondary corridor was compared to a road safety audit (RSA) which was recently completed and the results were similar for issues that could be identified from the roadway point of view.

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Abstract

Vehicle crashes on rural roadways in Kansas continue to be a serious safety concern. Many state agencies are utilizing systemic safety tools to identify, prioritize, and implement countermeasures based on numerous data sources. The United States Road Assessment Program (usRAP) is one such systemic tool which relies on determining areas of risk along a roadway without the need of localized crash data, which can sometimes be hard to obtain depending on the roadway. Three rural two-lane corridors were selected, including a US highway, Kansas highway, and a rural secondary road. Data collection for the usRAP software included manual speed data collection, system-wide centerline miles and crashes, crash costs, countermeasure costs, and manual roadway coding data every 100 m. The usRAP software evaluated each corridor and developed a star rating for each 100-m segment indicating areas of potential risk to vehicles, motorcycles, pedestrians, and bicyclists. Safer Roads Investment Plans were developed for each corridor based on the coded information. These plans included recommended countermeasures which mainly targeted run-off-road crashes, such as removing fixed objects in the clear zone, enhancing horizontal curves through delineation, and side slope improvements. Additionally, a benefit-cost ratio was provided for each countermeasure and also a program benefit-cost ratio. Output from usRAP for the rural secondary corridor was compared to a road safety audit (RSA) which was recently completed and the results were similar for issues that could be identified from the roadway point of view.

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The authors wish to thank the Kansas Department of Transportation for sponsoring this research and finding new and innovative ways to reduce fatal and serious injury crashes on rural roads. Representatives of the research team wish to thank KDOT personnel Tod Salfrank (project monitor) and technical advisory committee members Steven Buckley and Ron Seitz. The authors also wish to thank Doug Harwood and Ingrid Potts from MRIGlobal for training the research team on how to use usRAP and providing quality check and quality assurance for this project.

Table of Contents

List of Tables

List of Figures

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Chapter 1: Introduction

Vehicle crash prevention on rural roads and highways in the United States is a topic of serious concern for state transportation agencies, counties, and local jurisdictions. The National Highway Traffic Safety Administration (NHTSA) reported that, in 2012, approximately 19 percent of the United States population lived in rural areas, but rural crash fatalities accounted for approximately 54 percent of all traffic fatalities. Rural fatal crashes decreased annually from 24,957 to 18,170 (2003 to 2012); this decrease is still greater than the decrease in urban fatal crashes during the same time period, which fell from 17,783 to 15,296. The NHTSA also stated that approximately 31 percent of rural fatal crashes had a most harmful event of excessive speed, 54 percent occurred at night, and 31 percent involved a driver who had a blood alcohol content (BAC) of 0.08 or higher (NHTSA, 2014).

The *2013 Kansas Traffic Accident Facts Book* reported that approximately 5,525 crashes, or 36.4 percent of all crashes in 2013, occurred on rural roads, accounting for 231 fatal crashes (70.6 percent of all fatal crashes) compared to 96 fatal crashes on urban roads. Figure 1.1 shows the number of fatal crashes in Kansas on rural and urban roads since 2005 (KDOT, 2013).

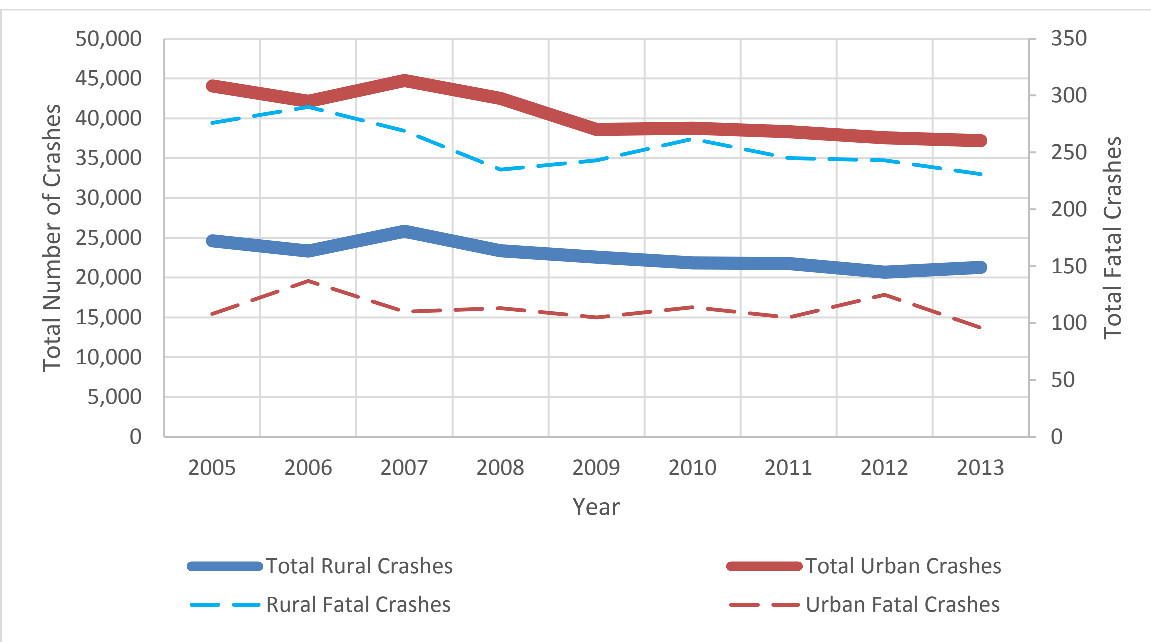


Figure 1.1: Total Number of Rural, Urban, and Fatal Crashes in Kansas

As shown in Figure 1.1, the overall numbers of crashes and fatal crashes in Kansas have been following national fatal and serious injury crash trends. However, the number of fatal rural crashes is higher than the number of fatal urban crashes, although the total number of urban crashes is higher than the total number of rural crashes. Kansas has implemented many safety programs to prevent crashes, including a primary seat belt law, a graduated licensing system, updating the Kansas Strategic Highway Safety Plan (SHSP) and developing regional safety coalitions, implementing FHWA Every Day Counts (EDC) programs, identifying and improving High Risk Rural Roads (HRRR), and financially investing in applied research for traffic safety.

The Kansas state highway primary system and paved secondary system are comprised of a significant amount of rural centerline road miles, which are typically two-lane roads with posted speed limits of 55 mph. These roads are often the principal routes for residents of rural Kansas to travel from their homes to larger communities. Unlike interstate highways, state highways, and arterial roads in urban areas, rural roadways accommodate minimal traffic but demonstrate a high prevalence of crashes. However, because of sometimes remote locations of many rural roadways, crashes often require increased time for emergency medical services (EMS) to reach and then transport patients to a local or regional hospital. Therefore, identification of dangerous rural roadway locations, investment prioritization for safety improvements, and implementation of roadway safety measures before vehicle crashes occur are critical steps for increasing rural roadway safety.

Traditional methods to identify safety improvement locations on rural roads have included hot spot or mass-action area determination through extensive crash analyses and countermeasure implementation. However, because many rural roadways experience low traffic volumes, hot spot identification can be difficult with minimal crashes and volumes, which may not identify areas of risk to the driver. A systemic approach to rural roadway safety utilizes roadway and intersection characteristics data to identify locations with potential for future crashes. Based on a risk assessment of a rural roadway network, design engineers and county engineers can identify locations, compare locations to historical crash data, and then conduct an engineering study to justify safety improvements.

1.1 Research Objectives

The primary objective of this research project was to demonstrate the effectiveness of the United States Road Assessment Program (usRAP) as a systemic safety tool for rural highways and paved secondary roads in Kansas. The goal was to determine if usRAP and its outputs beneficially help Kansas counties identify high-risk roadway segments without using historical crash data at each corridor. Secondary objectives included determining if usRAP was a viable tool to include in state- and county-level safety planning, and also seeking feedback on the usRAP outputs by the local road engineer of the Kansas Association of Counties.

1.2 Report Organization

This report includes six chapters. Chapter 2 includes an overview of current and past systemic highway safety programs and how the use of data, including roadway features and historical crash data, has made safety decision making more targeting. Chapter 3 provides the empirical setting for the research project, including corridor features, safety concerns, and baseline data needed to code usRAP. Chapter 4 gives an overview of the coding process, including a description of the training process, coding, and examples. Chapter 5 shows the usRAP outputs, including recommended countermeasures and benefit-cost ratios. Finally, Chapter 6 provides a discussion of the results and recommendations for implementing usRAP in Kansas.

Chapter 2: Literature Review

2.1 Data Collection of Roadway Information

Advances in computer systems during the 1980s allowed the Federal Highway Administration (FHWA) to create databases of roadway information including such features as vehicle crashes and geometry. In 1987, the Highway Safety Information System (HSIS) collected crash, roadway, and traffic volume data from Illinois, Maine, Michigan, Minnesota, and Utah, states chosen based on availability, quantity, and quality of data. These data were then used by the FHWA to make policy decisions, and also by engineers researching highway safety (Tan, 2011).

Another method of data collection is the Model Minimum Inventory of Roadway Elements (MMIRE), initiated in 2003. The FHWA, the American Association of State Highway and Transportation Officials (AASHTO), and the National Cooperative Highway Research Program (NCHRP) sponsored a study to investigate how highway agencies in the Netherlands, Germany, and Australia implemented traffic safety information. The study determined how non-crash data supplemented the Model Minimum Uniform Crash Criteria (MMUCC). The study proposed use of the MMIRE in conjunction with the MMUCC. The MMIRE creates a listing of roadway inventory and traffic elements to assist safety professionals in identifying locations for safety improvements and developing knowledge about roadway elements, designs that increase or decrease crash risk, and roadway treatment effects (Tan, 2011).

2.2 Development of Roadway Safety Analysis

As roadway geometry and crash data collected by state highway agencies have become more uniform when archived in a database, various analysis tools and models have been developed to utilize the collected data to enhance highway safety. Many of these tools have become systemic because they amalgamate many sources of data to identify locations for roadway safety improvements.

2.2.1 Run-off-Road Model

Gao, Kan, Li, and Pang (2008) developed a run-off-road (ROR) prediction model using roadway geometry, traffic volume, crashes, roadside hardware, and features from 31 rural two-lane highways totaling 704 km. Road data was categorized into more than 900 sections in order to analyze the collected data. The model predicted ROR accident frequency, fatality, and injury using four statistical distributions: Poisson, negative binomial, zero-inflated Poisson, and zero-inflated negative binomial. Because ROR crashes occur infrequently, the researchers used zero-inflation distributions. They concluded that horizontal curves, vertical grade, traffic volume, and proportion of trucks were primary factors in ROR crashes. However, it was found that additional research must be conducted to improve the ROR prediction models.

2.2.2 SafetyAnalyst

Harwood, Torbic, Richard, and Meyer (2010) developed *SafetyAnalyst*, an analytical tool to assist in the decision-making process when identifying and managing site-specific, system-wide improvements. *SafetyAnalyst* provides software tools that increase highway safety management efficiency for state and local highway agencies by creating a system-wide program of improvements. *SafetyAnalyst* is comprised of the following tools: the analytical tool, the administrative tool, the data management tool, and the implemented countermeasure tool. The analytical tool consists of the following six components to form the safety management capabilities needed by users:

- The *network-screening tool* uses traffic volumes and other roadway characteristics to identify sites with higher-than-expected crash frequencies and sites with expected levels of crash frequencies in order to potentially cost-effectively improve both types of sites. This tool also identifies sites with severe crashes and high percentages of specific crash types. Although the network-screening tool focuses on identifying spot locations and short segments with potential for safety improvements, it can also identify large sections of roadway.

- The *diagnosis tool* focuses on the nature of crash patterns at specific sites to determine if crash patterns occur at higher-than-expected frequencies. The diagnosis tool includes a basic collision diagramming tool that can interface with commercially available diagramming software in order to generate collision diagrams for particular sites, identify crash patterns at those sites, and determine if those patterns are higher than acceptable.
- The *countermeasure selection tool* assists in selecting appropriate countermeasures at specific sites based on site type, crash patterns, and safety concerns identified by the diagnosis tool. The user can then select a single countermeasure, multiple countermeasures, or combinations of countermeasures based on identified safety concerns. The user can also select two or more alternative countermeasures in order to evaluate the cost effectiveness of a countermeasure using the economic appraisal tool.
- The *economic appraisal tool* analyzes economic costs of specific countermeasures or alternative countermeasures selected in the countermeasure selection tool. *SafetyAnalyst* contains default construction cost estimates for each countermeasure, but the user can modify default estimates based on local costs. The economic appraisal tool can perform three types of appraisals: cost effectiveness (countermeasure cost per crash reduced), benefit-cost ratio (ratio of monetary benefits to countermeasure costs), and net present value (excess of monetary benefits over countermeasure costs). Effectiveness and benefits are estimated from observed, expected, and predicted crash frequency and crash modification factors for specific countermeasures.
- The *priority-ranking tool* ranks sites and proposed improvement projects based on estimates from the economic appraisal tool. Benefits and costs are compared across sites, and the *SafetyAnalyst* ranks projects based on cost effectiveness, benefit-cost ratio, or net present value. In addition, the priority ranking tool can configure an optimal set of projects to maximize safety benefits.

- The *countermeasure evaluation tool* allows *SafetyAnalyst* users to conduct before-and-after comparisons of implemented safety improvements. Evaluations are performed using the Empirical Bayes approach, which accounts for changes in safety that may be due to changes in other variables. The countermeasure evaluation tool can also evaluate shifts in proportions of crash types.

The administrative tool allows *SafetyAnalyst* to be set up on a highway agency's computer network. The administrative tool also manages access and use of the *SafetyAnalyst* software. The data management tool allows highway agencies to create a database to store information on roadway segments, and the implemented countermeasure tool provides a database with which the highway agency can document the date and location, and report physical improvements.

SafetyAnalyst closely refers to the Highway Safety Manual (HSM) and the FHWA's Interactive Highway Safety Design Model (IHSDM). All three tools extensively use safety performance functions (SPFs) and accident modification factors (AMFs) to predict crash frequency and severity (Harwood et al., 2010). *SafetyAnalyst* was created to improve effectiveness in decision-making and to strengthen support for the decisions made. Long-term viability of *SafetyAnalyst* is determined by continuous software enhancement to meet users' evolving needs (Harwood et al., 2010).

2.2.3 FHWA GIS and HSIS

In 1999, the FHWA integrated geographical information system (GIS) capabilities with the HSIS to create a crash analysis tool. The information merged traditional GIS features to allowed spatially located crash locations/information using the following crash analysis tools:

- *Spot/intersection analysis* evaluates crashes at user-designated spots or intersections within a certain search radius and produces a report that lists the number of crashes at a location.

- *Strip analysis* evaluates crashes along a segment of roadway specified by the user. Strip analysis produces a report similar to the spot/intersection analysis report.
- *Cluster analysis* evaluates crashes near a certain roadway feature, such as a bridge abutment, within a user-defined radius. The program only identifies areas in which the number of crashes meets a user-defined minimum threshold.
- *Slide-scale analysis* evaluates roadways similarly to strip analysis except slide-scale analysis segments are not fixed. For example, if the user-defined segment is 1.00 km and the increment length is 0.25 km, the program first analyzes the segment from 0.00 km to 1.00 km and then moves the increment length to analyze the segment from 0.25 km to 1.25 km.
- *Corridor analysis* evaluates high crash locations (hot spots or mass-action areas) along a specified corridor that may contain multiple routes that would not typically be easily linked by other analysis methods. In addition to producing a report similar to the other analysis programs, corridor analysis also generates a map that identifies roadways including crash locations (FHWA, 1999).

2.2.4 United States Road Assessment Program (usRAP)

The usRAP is a program for the United States that is based on the European Road Assessment Program (EuroRAP) and the International Road Assessment Program (iRAP). EuroRAP began in 1999, and the usRAP adaptation was created in 2004 and has been successfully tested and used in Florida, Michigan, Illinois, Iowa, Kentucky, New Jersey, New Mexico, Utah, and Washington (usRAP, 2016). When analyzing roadways, very specific information on roadway viewable physical characteristics (e.g., pavement, clear zone, and vertical and horizontal alignment) is coded into a preprocessor to prepare the information for the usRAP software. After the information is uploaded into the usRAP software, a star rating map and a safer roads investment plan are created. The star rating map is a visual representation of safety risks along the roadway, and the safer roads investment plan contains a table that suggests countermeasures, countermeasure locations, and benefits and costs associated with the countermeasures.

2.2.5 Road Safety Audit

A roadway can also be analyzed using a road safety audit (RSA), which is a formal safety evaluation of an existing road or intersection conducted by an independent team of highway engineers and traffic safety experts. An RSA typically requires five steps:

1. Identify a project to be audited.
2. Select an RSA team of adequately qualified individuals.
3. Review project information.
4. Perform field observations.
5. Conduct analysis and prepare a report.

Project parameters that must be defined before conducting an RSA include schedule for completion, team requirements, or audit tasks. In addition, the RSA team must remain independent and not directed by the project owner.

The project owner selects the RSA team, and an ideal RSA team should consist of a road safety specialist, a traffic operations engineer, a road design engineer, a local contact person, and additional experts depending on the size or complexity of the project. A road safety specialist should have expertise in road safety, including key factors that can lead to crashes. A traffic operations engineer should know the principles of traffic flow, causes of congestion, and other factors that could impact the traveling public, as well as knowledge about sign placement and pavement markings. A road design engineer should be experienced in roadway design and be familiar with federal, state, and local standards in road design. Police officers are ideal choices for the local contact person because they are familiar with the area under review and may have additional information (e.g., unreported crashes, number of citations, etc.) that can be useful to safety designs. Other specialists can be chosen depending on the area in question (i.e., specialists in maintenance, first responders, etc.).

Once an RSA team is compiled, a formal meeting is conducted to set the context of the audit and review the project information. Before the meeting, the owner of the project must provide all relevant information to the team, mainly historical crashes. At the end of the meeting, all parties should have a clear understanding of each person's role and responsibility in the RSA team.

In order to complete the RSA, the RSA team must conduct a field investigation. Two approaches are typical for the field review. The first approach requires each RSA team member to independently review the road and then review each identified issue. The second approach requires the RSA team to visit the site as a group and note each issue (or safety concern) the team encounters. During the field investigation, photographs and/or video should be taken of each problem diagnosed or areas in need of further investigation. For an objective evaluation, every possible movement should be considered and a nighttime field review should be completed to evaluate potential problem areas under dark conditions. Finally, the RSA team should review all safety issues identified during the field investigation to finalize research findings and develop possible solutions. Upon completion of the review, the audit team produces a clear and concise report stating each safety issue and a description of the problem. The report is then delivered to the project owner, who provides a written response to the findings and incorporates the findings, discussion, and recommendations where applicable (FHWA, 2006).

Chapter 3: Empirical Setting

3.1 Corridor Selection

Three study corridors in Kansas were selected for evaluation in this study. These corridors represented three types of roadways commonly found in Kansas: a US highway, a Kansas highway, and a rural secondary road. All three roadways were two-lane undivided and were considered rural outside of incorporated areas. The research team selected two of the corridors from driving experience and visual investigation of the roadway; crash data were not used to identify the highest-risk roads for evaluation in this project. Prior to data collection, the research team drove each corridor in both directions and used a GoPro video camera to create a video log and note potential safety issues, providing a resource for future coding discussions.

The first corridor was US-40 from Topeka, KS, to Lawrence, KS, a two-lane undivided highway that serves as a commuter corridor for drivers between the two cities (Figure 3.1). The corridor length was 19 miles and had a posted speed limit of 60 mph.

Figure 3.1: US-40 Northbound from Lawrence, KS, to Topeka, KS

The second study corridor was K-5 between Kansas City, KS, and Lansing, KS. This corridor was also a two-lane undivided paved highway with a posted speed limit of 55 mph (Figure 3.2). K-5 was unique because the corridor had many horizontal and vertical curves that incorporated numerous blind spots and visual traps (a minor road on the tangent extended). The corridor is a well-known weekend route for motorcyclists and high-performance car enthusiasts from the Kansas City metropolitan area. Many signs and pavement marking upgrades were installed in 2011 as safety improvements.

Figure 3.2: K-5 Northbound from Kansas City, KS, to Lansing, KS

The third corridor was RS 20 and RS 25, a two-lane, undivided, rural paved secondary roadway with a posted speed limit of 55 mph (Figure 3.3). RS 20 intersects RS 25 at a horizontal curve at which point drivers in the westbound direction face a visual trap where they primarily see a tangent roadway and not the curve transition. KDOT recommended this corridor for usRAP demonstration because an RSA was recently completed on the corridor and KDOT wanted to compare the results and recommendations between the RSA and usRAP.

Figure 3.3: RS 20 Westbound from Lancaster, KS

3.2 usRAP Calibration Data

Calibration of usRAP software was required before coding each corridor described in the previous section. The calibration process requires corridor operational data (annual average daily traffic [AADT] and speed), system-wide centerline mileage for each type of roadway, system-wide crash data, 5 years of crash costs, and current estimated countermeasure costs for Kansas.

3.2.1 AADT and Speed

Annual average daily traffic (AADT) was determined for each roadway using KDOT traffic count maps. The District One traffic count map, which included all three study corridors, was published in March 2015. AADTs were determined for each study corridor as shown in Table 3.1.

Table 3.1: Study Corridors' AADT

Corridor	AADT (vehicles)
US-40	5,000
K-5	2,500
RS 20	750
RS 25	850

Source: KDOT (n.d.)

A speed study was also conducted at each corridor site in both directions of travel. The research team conducted the speed study on-site with a Doppler radar gun. Thirty vehicle speeds were captured in each direction, and the data were combined, resulting in 60 observations of trucks, cars, and motorcycles at each corridor. The research team parked a university vehicle perpendicular to the roadway at approximately the halfway point of each corridor. The parked vehicle was positioned to avoid obstructions in order to capture passing speeds and to be inconspicuous so passing drivers would not suspect unusual activity and consequently adjust their speed. The parked vehicle was located on a straight level tangent section so vehicle speeds would not be affected by horizontal or vertical curves. Table 3.2 summarizes the speed study.

Table 3.2: Summary of Corridor Speed Studies

Corridor	Posted Speed Limit	Average Speed	85th Percentile Speed	Minimum Speed	Maximum Speed
US-40	60 mph	61 mph	64 mph	52 mph	72 mph
K-5	55 mph	51 mph	57 mph	38 mph	65 mph
RS 20 and 25	55 mph	57 mph	61 mph	50 mph	65 mph

As shown in Table 3.2, 85th percentile speeds were higher than posted speed limits as expected; however, average speeds were slightly above and below posted speed limits. The research team concluded that drivers on K-5 are aware of constant changes in horizontal alignment, as reflected in the collected values.

3.2.2 System-Wide Centerline Miles

The research team worked with KDOT to extract the number of centerline miles for each study corridor, revealing that Kansas contains a total of 4,418.9 miles of US highway centerline miles and 4,550.5 Kansas highway centerline miles. KDOT and the research team were unable to determine centerline mileage for paved rural secondary roads due to the current Kansas roadway geometric database. The usRAP default calibration parameters were used for the rural secondary roads based on other states' data evaluated using usRAP.

3.2.3 Current Kansas Crash Costs

Current and historical crash costs were compiled for this research project. At least 5 years of costs for five levels of severity are required for usRAP. At the time of this report, costs from 2014 were most recent, as shown in Table 3.3.

Table 3.3: Current and Historical Crash Costs for Kansas

Year	Crash Severity				
	Fatal Crash	Disabling Injury Crash	Minor Injury Crash	Possible Injury Crash	Property Damage Only Crash
2010	$3,853,550.00	$266,800.00	$53,400.00	$28,200.00	$3,000.00
2011	$3,916,450.00	$271,150.00	$54,250.00	$28,650.00	$3,050.00
2012	$4,031,000.00	$279,100.00	$55,850.00	$29,500.00	$3,150.00
2013	$4,095,300.00	$283,550.00	$56,750.00	$29,950.00	$3,200.00
2014	**$4,159,950.00**	**$288,000.00**	**$57,600.00**	**$30,400.00**	**$3,200.00**

According to Table 3.3, if all persons involved in a crash were unharmed (property damage only, or PDO, crash) in 2014, the cost of $3,200.00 was assigned to the crash. If one or more persons were involved in a crash with a possible injury, a minor injury, or a disabling injury, the costs of $30,400, $57,600, and $288,000, respectively, were assigned to each person in the vehicle. If a crash resulted in one or more fatalities, a value of $4,159,950 was assigned to each crash.

3.2.4 Estimated Countermeasure Costs

The usRAP program has approximately 192 possible built-in countermeasures for urban and rural environments. These countermeasures range from low-cost to high-cost, which may range from signs to large reconstruction projects, respectively. Countermeasures can be included or excluded from the analysis and recommendations depending on transportation agency goals and guidelines pertaining to certain geometric conditions (e.g., horizontal curves), a specific benefit-cost ratio, or long-range budget plan. Each countermeasure has a low, medium, and high cost that can be adjusted prior to software coding.

Of the 192 possible countermeasures, the research team selected 93 countermeasures that were applicable to Kansas and rural environments, as presented in Appendix A. Built-in costs from usRAP were determined to be relatively reflective of actual countermeasure costs in Kansas. The research team met with the KDOT Bureau of Local Projects to verify countermeasure costs and how to determine what would be considered a low price for a certain countermeasure and a high price for the same countermeasure. This was based on a number of identified KDOT projects, which included the countermeasure cost. Prices of the following countermeasures were adjusted: protected turn lane (unsignalized three-legged), protected turn lane (unsignalized four-legged), protected turn provision at existing signalized site (three-legged), protected turn provision at existing signalized site (four-legged), signalized intersections (four-legged), roundabout, signalized pedestrian crossing, street lighting (midblock), and street lighting (intersection).

All countermeasure costs provided by KDOT were considered to be medium costs as shown in Appendix A. Low and high costs for each countermeasure were determined using the percentage increase and decrease noted in the original usRAP countermeasure cost sheet. KDOT's countermeasure costs were also adjusted if the countermeasure units were not identical in unit cost or per linear mile.

3.2.5 System-Wide Crash Data

If system-wide historical crash data are available, crash summaries can be uploaded into the usRAP program to help calibrate road type analysis in a certain area. For this study, historical crash data were available for the US highway system and the Kansas highway system. Table 3.4 summarizes crashes on US highways in Kansas between 2010 and 2014 using the KABCO crash severity scale. The KABCO scale is a measure of the functional injury severity level of the victim at the crash scene.

Table 3.4: System-Wide Crashes for US Highways in Kansas (2010–2014)

Crash Type	Number of Crashes by Crash Severity Level					
	Total Crashes	Fatal (K) Crashes	Disabling (A) Injury Crashes	Minor (B) Injury Crashes	Possible (C) Injury Crashes	Property Damage (O) Crashes
Pedestrian-involved crash	27	9	8	5	5	0
Bicycle-involved crash	12	1	3	2	6	0
Motorcycle-involved crash	314	28	61	117	63	45
All other crashes	21,305	264	455	1,381	1,377	17,828

As shown in Table 3.4, the numbers of pedestrian-involved and bicycle-involved crashes were considerably lower than motorcycle-involved and all other crashes. US highways in Kansas are typically high-speed facilities that many times accommodate pedestrians and bicyclists; however, these groups are often times lower than in urban areas due to the fact that there is sometimes limited shoulder space for bicyclists and many times no sidewalk facilities as compared to an urban roadway. Table 3.5 shows a KABCO severity scale crash summary for Kansas highways.

Table 3.5: System-Wide Crashes for Kansas Highways (2010–2014)

Crash Type	Number of Crashes by Crash Severity Level					
	Total Crashes	Fatal (K) Crashes	Disabling (A) Injury Crashes	Minor (B) Injury Crashes	Possible (C) Injury Crashes	Property Damage (O) Crashes
Pedestrian-involved crash	24	3	6	8	7	0
Bicycle-involved crash	17	1	3	7	6	0
Motorcycle-involved crash	297	27	78	109	43	40
All other crashes	15,048	163	353	1,064	951	12,517

Similar to Table 3.4, results in Table 3.5 indicate fewer pedestrian-involved and bicycle-involved crashes compared to motorcycle-involved and all other crashes. This result could be attributed to the presence of low-speed and high-speed facilities on Kansas highways, consequently limiting pedestrian crossings and bicycle movement areas similarly to US highways in Kansas.

Historical crash data could not be extracted for the entire rural secondary roadway system because these two roads are on the paved rural secondary system and KDOT has limited crash data outside of incorporated areas. In addition, only limited information was available on roadway geometrics. Therefore, for this study, default calibration parameters were used based on AADT, roadway type, and posted speed limit. The research team, along with MRIGlobal, determined that parameters used in the usRAP software reflected the current corridor being coded.

3.2.6 Corridor Crash Summary

Five years of crash data for US highways, Kansas highways, and rural secondary roads were extracted from the KDOT crash database for exploratory analysis of common vehicle crashes in each corridor. Although the usRAP program does not require historical crash data for corridors under investigation, usRAP results are often compared to corridor historical crash data in order to find common trends and determine if the recommended countermeasure or series of countermeasures are appropriate to the identified location so an engineering study is completed.

Tables 3.6, 3.7, and 3.8 summarize crash types and crash severity for each corridor in this study. The crash type classifications of pedestrian-involved, bicycle-involved, motorcycle-involved, and all other crashes (e.g., vehicle occupant) corresponded to the usRAP output data (star ratings and Safer Roads Investment Plans) to allow straightforward comparison of actual data to predicted data. Data from the years 2010 to 2014 were extracted; at the time of this study, 2015 crash data were not verified and therefore not included. Crash data from RS 20 and RS 25 were manually extracted from county crash records.

Table 3.6: Historical Crash Summary for US-40 (2010–2014)

Crash Type	Number of Crashes by Crash Severity Level					
	Total Crashes	Fatal (K) Crashes	Disabling (A) Injury Crashes	Minor (B) Injury Crashes	Possible (C) Injury Crashes	Property Damage (O) Crashes
Pedestrian-involved crash	0	0	0	0	0	0
Bicycle-involved crash	0	0	0	0	0	0
Motorcycle-involved crash	8	0	1	5	1	1
All other crashes	236	1	6	23	18	188

Table 3.7: Historical Crash Summary for K-5 (2010–2014)

Crash Type	Number of Crashes by Crash Severity Level					
	Total Crashes	Fatal (K) Crashes	Disabling (A) Injury Crashes	Minor (B) Injury Crashes	Possible (C) Injury Crashes	Property Damage (O) Crashes
Pedestrian-involved crash	0	0	0	0	0	0
Bicycle-involved crash	0	0	0	0	0	0
Motorcycle-involved crash	4	0	1	2	0	1
All other crashes	75	0	3	13	8	51

Table 3.8: Historical Crash Summary for RS 20 and RS 25 (2010–2014)

Crash Type	Number of Crashes by Crash Severity Level					
	Total Crashes	Fatal (K) Crashes	Disabling (A) Injury Crashes	Minor (B) Injury Crashes	Possible (C) Injury Crashes	Property Damage (O) Crashes
Pedestrian-involved crash	0	0	0	0	0	0
Bicycle-involved crash	0	0	0	0	0	0
Motorcycle-involved crash	0	0	0	0	0	0
All other crashes	35	0	1	4	1	29

As shown in Tables 3.6, 3.7, and 3.8, no pedestrian-involved or bicycle-involved crashes occurred between 2010 and 2014 on the evaluated corridors. However, motorcycle-involved crashes and all other crashes occurred on K-5 and US-40. The research team also investigated the sequence of events for all crashes shown in Tables 3.4 through 3.6 to determine the most harmful event, or the action taken by the vehicle to determine the crash severity. The purpose of these crash analyses were to determine common trends among the corridors. Analysis results are shown in Figures 3.4 through 3.6. Figure 3.4 shows results from the US-40 corridor.

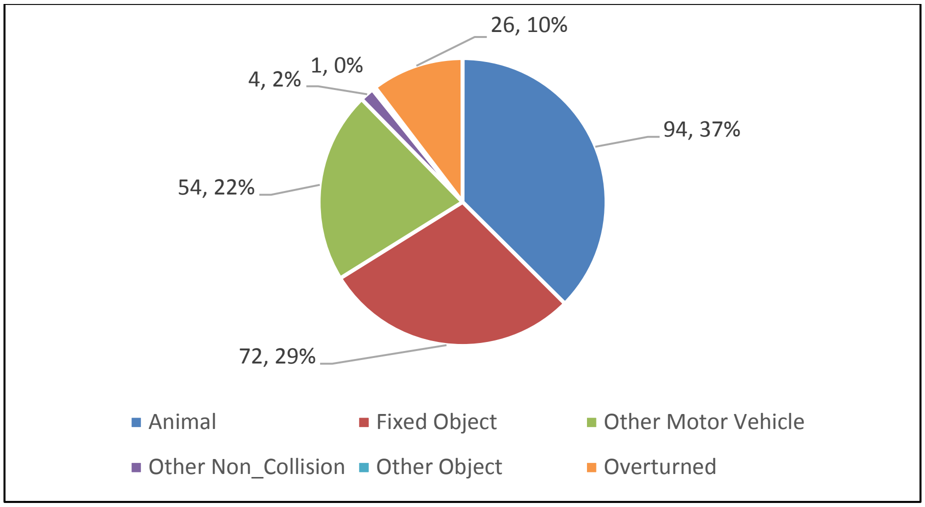


Figure 3.4: US-40 First Harmful Events, Number of Crashes, and Percentages (2010–2014)

As shown in Figure 3.4, 37 percent of all crashes involved an animal and 29 percent of all crashes involved a vehicle departing the roadway and hitting a fixed object. The third highest crash type percentage, 22 percent, involved another vehicle. Figure 3.5 shows the number of crashes, percentages, and most harmful events for the K-5 corridor.

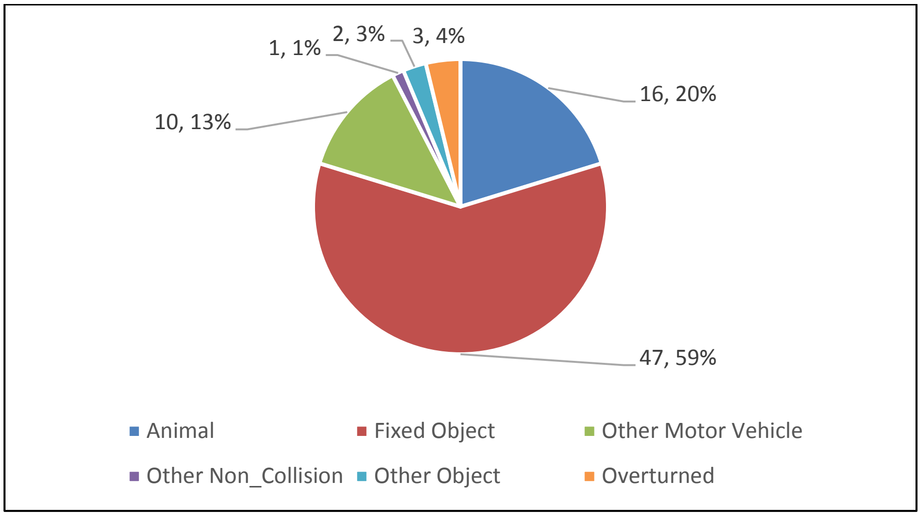


Figure 3.5: K-5 First Harmful Events, Number of Crashes, and Percentages (2010–2014)

As shown in Figure 3.5, over 50 percent of the crashes on K-5 involved the vehicle hitting a fixed object. Similar to US-40 as shown in Figure 3.4, 20 percent of crashes involved an animal and the third highest crash type involved another vehicle. Figure 3.6 shows the number of crashes, percentages, and most harmful events for RS 20 and RS 25.

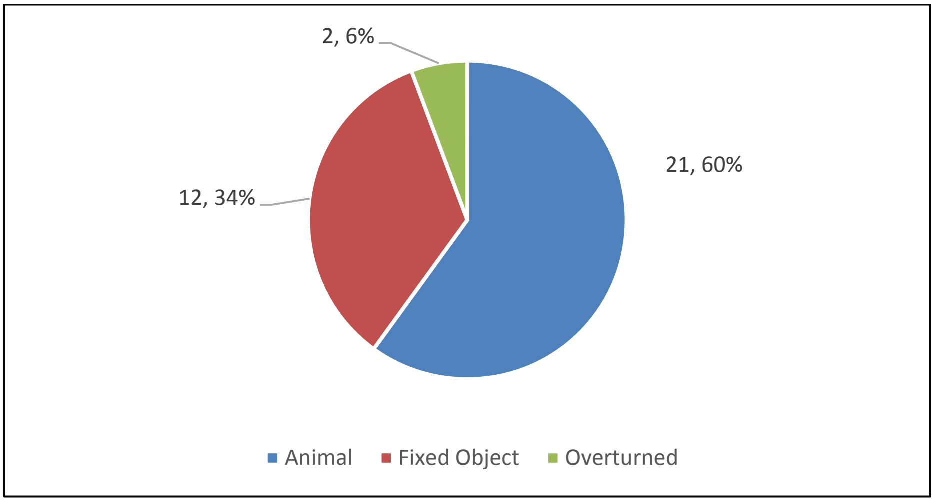


Figure 3.6: RS 20 and RS 25 First Harmful Events, Number of Crashes, and Percentages (2010–2014)

As shown in Figure 3.6, approximately 60 percent of all crashes involved a vehicle striking an animal, and over 30 percent occurred because a vehicle departed the roadway and hit a fixed object. Six percent of crashes resulted in an overturned vehicle when that vehicle departed the roadway. On a site visit to RS 20 and RS 25, the research team discovered that the bridge infrastructure improvement had failed, as shown in Figure 3.7. Although the failed wingwall of the rural bridge posed no direct threat to traffic safety being far into the clear zone, it was an indication that other aspects of the bridge may be a safety hazard, especially if the roadway gives way.


Figure 3.7: RS 25 Bridge Wingwall Failure (2015)

This is an example of a structural issue that may or may not appear in the usRAP coding process depending on the view of the coder. The view of the coder and limitations of the usRAP software will be further explained in further chapters and sections.

Chapter 4: Coding Methodology

4.1 usRAP Software

Data described in the previous section and roadway coded data were uploaded to the usRAP software, a web-based platform. This chapter describes the methodology used to code the roadway database.

4.1.1 Training Summary

Prior to coding the three Kansas corridors, the research team, including undergraduate student coders, participated in a 2-day training class administered by MRIGlobal. The MRIGlobal team, who are experts in the development, testing, and implementation of usRAP and iRAP, presented a prepared manual that explained each variable the research team was to code. The usRAP software relies on a visual inspection of the roadway and judgment by the research team and student coders so extreme cases of each coding variable were explained and examples of each variable were given to the research team by the MRIGlobal team. To be a student coder on the research project, undergraduate students had to have taken transportation classes, which covered highway design principals. Based on previous research studies involving usRAP coding, a coding time of 30 minutes per 1 mile of coding was estimated for this project.

4.1.2 Explanation of Variables

As stated, the research team was given a manual that explained required variables for each 100-m (approximately 300-ft) segment. Figure 4.1 shows an example of a variable and explanation from the manual.

Based on information in Figure 4.1, the research team coder was asked if a school zone warning is present in the Google Street View or a series of photos from manual data collection. The research team was instructed not to speculate regarding roadway features—the variable in question must be visibly present in Google Street View or a photo image. For example, evidence of a pedestrian crossing or bicycles may exist at a data coding point, but these variables cannot be coded unless a pedestrian or bicyclist is visually seen in Street View or a photo. The research team noted pedestrian crossing points as a complicated variable to code, especially when pavement markings were worn, sidewalks ended at intersections, or residents had to cross the road to collect daily mail from a mailbox. Figure 4.2 shows coding with visual inspection for a two-lane roadway.

5.59 School Zone Warning

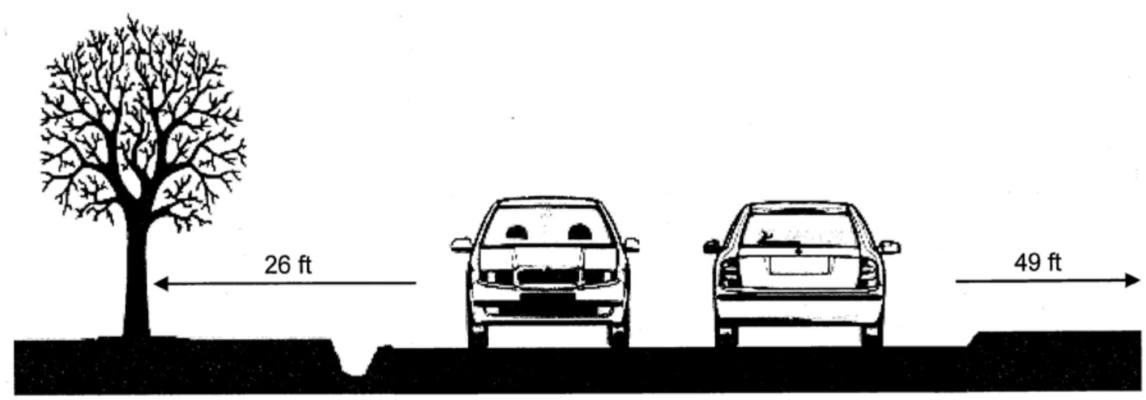
The School Zone Warning attribute addresses whether a school is present and whether specific traffic control devices are used to call the attention of motorists to the presence of the school and, therefore, to the possibility of students walking to and from school.

Coding Options

The codes used for this attribute are:

Code	Description
3	School present, but no school zone warning devices
2	School zone static signs or road markings
1	School zone flashing beacons
4	Not applicable (no school present at this location)

Figure 4.1: School Warning Variables and Codes



Attribute	Category	Notes
Roadside Severity Distance—Right Side	> 30 ft	Distance from edge of traveled way to nearest roadside object on the right is greater than 30 ft
Roadside Severity Object—Right Side	No object	Nearest severe object on the roadside is more than 30 ft from the right edge of the traveled way
Roadside Severity Distance—Left Side	15 to 30 ft	Distance from left edge of traveled way to tree on the left roadside; ditch is not deep enough to be coded
Roadside Severity Object—Left Side	Tree	Tree on the left roadside
Median Type	Centerline only	Undivided roadway with centerline only

Figure 4.2: Two-Lane Roadway Geometric Characteristics and Coding

As shown in Figure 4.2, the coder is traveling in a single direction (right side of the roadway), "roadside severity distance—right side" is estimated to be greater than 30 ft, no fixed object is present on the right side, "roadside severity distance—left side" is estimated to be between 15 and 30 ft, the fixed object is a tree, and the median type is a centerline (as compared to a raised or turf median). However, other variables may also exist for the roadway (Figure 4.2) as shown in the following list.

- Carriageway/roadway type
- Upgrade cost
- Observed motorcycle flow
- Observed bicycle flow
- Observed pedestrian flow across the road
- Observed pedestrian flow along the road (left and right sides)
- Lane use (left and right sides)
- Area type
- Speed limit
- Motorcycle speed limit
- Truck speed limit
- Median type
- Centerline rumble strips
- Roadside severity distance (left and right sides)
- Roadside severity object (left and right sides)
- Shoulder rumble strips
- Paved shoulder (left and right sides)
- Intersection type
- Intersection channelization
- Intersecting road volume
- Intersection quality
- Property access points
- Number of through lanes
- Lane widths for through traffic lanes
- Curvature
- Quality of curve
- Grade
- Road condition
- Road surface/skid resistance
- Delineation
- Street lighting pedestrian crossing facility (inspected road)
- Pedestrian crossing quality
- Pedestrian crossing facility (side road)
- Pedestrian fencing
- Speed management/traffic calming
- Vehicle parking
- Sidewalk (left and right sides)
- Service road
- Motorcycle facility
- Bicycle facility
- Roadworks (work zone)
- Sight distance
- School zone warning
- School zone crossing guard

The coder has the option to hold any of these variables constant between data collection points. This saves considerable time, especially if the roadway is similar for many miles at a time (rural roadways). All variables were evaluated for each segment of roadway in one direction (north, south, east, or west); two directions were unnecessary. The following sections describe how each 100-m segment was determined for two of the corridors.

4.2 Establishing 100-m Centerline Coordinates for Google Street View

The roadway database in the usRAP software for risk evaluation is populated by coding roadway features every 100 m (approximately 300 ft) on Google Maps or manually coding in one or both directions depending on roadway type or roadway network. In order to expedite the database population, the research team developed a macro that produced latitude and longitude coordinates every 100 m for the centerline of a given roadway. Using Google Earth for the beginning and ending coordinates of the evaluated corridor, directions were generated using the "Get Directions" feature shown in Figure 4.3.

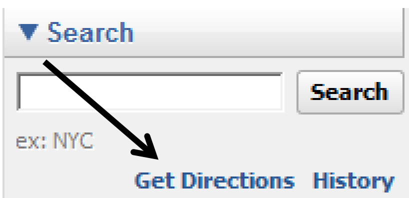


Figure 4.3: "Get Directions" Option in Google Earth

For undivided roadways, the coordinates appeared in a direction from "A" to "B," as shown in Figure 4.4. For example, if an undivided roadway spans east to west (or vice versa) and the start coordinate "A" is in the west and the ending coordinate "B" is in the east, then the direction of coordinates would be from west to east. Divided roadways require a set of directions for both directions of travel. For example, if a divided highway runs north to south (or vice versa), sets of unique labels are required for directions of north to south and south to north. In order to achieve optimal results, the start coordinate and end coordinate were placed in the center of the roadway.

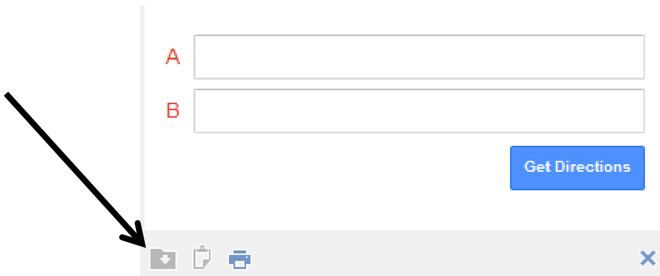


Figure 4.4: Start "A," End "B," and "Copy Current Results" Option

Once directions were obtained for a given roadway, the results were saved using the "copy current search results to My Places button" shown in Figure 4.4. Directions were then saved to a location on the computer as a .kml file. Notepad++ was used to extract coordinates along the roadway, saved in the form of comma-separated values to be used in Microsoft Excel, as shown in Figures 4.5 and 4.6.

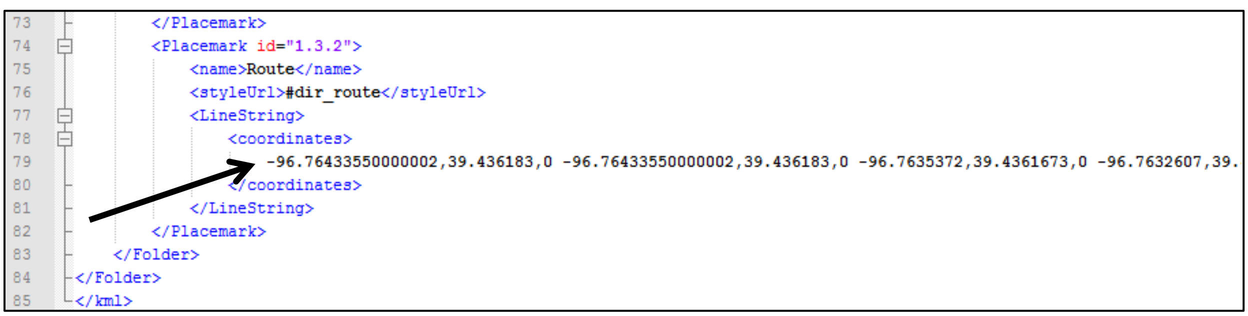


Figure 4.5: Coordinates along the Roadway

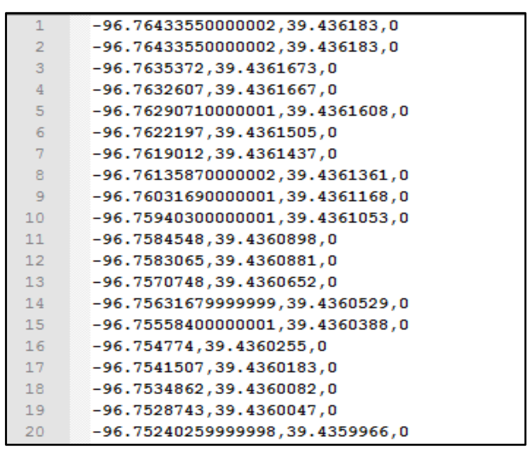


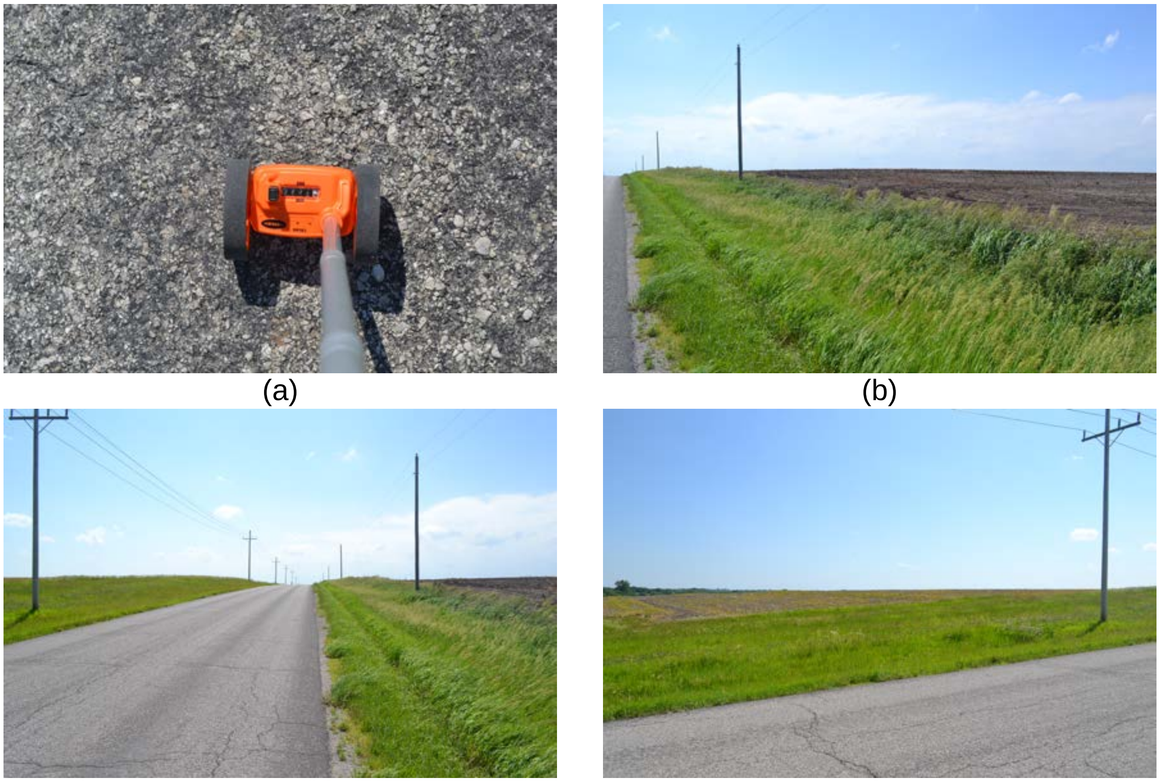
Figure 4.6: Coordinate in Comma-Separated Values Form (.csv)

Once the values were exported into Excel, the macro used the haversine formula to calculate the distance between each set of coordinates and saved the distances in columns "C" and "D." The haversine formula was used to calculate a certain distance, while taking into consideration the curvature of the earth's surface. Intervals of 100 m were then created to span the distance of the roadway, and coordinates for each 100-m section were found by interpolating between two coordinate points. For example, if the distance between the first two sets of coordinate points was 150 m, then the program interpolated the coordinates at 100 m before proceeding to the next 100-m section. Latitude and longitude coordinates were uploaded to the usRAP software spreadsheet, followed by coding as described in Section 4.3. The research team found that this efficient methodology increased precision and accuracy as compared to estimating the latitude and longitude using only a cursor in Google Earth.

4.3 Manual Field Data Collection

As of 2014 when this research study was conducted, Google Street View covered a considerable percentage of the Kansas roadways. However, many rural paved secondary roads were not covered, thereby requiring manual field data collection of segments. Previous usRAP studies relied on video data from a video camera placed on a dashboard. The driver drove at a constant speed and segments were extracted using time. Because the RS 20 and RS 25 corridor did not have Google Street View at the time of the study, the research team tried to extract segments based on a video log collected by a GoPro camera system. However, recording time was unavailable for this type of video technology and thousands of frames required sorting. The research team decided to manually collect segments using a wheel and digital camera, as shown in Figure 4.7.

As shown in Figure 4.7a, the research team measured out 300-ft segments along the side of the roadway and then took three photos, including the right shoulder (Figure 4.7b), the centerline (Figure 4.7c), and the left shoulder (Figure 4.7d). Both data collection methodologies were used in the project and coded in the usRAP software environment as explained in Section 4.4.



(a) (b) (c) (d)

Figure 4.7: Manual Data Collection at One Segment along RS 25 (Westbound)

4.4 usRAP Software Coding Environment

Coding of the usRAP software was performed over a 3-month period. The research team utilized two monitors for the coding; the first monitor, as shown in Figure 4.8, showed the roadway in Google Street View or photos from manual data collection. The research team was able to pan left to right, zoom in and out on a certain location, and opposing view (behind) to further investigate any variables. The Google Street View location was determined based on the coding screen (Figure 4.9) and pre-inputted latitude and longitude of each 100-m segment as described in Section 4.3.

The research team coded the Excel database using the user interface, as shown in Figure 4.9. Each variable was coded for each 100-m segment. Roadway sections were also specified in the coding menu, and a section for this project was defined as the distance between two major intersections. Once the researchers were comfortable with the coding procedure, 1 mile of coding could be completed in about 30 minutes.

Figure 4.8: Google Street View of a Specific Segment along US-40 (Left Monitor)

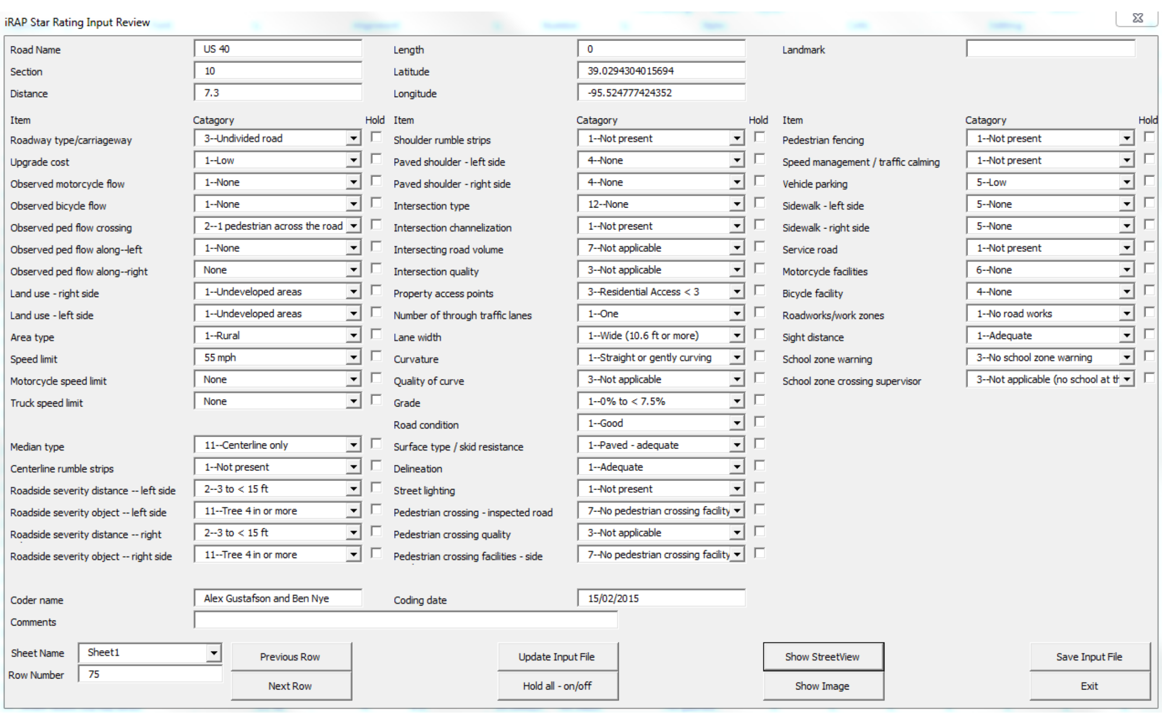


Figure 4.9: usRAP Software Coding Screen for a Specific Segment along US-40 (Right Monitor)

Many variables the research team had to code could remain constant when the researchers selected the “hold” button. In general, the coding process revealed that variables including a clear zone on both the driver and passenger sides of the vehicle, fixed objects, the presence of pedestrians, and horizontal curve characteristics frequently changed between segments. In addition to coded variables for each segment, researchers then added comments and landmarks (e.g., intersections, interstate ramps, or county lines), potentially aiding the quality assurance/quality control (QA/QC) process described in Section 4.6.

4.5 Database Development

The user interface shown in Figure 4.9 is a macro in front of an Excel worksheet that populates an Excel file with inputted latitude and longitudes or placeholders for manual field data collection. The research team overrode data through the macro or changed numbers on the worksheet without the macro. These operations were performed as part of the QA/QC process described in Section 4.6.

4.6 QA/QC Process

The research team utilized student researchers to code the usRAP software. Students worked in groups of two as they progressed along the corridor double-checking inputted variables. Once a corridor was completely coded from a specific start to an end point, a senior researcher verified the student coding by examining the coded variables every half-mile. If disagreement was found between coded variables, the senior researcher either adjusted segments around the questionable segment or asked the student researcher to view the corridor or segments again. Once the research team completed a corridor, the coded files were given to the MRIGlobal team for a final check and adjustment. The research team was certain the layers of QA/QC enabled the highest quality results. Once the QA/QC process was complete, data were uploaded to the usRAP website for analysis.

Chapter 5: Results of Selected Kansas Corridors

5.1 Analysis

Using the coded data and operational characteristics for each corridor, the usRAP program determines a road protection score for each segment using built-in modeling algorithms to determine if a segment has a high risk of a serious injury or fatal crash based on coded variables having a known impact or relationship with crash occurrence. Determination of risk and the possibility of a serious injury or fatal crash occurrence are translated into a star ranking (AAA, 2012a, 2012b, 2012c; Knapp, Hallmark, & Bou-Saab, 2014). The star ranking is an indicator of risk based on coded variables, number of centerline miles, and system-wide historical crash experience. Each segment is assigned a color-coded star rating from 1 to 5.

A segment star rating is based on the presence or absence of a roadway feature. A 4-star or 5-star rating assigned to a segment may have one or more of the following (Knapp et al., 2014): separation of opposing traffic by a wide median turf barrier, good pavement markings and intersection design, wide lanes and paved shoulders, roadside free of unprotected hazards such as fixed objects, and good facilities for bicycles and pedestrians. Roadway segments assigned a 1-star or 2-star rating may exhibit the following characteristics: two-lane undivided roadways, high posted speed limit, frequency of horizontal curve and intersections, narrow lanes, unpaved shoulders, unprotected fixed objects in the clear zone, or hidden intersections.

The Safer Roads Investment Plan in the usRAP software considers 70 countermeasures based on star ratings and information in the coded databases. Benefit-cost ratios developed from known countermeasure effectiveness and proposed safety improvement locations are determined based on the highest benefit-cost ratio. A benefit-cost ratio is assigned to the analysis based on priorities of state highway agencies or local jurisdictions. If a specified benefit-cost ratio is not inputted into the program, all 70 countermeasures can be listed, many with very low benefit-cost ratios. For this project, a benefit-cost ratio of 1 was used for countermeasure selection, meaning that when the usRAP software was performing the Safer Roads Investment Plan, a countermeasure was not considered if it had a benefit-cost ratio equal to or less than 1.

5.2 Corridor Outputs

As explained in Section 5.1, the usRAP software provides many outputs for a corridor under investigation. The following outputs were obtained for each of the three corridors:

- Star ratings for the selected corridor, which included separate star rating maps illustrating existing risk for pedestrians, bicycles, motorcycles, and vehicle occupants. For this research project, all 100-m segments were combined into a section. A section was defined as the distance from the beginning of the corridor to the end of the corridor, or from a major intersection to another major intersection.
- The Safer Roads Investment Plan for each corridor, which included selected countermeasures with a benefit-cost ratio equal to or greater than 1. The results of the Safer Roads Investment Plan provided outputs in table format. This table included the length or quantity of the countermeasure, fatal and serious injuries prevented by the countermeasure over the course of 20 years, countermeasure cost, countermeasure benefits, costs saved per fatal and serious injury crash over 20 years, and a program benefit-cost ratio. A program benefit-cost ratio means that the countermeasure was fully implemented at every site suggested.
- The Safer Roads Investment Plan for each corridor also included a program summary. The program summary output described if every countermeasure and location were implemented as suggested by the usRAP software, then a determined overall benefit-cost ratio could be determined in table format. The overall program table included the total number of fatal and serious injury crashes prevented in a 20-year period, the total costs and total benefits, total costs saved per fatal and serious injury crash, and total program benefit-cost ratio.
- Within the Safer Roads Investment Plan, the countermeasure location was viewed on Google Maps, including latitude and longitude as well as

individual benefit-cost ratios for each location. A countermeasure analysis Excel sheet was downloaded, and the highest benefit-cost ratio countermeasure was identified for priority consideration, as explained in Sections 5.3, 5.4, and 5.5.

Information presented in Sections 5.3 through 5.5 is web-based and can be accessed only by the state highway agency or local jurisdictions with restrictions in order to prevent changes to the coding and roadway background information. The following sections include screen-captured images from the usRAP website.

5.3 US-40 Outputs

Figures 5.1 through 5.4 show the star ratings for US-40. Each star rating is color-coded: 5-star rating is green, 4-star rating is yellow, 3-star rating is orange, 2-star rating is red, and 1-star rating is black. The website overlays the results on top of Google Maps, allowing users to zoom in to specific roadway segments and view attributes and nearby roads, buildings, lakes, and other physical features.

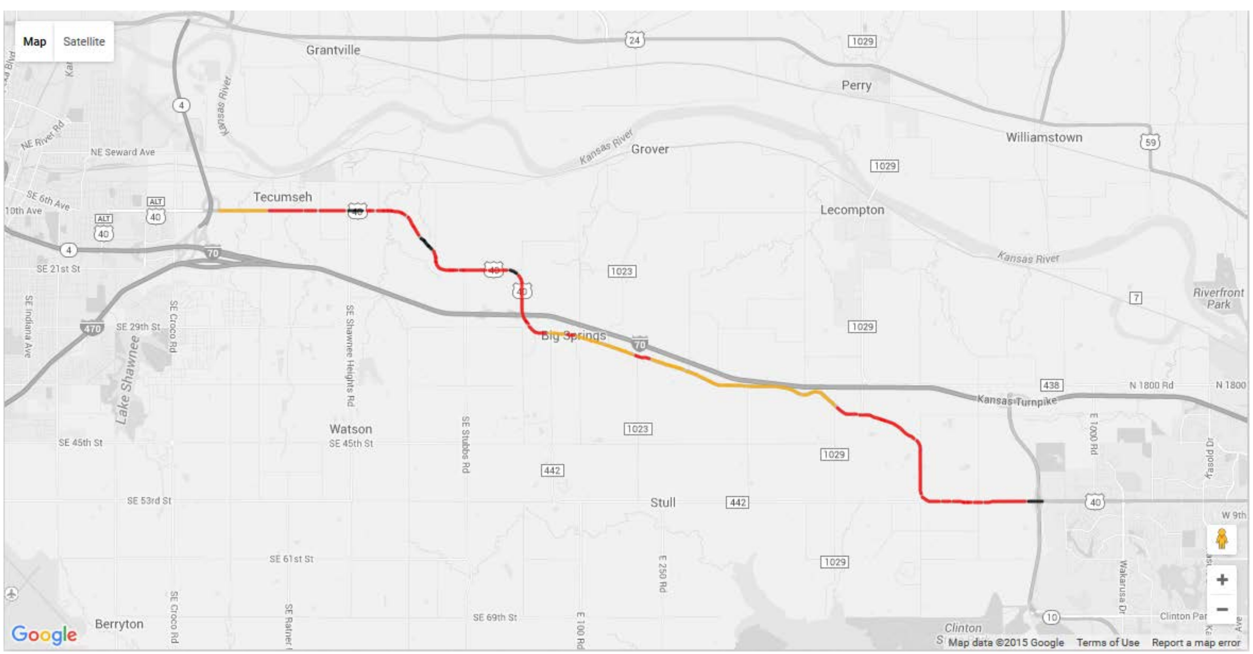


Figure 5.1: US-40 Star Rating for Vehicle Occupants before Countermeasure Implementation

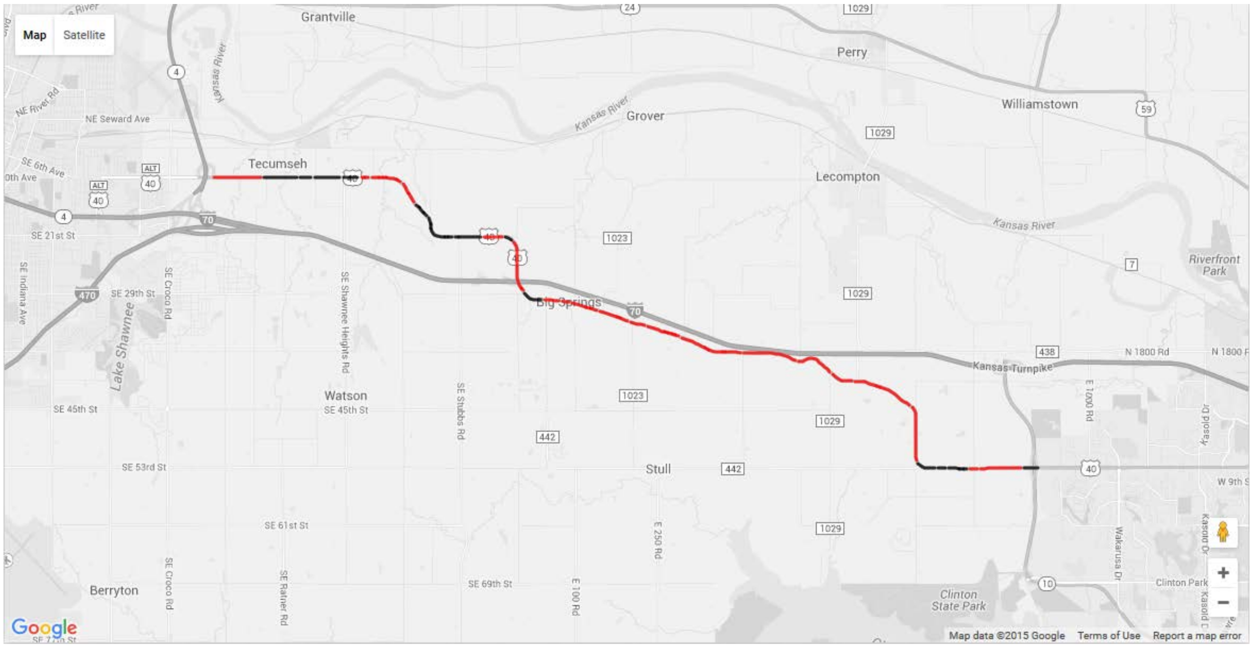


Figure 5.2: US-40 Star Rating for Motorcycles before Countermeasure Implementation

As shown in Figures 5.1 and 5.2, low star ratings occurred around horizontal curves (black color) for vehicle occupants and motorcycles. A couple segments within the corridor contained differing roadway geometry and entrances to businesses (including a quarry) in which roadway geometry differed from a traditional two-lane undivided highway. This corridor had no 4-star or 5-star ratings, as was expected since 4-star and 5-star roads are traditionally roadways with multiple wide lanes, paved shoulders, and wide clear zones, such as interstates with limited access or divided highways with large clear zones, paved shoulders, and a median for recovery. Researchers from MRIGlobal who assisted with the training and QA/QC process stated that 3-star, 2-star, and 1-star ratings are typical for rural two-lane undivided highways. Figures 5.3 and 5.4 show star ratings for bicycles and pedestrians on US-40.

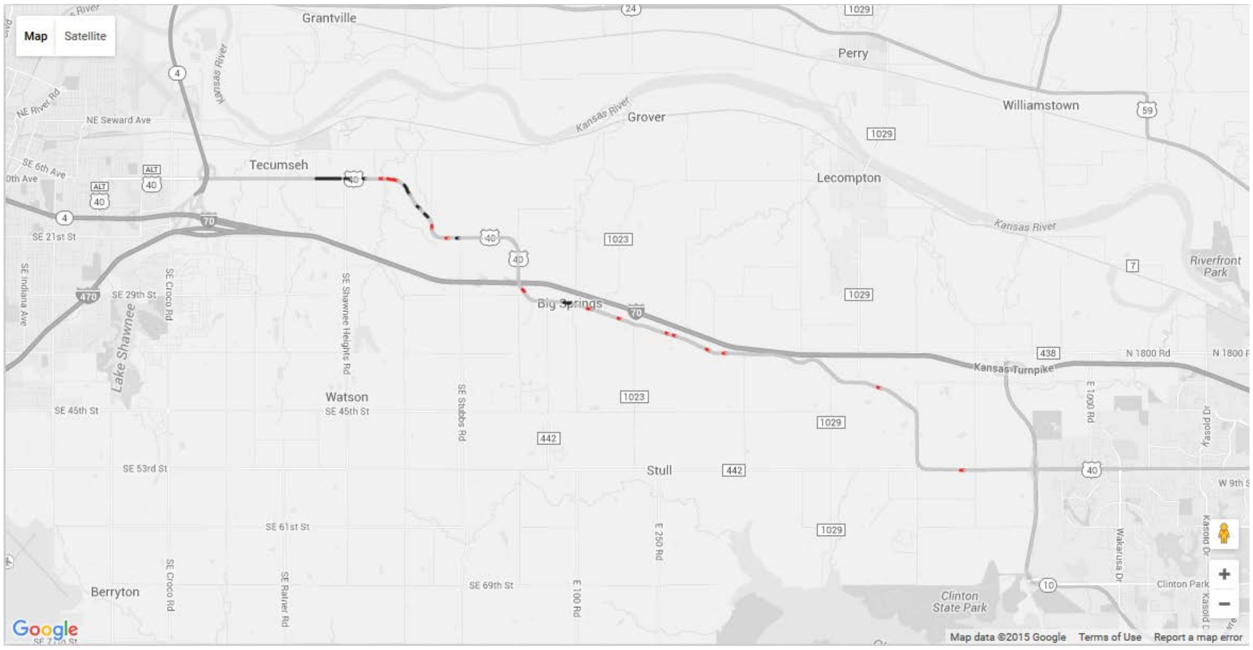


Figure 5.3: US-40 Star Rating for Pedestrians before Countermeasure Implementation

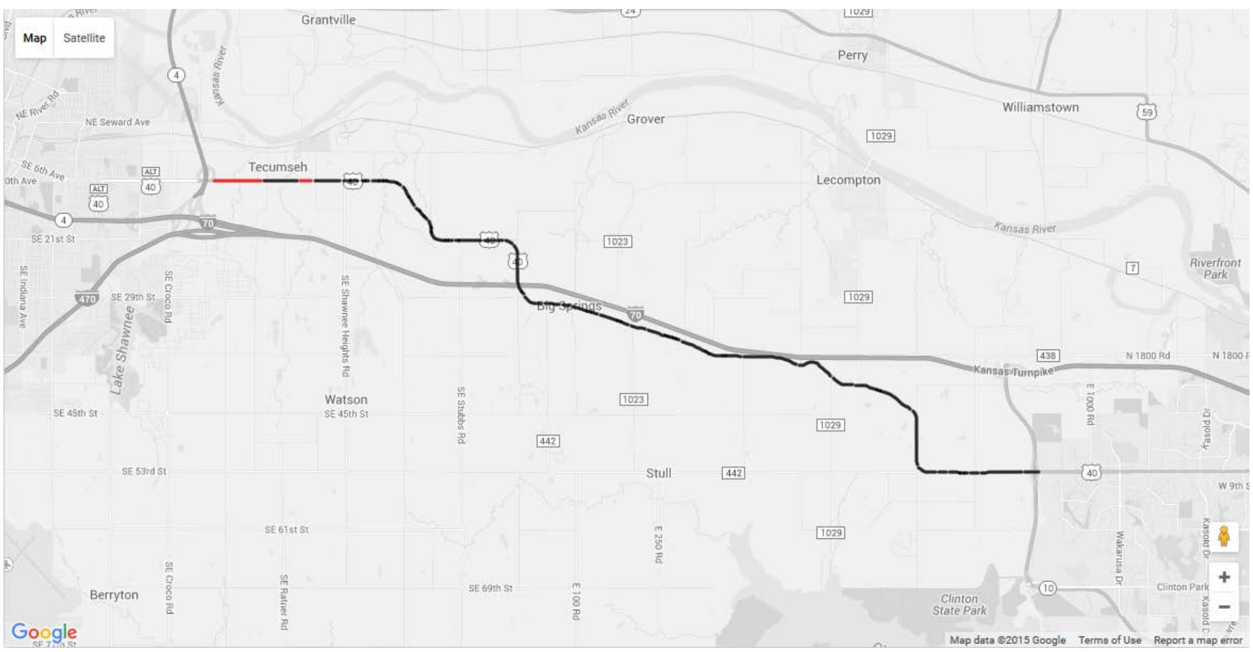


Figure 5.4: US-40 Star Rating for Bicycles before Countermeasure Implementation

As shown in Figure 5.3, very few segments within the study showed the existence or evidence of a pedestrian facility. The few red or black sections can show this with much of the corridor having no star ratings. Many of those limited pedestrian facilities included mailboxes located directly across US-40 from the home, requiring the resident to cross US-40 to retrieve daily mail. Sidewalks were observed near Topeka, KS (west side of Figure 5.4 near Topeka, KS), but these facilities were located only on one side of the road. Results shown in Figure 5.4 were expected since a rural two-lane undivided highway did not have bicycle facilities such as a paved shoulder, bike lanes, or other features to increase roadway safety for bicyclists. Star ratings for Figures 5.1 through 5.4 were also displayed in the usRAP software in table format (Table 5.1), where star ratings were quantified in distance (km) and percentages.

Table 5.1 shows that 9.10 kilometers, or 33 percent of the total 27.50 km, were 3 stars for vehicle occupants; 16.60 km, or 60 percent, were 2 stars; and 1.80 km, or 7 percent, were 1 star. For motorcycles, 71 percent, or 19.50 km, were 2 stars, and 8.00 km, or 29 percent, were 1 star. A total of 23.60 km were not applicable to pedestrians and over 93 percent, or 25.70 km, were 1 star for bicyclists.

Table 5.1: US-40 Star Ratings, Lengths, and Percentages for Vehicle Occupants, Motorcycles, Pedestrians, and Bicycles

	Vehicle Occupants		Motorcycles		Pedestrians		Bicyclists	
	Length (km)	Percent	Length (km)	Percent	Length (km)	Percent	Length (km)	Percent
5 Stars	0.00	0%	0.00	0%	0.00	0%	0.00	0%
4 Stars	0.00	0%	0.00	0%	0.00	0%	0.00	0%
3 Stars	9.10	33%	0.00	0%	0.00	0%	0.00	0%
2 Stars	16.60	60%	19.50	71%	1.70	6%	1.80	7%
1 Star	1.80	7%	8.00	29%	2.20	8%	25.70	93%
N/A	0.00	0%	0.00	0%	23.60	86%	0.00	0%
Totals	**27.50**	**100%**	**27.50**	**100%**	**27.50**	**100%**	**27.50**	**100%**

Table 5.2 presents results of the Safer Roads Investment Plan, which provided recommended countermeasures for US-40. As shown, clearing roadside hazards on the passenger side (south side of the road traveling eastbound) demonstrated the highest program benefit ratio of 14. However, 13.60 km out of the total 27.50 km (approximately 49 percent) needed roadside clearing. The countermeasure with the next highest benefit-cost ratio was clearing the roadside on the driver side (north side of the road traveling eastbound). If these two countermeasures were considered, nine fatal and serious injury crashes could be prevented over a 20-year period with a

$205,000 investment. Clearing the roadside would allow drivers to recover if they departed the roadway and also prevent fixed-object crashes that were found to be the most common type of crash in a 5-year period, as shown in Figure 3.4. Other countermeasures recommended with a lower benefit-cost ratio included roadside barriers, sideslope improvements, shoulder rumble strips, pedestrian facilities, and wider centerline markings.

The usRAP software also allows users to more closely view each countermeasure by clicking on each countermeasure title. Table 5.2 is located on the usRAP website where users are directed to pages based on research, the Highway Safety Manual (HSM), and international standards. For example, if a user was investigating only "clear roadside hazards—passenger side," Figure 5.5 would appear on the screen with the recommended location where the roadside should be cleared.

Table 5.2: Safer Roads Investment Plan for US-40 (Recommended Countermeasures Analysis)

Countermeasure	Length/Sites	FSIs Saved	Benefit ($)	Estimated Cost ($)	Cost per FSI Saved ($)	Program BCR
Clear roadside hazards—passenger side	13.60 km	5	1,493,293	109,980	23,823	14
Clear roadside hazards—driver side	11.70 km	4	1,240,354	95,940	25,020	13
Sideslope improvement—driver side	1.40 km	1	188,798	81,900	140,319	2
Roadside barriers—passenger side	1.30 km	1	347,057	253,500	236,271	1
Roadside barriers—driver side	0.90 km	1	257,662	187,200	235,010	1
Bicycle lane (on road)	2.60 km	0	34,609	30,810	287,965	1
Sideslope improvement—passenger side	0.70 km	0	101,761	46,800	148,763	2
Shoulder rumble strips	0.30 km	0	24,316	21,177	281,710	1
Footpath provision driver side (adjacent to road)	1.20 km	0	38,939	28,080	233,261	1
Wide centerline	2.60 km	0	20,581	15,600	245,181	1

Table 5.3 presents a summary for the US-40 corridor if all countermeasures were implemented as a program for the corridor, including potentially preventing 12 fatal and serious injury crashes over a 20-year period with a benefit-cost ratio of 4. To accomplish this safety benefit, it would require an investment of $870,987 and have an expected benefit of $3,747,370.

Table 5.3: Program Safer Roads Investment Plan for US-40 (Overall)

Total FSIs Saved	Total Benefits ($)	Estimated Costs ($)	Cost per FSI Saved ($)	Program BCR
12	3,747,370	870,987	75,183	4

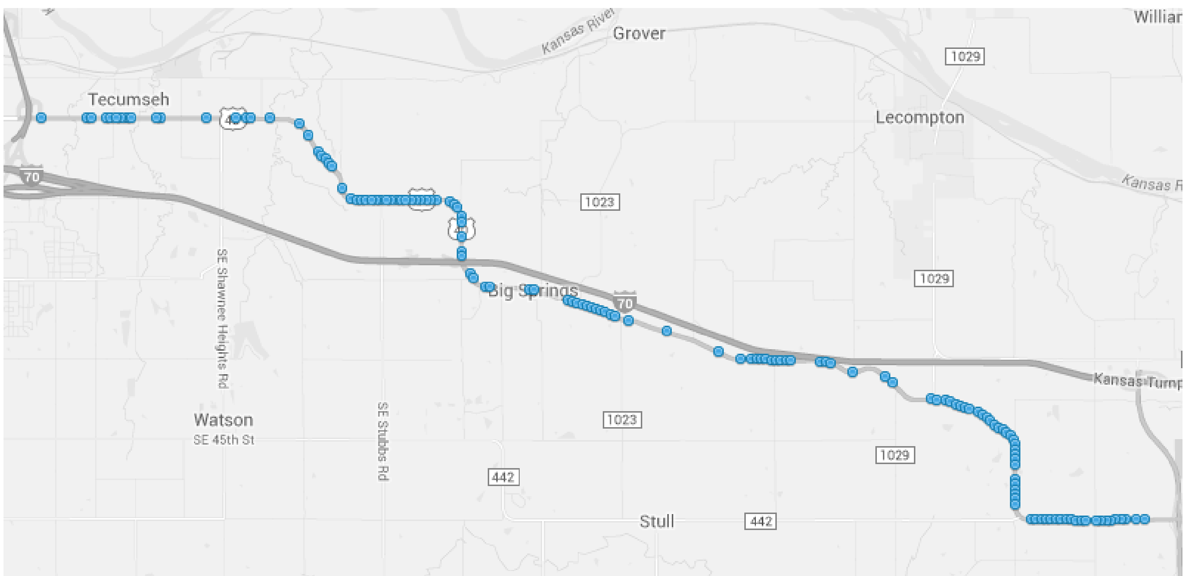


Figure 5.5: Recommended Locations of "Clearing Roadside Hazard—Passenger Side" for US-40

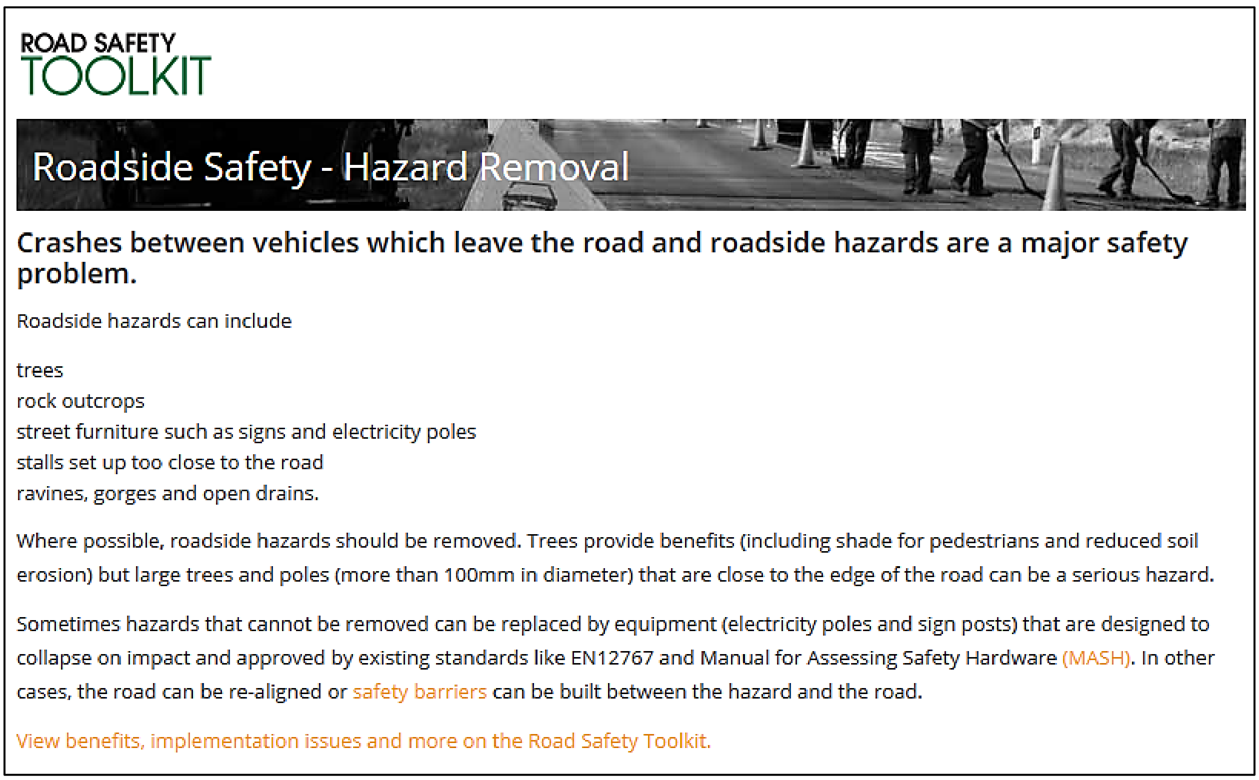
As shown in Figure 5.5, the roadside could be cleared at almost every location along the corridor with the exception of areas where the roadside was clear of fixed objects. When the user clicks on a location within the map, information is provided for the selected segment, as shown in Figure 5.6.

Figure 5.6: Countermeasure Information at a Selected Segment along US-40

Figure 5.7: Section 20 of US-40 Showing Roadside Hazards that must be Removed to Increase Safety

As shown in Figure 5.6, the selected location included the road name, section number, distance from the start of analysis, expected cost, fatal and serious injuries prevented over a 20-year period, cost saved per fatal and serious injury crash, and location benefit-cost ratio. Figure 5.6 also shows that the selected location had an estimated benefit-cost ratio of 15.09, which is higher than the overall average benefit-cost ratio listed in Table 5.2. The usRAP software allows a user to also view a location on Google Street View, as shown in Figure 5.7.

As shown in Figure 5.7, clearing the roadside on the passenger side of the vehicle would beneficially remove a large tree that a vehicle could strike. The research team considered the clear zone in this segment to be the edge of the roadway to the fence line. In addition to viewing the location on Google Street View, the usRAP software includes countermeasure information on a linked page, as shown in Figure 5.8.


ROAD SAFETY TOOLKIT

Roadside Safety - Hazard Removal

Crashes between vehicles which leave the road and roadside hazards are a major safety problem.

Roadside hazards can include

trees
rock outcrops
street furniture such as signs and electricity poles
stalls set up too close to the road
ravines, gorges and open drains.

Where possible, roadside hazards should be removed. Trees provide benefits (including shade for pedestrians and reduced soil erosion) but large trees and poles (more than 100mm in diameter) that are close to the edge of the road can be a serious hazard.

Sometimes hazards that cannot be removed can be replaced by equipment (electricity poles and sign posts) that are designed to collapse on impact and approved by existing standards like EN12767 and Manual for Assessing Safety Hardware (MASH). In other cases, the road can be re-aligned or safety barriers can be built between the hazard and the road.

View benefits, implementation issues and more on the Road Safety Toolkit.

Figure 5.8: Roadside Safety – Hazard Removal Implementation and Effectiveness Information on the usRAP Website

In addition to a general description of the countermeasure (Figure 5.8), the website page contains links to federal websites, research reports, toolboxes, and, in many cases, the crash modification clearing house. Many research studies currently linked are international reports, although an increasing number of US research reports have been populating the website.

The usRAP software also allows users to download all results and select analysis spreadsheets. One useful analysis is the countermeasure selection worksheet in which usRAP tests each countermeasure and accepts countermeasures with estimated benefit-cost ratios greater than or equal to 1. For the US-40 corridor, the research team selected the "clear roadside hazards—passenger side" countermeasure because it had the highest average benefit-cost ratio according to Table 5.2. In the countermeasure spreadsheet, this variable was isolated for every segment analyzed. As shown in Figure 5.6, every countermeasure location had a unique benefit-cost ratio ranging from 1 to 22. Segments with a benefit-cost ratio of only 22 (highest possible) were selected, and the latitude and longitude of the segment were extracted. Using a .csv file to .kml open-source macro, the locations were plotted on Google Earth, as shown in Figure 5.9.

As shown in Figure 5.9, numerous locations were found to have a benefit-cost ratio of 22, as compared to hundreds of sites with a positive benefit-cost ratio, as shown in Figure 5.5. The advantage of the process illustrated in Figure 5.9 is that if a state highway agency or local jurisdiction has limited resources for roadway safety improvements, these sites are clearly identified as priority investments or sites for an engineering study.

Finally, the usRAP software uniquely estimates corridor star ratings if all countermeasures are implemented. The research team found minimal change in bicycle and pedestrian star ratings, but star ratings of motorcycles and vehicle occupants did change, as shown in Figures 5.10 and 5.11 for US-40. The usRAP software also provides star ratings for roadway length changes and percentage changes for each star rating, as shown in Table 5.4.

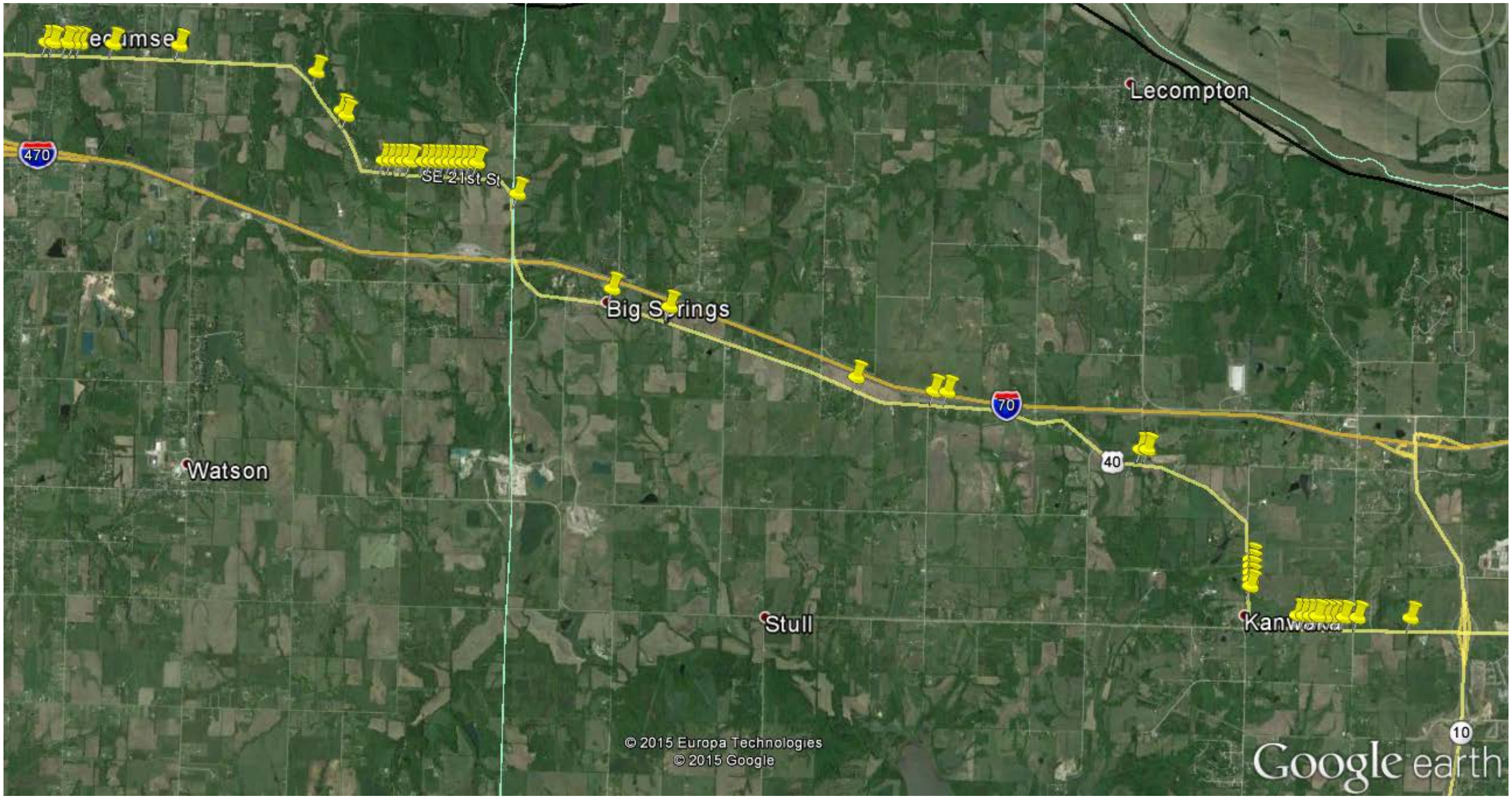


Figure 5.9: Recommended Locations for Clear Roadside Hazards along US-40 Based on the Highest Benefit-Cost Ratio of 22

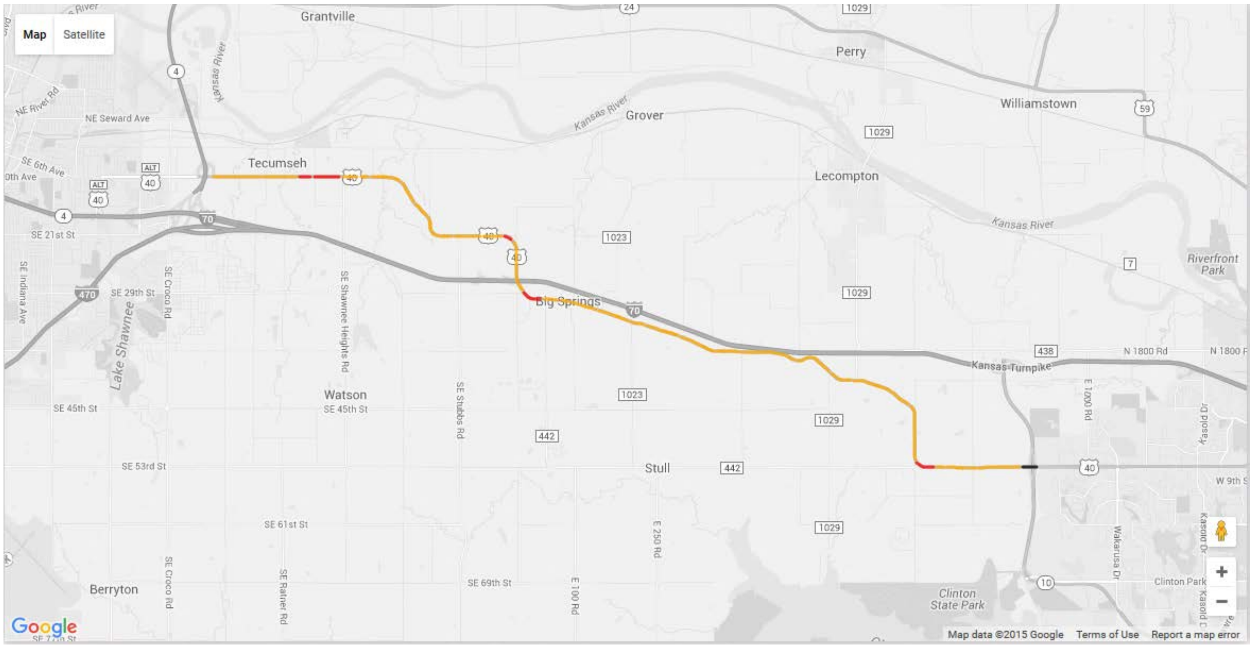


Figure 5.10: Predicted Star Ratings for US-40 for Vehicle Occupants after All Countermeasures were Implemented

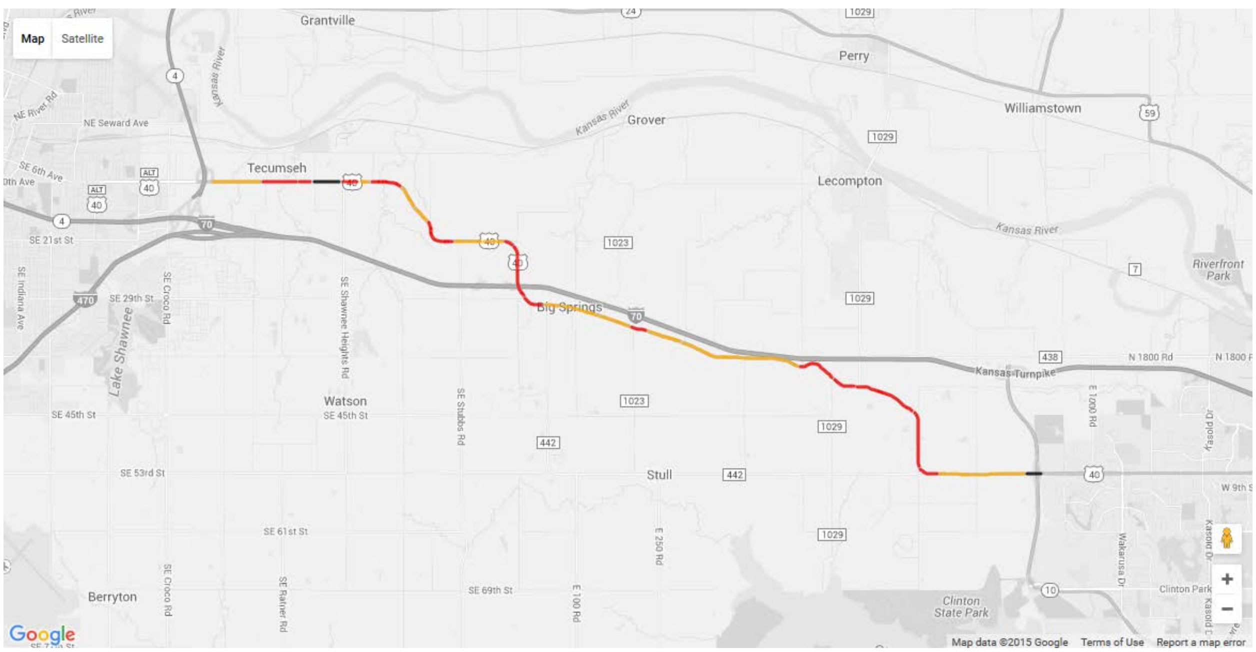


Figure 5.11: Predicted Star Ratings for US-40 for Motorcycles after All Countermeasures were Implemented

Table 5.4: Before-and-After Countermeasure Implementation Star Ratings, Lengths, and Percentages for Vehicle Occupants and Motorcycles for US-40

	Vehicle Occupants				Motorcycles			
	Before		After		Before		After	
	Length (km)	Percent	Length (km)	Percent	Length (km)	Percent	Length (km)	Percent
5 Stars	0.00	0%	0.00	0%	0.00	0%	0.00	0%
4 Stars	0.00	0%	0.00	0%	0.00	0%	0.00	0%
3 Stars	**9.10**	**33%**	**24.30**	**88%**	0.00	0%	**13.60**	**49%**
2 Stars	**16.60**	**60%**	**2.70**	**10%**	**19.50**	**60%**	**12.60**	**46%**
1 Star	**1.80**	**7%**	**0.50**	**2%**	**8.00**	**29%**	**1.30**	**5%**
N/A	0.00	0%	0.00	0%	0.00	0%	0.00	0%
Totals	**27.50**	**100%**	**27.50**	**100%**	**27.50**	**100%**	**27.50**	**100%**

As shown in Table 5.4, countermeasure implementation increases safety for vehicle occupants and motorcycles. Although it does not eliminate 1-star and 2-star segments, the corridor as a whole is improved considering the length and percent change for 3-star rating. For example, for vehicle occupants, 9.10 km, or 33 percent of the 27.50 km corridor, would become 24.30 km, or 88 percent, of the total length if the countermeasure were implemented. The key to this table is that all countermeasures must be implemented, not just one or two in various locations. Depending on the local jurisdiction or state safety funding, star ratings would be expected to increase with implementation of a single corridor, but not to the predicted star rating levels shown in Table 5.4. A similar analysis as to the process described for US-40 was performed for K-5 and RS 20 and RS 25, is presented in the following sections.

5.4 K-5 Outputs

Similar to outputs of US-40, K-5 had a larger quantity of 2-star and 1-star rating segments for all analysis types (vehicle occupants, motorcycles, pedestrians, and bicyclists). Maps presented in Figures 5.12, 5.13, and 5.14 for vehicle occupants, motorcycles, and pedestrians, respectively, had identical star ratings, including two distinct parts of the corridor with 1-star ratings, as shown in black.

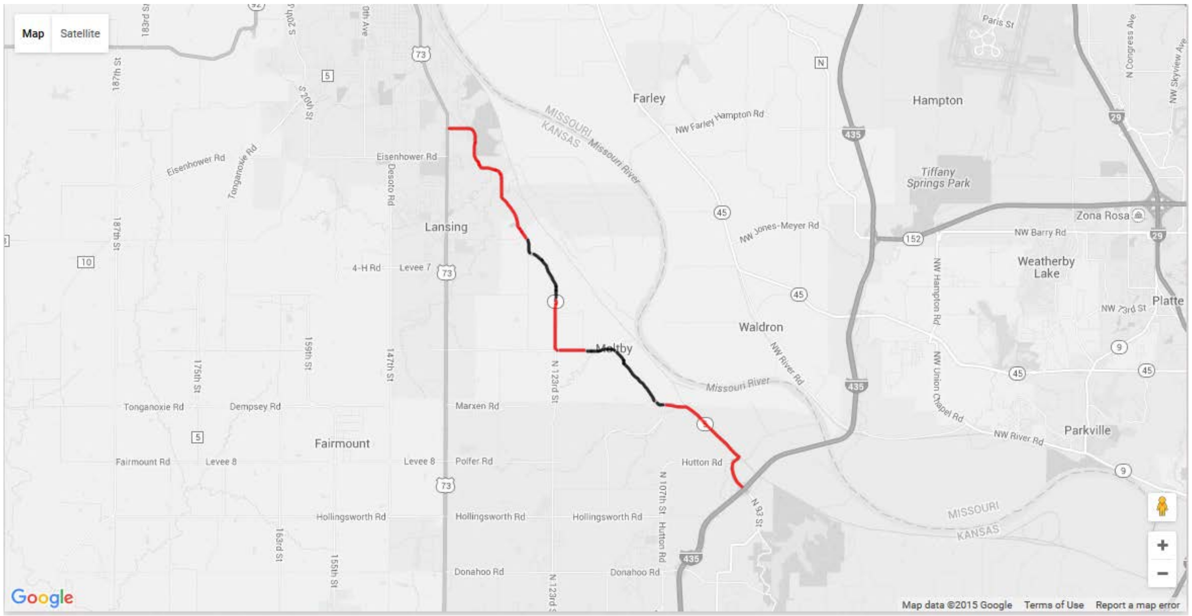


Figure 5.12: K-5 Star Rating for Vehicle Occupants before Countermeasure Implementation

Figure 5.13: K-5 Star Rating for Motorcycles before Countermeasure Implementation

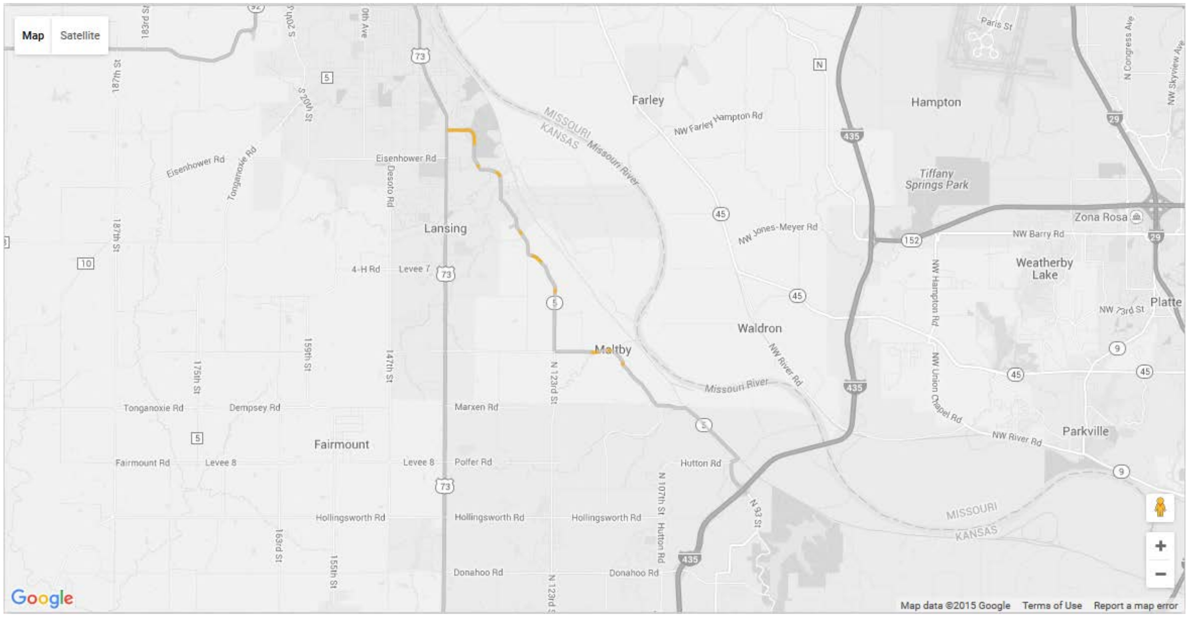


Figure 5.14: K-5 Star Rating for Pedestrians before Countermeasure Implementation

Figure 5.14 shows star ratings for pedestrians on existing roadway conditions. As shown, the segments identified for pedestrian facilities were 3 stars. In general, this corridor contained segments with adequate sight distance, access to mailboxes, and sidewalk facilities near the city of Lansing, KS (top part of Figure 5.14). Figure 5.15 shows star ratings for bicyclists on K-5.

Figure 5.15: K-5 Star Ratings for Bicycles before Countermeasure Implementation

As shown in Figure 5.15, star ratings for bicycles were similar to motorcycle and vehicle occupant star ratings, with 1-star segments incorporating areas with many horizontal curves, changes in vertical alignment, and limited sight distances. Table 5.5 summarizes K-5 star ratings to show length and percentages for each analysis.

Table 5.5: K-5 Star Ratings, Lengths, and Percentages for Vehicle Occupants, Motorcycles, Pedestrians, and Bicycles

	Vehicle Occupants		Motorcycles		Pedestrians		Bicyclists	
	Length (km)	Percent	Length (km)	Percent	Length (km)	Percent	Length (km)	Percent
5 Stars	0.00	0%	0.00	0%	0.00	0%	0.00	0%
4 Stars	0.00	0%	0.00	0%	0.00	0%	0.00	0%
3 Stars	0.00	0%	0.00	0%	2.50	15%	0.00	0%
2 Stars	11.00	68%	11.00	68%	1.70	6%	11.00	68%
1 Star	5.20	32%	5.20	32%	2.20	8%	5.20	32%
N/A	0.00	0%	0.00	0%	13.70	85%	0.00	0%
Totals	**16.20**	**100%**	**16.20**	**100%**	**16.20**	**100%**	**16.20**	**100%**

Columns of interest in Table 5.5 are vehicle occupants and motorcycles. As shown, 11 km, or 68 percent of the total 16.20 km, were 2-star ratings, and 5.20 km, or 32 percent of the 16.20 km total, were 1-star ratings. For pedestrians, 13.70 km were not applicable for pedestrian rating; results for motorized vehicles were similar to results for bicycles.

The usRAP software developed proposed countermeasures for K-5, as shown in Table 5.6. “Improve curve delineation” had the highest benefit-cost ratio of 13. However, zero fatal and serious injury crashes over a 20-year period were found. Improvement of curve delineation (e.g., larger chevrons, pavement markings, etc.) typically reduces ROR crashes, which often result in minor injuries or PDO crashes only if sufficient clear zone exists on both the driver and passenger sides of the vehicle.

Other countermeasures with a high benefit-cost ratio include “clear roadside hazards—passenger side,” with a benefit-cost ratio of 11 similar to US-40 and an estimated two fatal and serious injury crashes saved over a 20-year period. “Clear roadside hazards—driver side” had a benefit-cost ratio of 10 and an estimated three fatal and serious injury crashes prevented over a 20-year period.

Table 5.7 shows the program analyses if all recommended countermeasures were implemented. An estimated 11 fatal and serious injury crashes could be prevented over a 20-year period, with a program benefit-cost ratio of 3 and a cost of $3,449,726.

Table 5.6: Safer Roads Investment Plan for K-5 (Recommended Countermeasures Analysis)

Countermeasure	Length/ Sites	FSIs Saved	Benefit ($)	Estimated Cost ($)	Cost per FSI Saved ($)	Program BCR
Improve curve delineation	0.40 km	0	76,040	6,046	25,719	13
Clear roadside hazards—passenger side	6.50 km	2	721,776	67,860	30,412	11
Clear roadside hazards—driver side	7.90 km	3	848,400	83,460	31,821	10
Roadside barriers—driver side	2.40 km	3	847,004	491,400	187,664	2
Roadside barriers—passenger side	1.90 km	2	727,266	393,900	175,196	2
Lane widening (up to 1.5 ft)	0.30 km	0	44,054	28,236	207,328	2
Sideslope improvements—passenger side	0.30 km	0	37,378	17,550	151,875	2
Sideslope improvements—driver side	0.20 km	0	38,321	17,020	143,665	2
Footpath provision driver side (adjacent to road)	0.60 km	0	26,875	14,040	168,985	2
Wide centerline	0.80 km	0	7,927	4,680	190,979	2
Shoulder sealing passenger side (<3 ft)	0.30 km	0	21,514	19,500	293,193	1
Shoulder sealing driver side (<3 ft)	0.40 km	0	18,480	15,600	273,059	1
Shoulder sealing driver side (>3 ft)	0.30 km	0	34,691	23,400	218,191	1

Table 5.7: Program Safer Roads Investment Plan for K-5 (Overall)

Total FSIs Saved	Total Benefits ($)	Estimated Costs ($)	Cost per FSI Saved ($)	Program BCR
11	3,449,726	1,182,692	110,897	3

The research team further explored the "improve curve delineation" countermeasure due to the curve length of 0.40 km, potentially indicating that the usRAP software identified a particularly risky horizontal curve along the corridor. The curve of interest is shown in Figure 5.16.

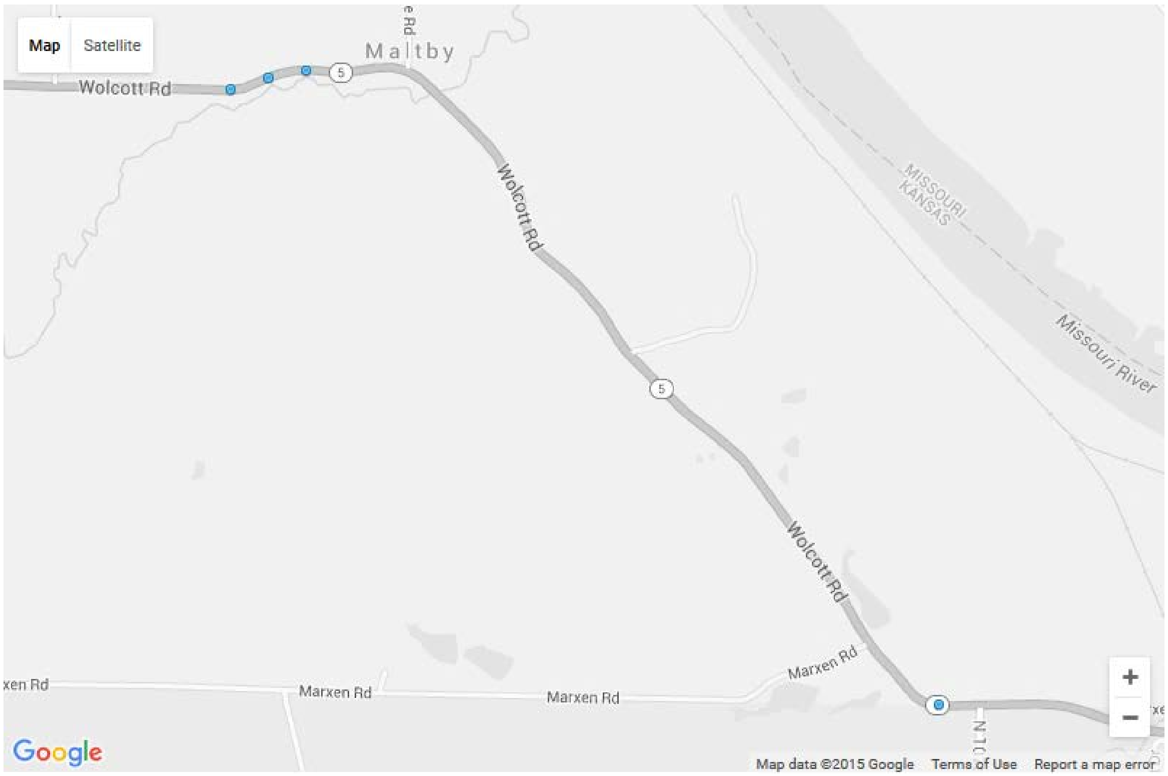


Figure 5.16: Recommended Locations of "Improve Curve Delineation" for K-5

As shown in Figure 5.16, the usRAP software isolated a series of connected horizontal curves along K-5 that were candidate locations for curve delineation countermeasures. Figure 5.17 shows an aerial view of the horizontal curves that included many trees close to the roadway on both sides, a stream to the south, and a ditch connecting to private property to the north.

Figure 5.17: Recommended Locations for “Improve Curve Delineation” along K-5 Based on the Highest Benefit-Cost Ratio of 15

Prior to this study, Wyandotte County had made significant improvements to other curves along the corridor, including adding new high-visibility signage and high-friction surface treatment for most of the corridor length. However, the research revealed that the identified set of curves were one of the few sets of horizontal curves that did not receive any countermeasure enhancements. Figure 5.18 shows the Google Street View of horizontal curves in the eastbound direction on K-5.

Figure 5.18: Google Street View of Two Horizontal Curves along K-5 that Require Countermeasures

A combination of countermeasures could increase safety at the location shown in Figure 5.18, including chevrons, delineators, removal of fixed objects close to the roadway, or enhanced pavement markings. Changes in vertical alignment and delineation would also help drivers negotiate this segment of the corridor with a high posted speed limit. After further investigation of this location, the usRAP software proposed a benefit-cost ratio for implementing a curve-related countermeasure (Figure 5.19).

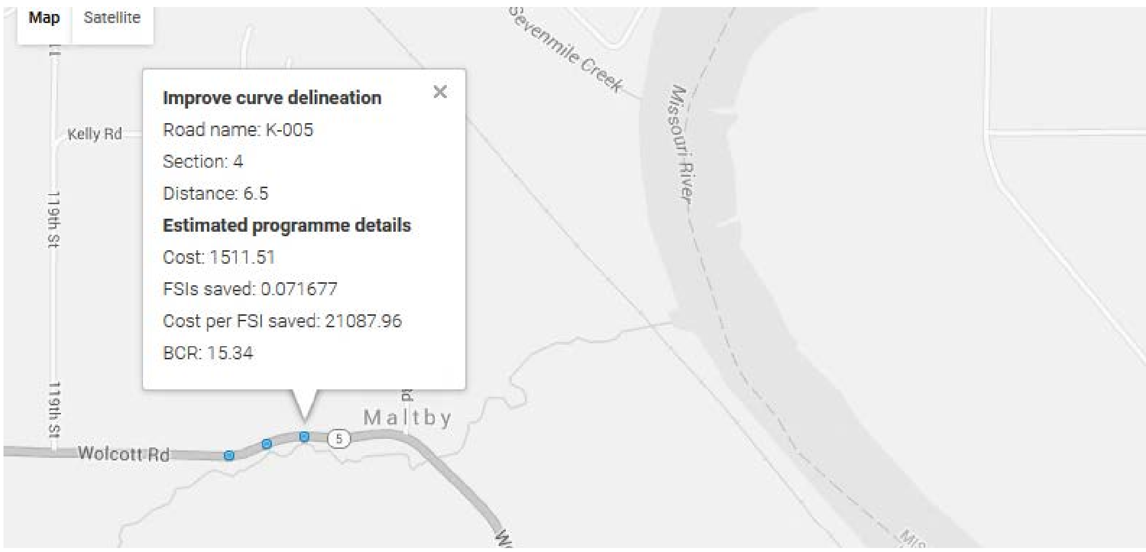


Figure 5.19: Countermeasure Information at the Horizontal Curve Segment along K-5

As shown in Figure 5.19, the easternmost horizontal curve in the series of three horizontal curves had a countermeasure estimated benefit-cost ratio of 15.34 and an estimated cost of $1,511.51. If a local jurisdiction or state highway agency wanted to improve curve delineation, the usRAP software provides an extensive library and toolbox pertaining to horizontal curves, as demonstrated in Figure 5.20.

The usRAP software also provided predictions for star rating improvements if all recommended countermeasures were implemented. Similar to US-40, no differences in star ratings were observed for pedestrians and bicyclists based on limited facilities or potential future facilities along the corridor. Proposed star ratings for K-5 with implemented countermeasures for vehicle occupants and motorcycles are shown in Figures 5.21 and 5.22.

Centre and edge delineation treatments help drivers judge their position on the road, and provide advice about conditions ahead. Delineation treatments are particularly helpful where visibility can become poor (for example, due to rain, fog or darkness) and on sharp bends.

There are many delineation treatments available, and these should be used in a consistent manner along a route or road network. Example delineation treatments include:

Line marking

Painted line marking is relatively cheap. Centrelines can be used to discourage overtaking or accidental 'drifting' from the lane. Edge lines help drivers judge the alignment of the road ahead and can reduce run-off-road crashes. Line marking is also effective at reducing shoulder damage, and therefore in reducing maintenance costs. Rumble strips or profiled line marking applied as an edgeline or centreline can be effective in reducing run-off-the-road and head-on crashes, particularly crashes related to driver fatigue.

Retroreflective Pavement Markers (RRPMs)

Retro-reflective pavement markers or road studs ('cats eyes') are usually used in conjunction with painted line marking to warn drivers of changes in alignment in the road ahead. RRPM's are particularly helpful in darkness or during wet weather when line marking becomes difficult to see.

Guide posts

Guide posts assist the road user by indicating the alignment of the road ahead, especially at horizontal and vertical curves. Guide posts are usually about one metre high and set about one metre from the edge of the road. They can be equipped with reflectors, or painted with reflective paint, and so are especially useful at night. They should not constitute a roadside hazard, and so should be constructed of lightweight, frangible, durable material. Guide posts may be necessary in some locations to show a road route in heavy snow.

Chevron alignment markers (CAMs)

CAMs or 'chevrons' can be installed along the outside of a bend to provide drivers with a better view of the bend as they approach it, and to assist them in positioning the vehicle during the bend.

Warning signs and advisory speed signs

Warning signs inform drivers of the nature of a hazard they are approaching. Advisory signs, including advisory speed signs, tell drivers how to navigate the hazard safely. For example, hazardous bend signs placed on the approach to the bend can inform the driver of how the road alignment changes. Hazardous bend signs can be mounted above an advisory speed limit sign which states a safe speed for the bend.

Benefits | Implementation issues

- Road markings are among the most cost-effective treatments to make roads safer.
- Delineation improvements have been shown to reduce head-on and run-off road crashes.
- Helps drivers to maintain a safe and consistent lateral vehicle position within the lane.
- Reduction in nighttime and low-visibility crashes.
- Reduction in pavement deterioration due to vehicles driving onto the shoulder.

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iRAP gTKP

Related Images

Treatment Summary

Costs	Low
Treatment life	1 year - 5 years
Effectiveness	10-25%

References

- iRAP Road Attribute Risk Factors – Delineation.
- NSW Transport, Delineation Technical Manuals.
- NSW Transport, Enhanced Delineation Devices.
- Federal Highway Administration, Low Cost Treatments for Horizontal Curve Safety.
- Department for Transport, Energy and Infrastructure (South Australia), Pavement Marking Manual.
- Towards Safer Roads, p68-69 and p160-161.
- CaSE Highway Design Note 2/01 (DFID)
- Austroads - Safety publications
- Ogden, K. W. (1996) Safer Roads - A Guide to Road Safety Engineering. Avebury Technical, Ashgate Publishing Limited, Grower House, Croft Road, Aldershot, England.

Related Road Users

- Car Occupants
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Figure 5.20: "Improve Curve Delineation" Implementation and Effectiveness Information on the usRAP Website

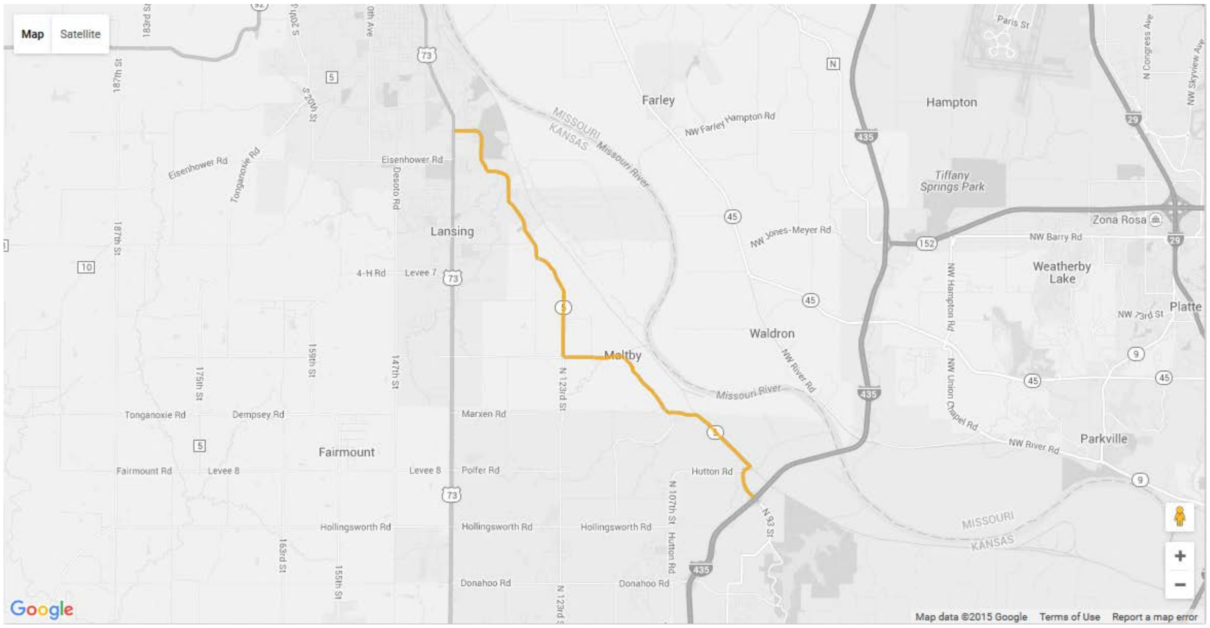

Figure 5.21: Predicted Star Ratings for K-5 for Vehicle Occupants after All Countermeasures were Implemented

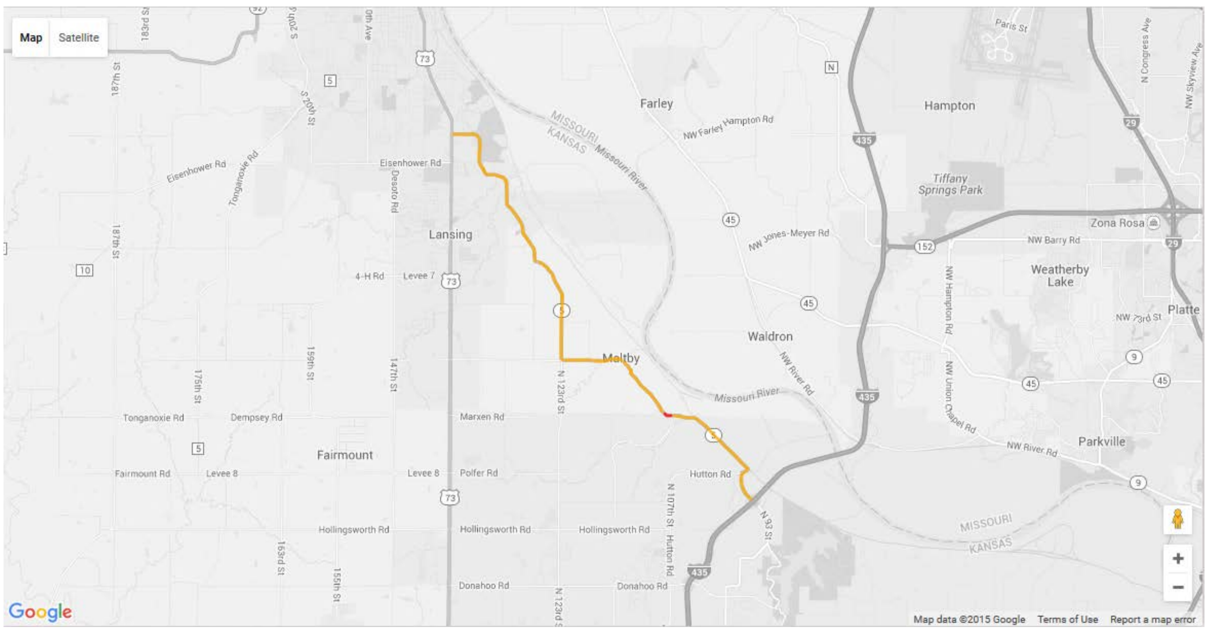

Figure 5.22: Predicted Star Ratings for K-5 for Motorcycles after All Countermeasures were Implemented

The usRAP software also provided star ratings for before and after countermeasure implementation, including roadway lengths and percentages. Table 5.8 provides before-and-after star ratings for vehicle occupants and motorcycles.

Table 5.8: Before-and-After Countermeasure Implementation Star Ratings, Lengths, and Percentages for Vehicle Occupants and Motorcycles for K-5

	Vehicle Occupants				Motorcycles			
	Before		After		Before		After	
	Length (km)	Percent	Length (km)	Percent	Length (km)	Percent	Length (km)	Percent
5 Stars	0.00	0%	0.00	0%	0.00	0%	0.00	0%
4 Stars	0.00	0%	0.00	0%	0.00	0%	0.00	0%
3 Stars	0.00	0%	**16.20**	**100%**	0.00	0%	**15.90**	**98%**
2 Stars	**11.00**	**68%**	0.00	0%	**11.00**	**68%**	**0.30**	**2%**
1 Star	**5.20**	**32%**	0.00	0%	**5.20**	**32%**	0.00	0%
N/A	0.00	0%	0.00	0%	0.00	0%	0.00	0%
Totals	**16.20**	**100%**	**16.20**	**100%**	**16.20**	**100%**	**16.20**	**100%**

As shown in Table 5.8, with countermeasure implementation K-5 would become almost an entirely 3-star rating roadway, with the exception of a 2-star location for motorcycles, which would be a significant improvement for the corridor considering the many unique geometric conditions the corridor currently contains. Before-and-after star rating information for pedestrians and bicycles were not included because it was predicted by the usRAP software that no changes in star ratings would occur even after all countermeasures were implemented.

5.5 RS 20 and RS 25 Outputs

Rural paved secondary roads RS 20 and RS 25 in Atchison County, KS, were selected for usRAP evaluation because KDOT had recently performed a practical road safety audit (RSA) (May 12, 2014) on RS 25 as part of the state's initiative to increase safety since the roadway had been identified as a High Risk Rural Road (HRRR). Figures 5.23 through 5.26 contain star ratings for RS 20 and RS 25 under current conditions for vehicle occupants, motorcycles, pedestrians, and bicycles, respectively.

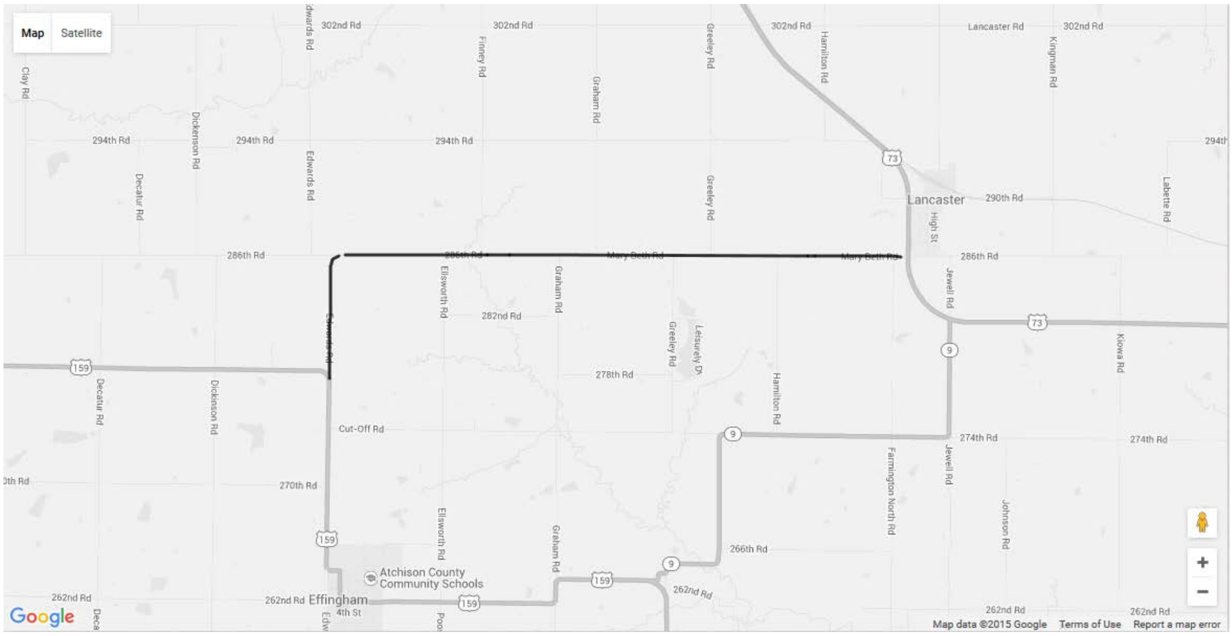

Figure 5.23: RS 20 and RS 25 Star Rating for Vehicle Occupants before Countermeasure Implementation

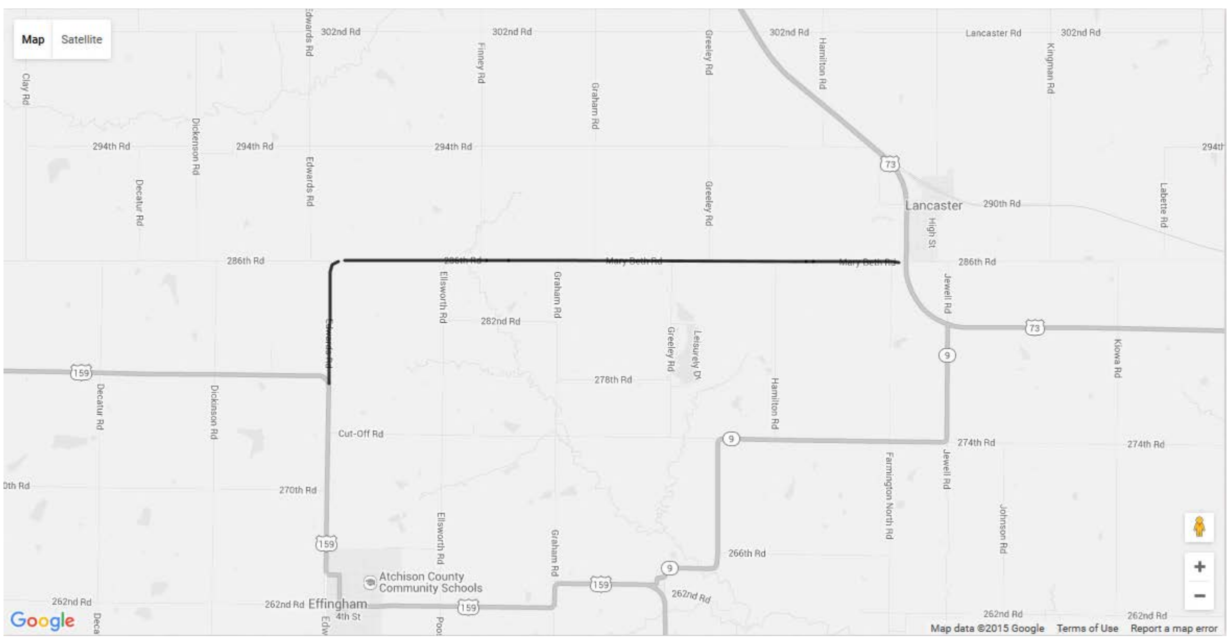

Figure 5.24: RS 20 and RS 25 Star Rating for Motorcycles before Countermeasure Implementation

As shown for vehicle occupants and motorcycles in Figures 5.23 and 5.24, respectively, the entire corridor had a 1-star rating based on coded variables the research team recorded from the manual data collection process. This star rating was expected, demonstrating a need for an RSA and a systemic tool to increase roadway safety. Figure 5.25 shows the 2-star rating for pedestrians along RS 20 and RS 25.

Figure 5.25: RS 20 and RS 25 Star Rating for Pedestrians before Countermeasure Implementation

Figure 5.25 shows two locations for potential pedestrians, including mailbox locations for private property with direct access to the roadway. However, Figure 5.26 shows no indication of bicyclists on the roadway; therefore, a star rating for bicyclists was not assigned to either roadway.

Figure 5.26: RS 20 and RS 25 Star Rating for Bicycles before Countermeasure Implementation

The length of each of star rating and the percentage of total roadway kilometers is shown in Table 5.9. For vehicle occupants and motorcycles, 9.80 km, or 100 percent of the total length, was a 1-star rating. For pedestrians, 0.40 km, or 4 percent of the total 9.80 km, had a 3-star rating, and for bicyclists, 9.80 km, or 100 percent of the roadway, was not applicable for bicycle travel or risk.

A list of countermeasures, which was determined by the usRAP software by the coded variables for RS 20 and RS 25, are listed in Table 5.10. As shown, the "improve curve delineation" countermeasure had the highest benefit-cost ratio of 14. This result was similar to K-5, which also had the highest benefit-cost ratio but zero fatal or serious injury crashes prevented over a 20-year period. The second and third countermeasures with the highest benefit-cost ratios of three and one fatal or serious injury crash prevented included the addition of roadside barriers on the passenger side and the driver side, respectively.

Table 5.11 shows overall program Safer Roads Investment Plan. If all recommended countermeasures and their locations were implemented, it was estimated that 12 fatal or serious injury crashes could be prevented over a 20-year period, with a benefit-cost ratio of 2, an implementation cost of $476,838, and a benefit of $1,065,768.

Table 5.9: RS 20 and RS 25 Star Ratings, Lengths, and Percentages for Vehicle Occupants, Motorcycles, Pedestrians, and Bicycles

	Vehicle Occupants		Motorcycles		Pedestrians		Bicyclists	
	Length (km)	Percent	Length (km)	Percent	Length (km)	Percent	Length (km)	Percent
5 Stars	0.00	0%	0.00	0%	0.00	0%	0.00	0%
4 Stars	0.00	0%	0.00	0%	0.00	0%	0.00	0%
3 Stars	0.00	0%	0.00	0%	0.00	0%	0.00	0%
2 Stars	0.00	0%	0.00	0%	0.40	4%	0.00	0%
1 Star	9.80	100%	9.80	100%	0.00	0%	0.00	0%
N/A	0.00	0%	0.00	0%	9.40	96%	9.80	100%
Totals	**9.80**	**100%**	**9.80**	**100%**	**9.80**	**100%**	**9.80**	**100%**

Table 5.10: Safer Roads Investment Plan for RS 20 and RS 25 (Recommended Countermeasures Analysis)

Countermeasure	Length/ Sites	FSIs Saved	Benefit ($)	Estimated Cost ($)	Cost per FSI Saved ($)	Program BCR
Improve curve delineation	0.20 km	0	42,409	3,023	22,781	14
Roadside barriers—passenger side	0.40 km	1	244,972	78,000	101,757	3
Roadside barriers—driver side	0.50 km	1	298,192	97,500	104,494	3
Improve delineation	8.00 km	1	386,701	241,842	199,867	2
Skid resistance (paved road)	0.40 km	0	93,494	5,676	193,036	2

Table 5.11: Program Safer Roads Investment Plan for RS 20 and RS 25 (Overall)

Total FSIs Saved	Total Benefits ($)	Estimated Costs ($)	Cost per FSI saved ($)	Program BCR
12	1,065,768	476,838	142,986	2

The research team investigated locations where the usRAP software recommended the variable “improve curve delineation,” including two locations at the only horizontal curve connecting RS 20 and RS 25, as shown in Figure 5.27.

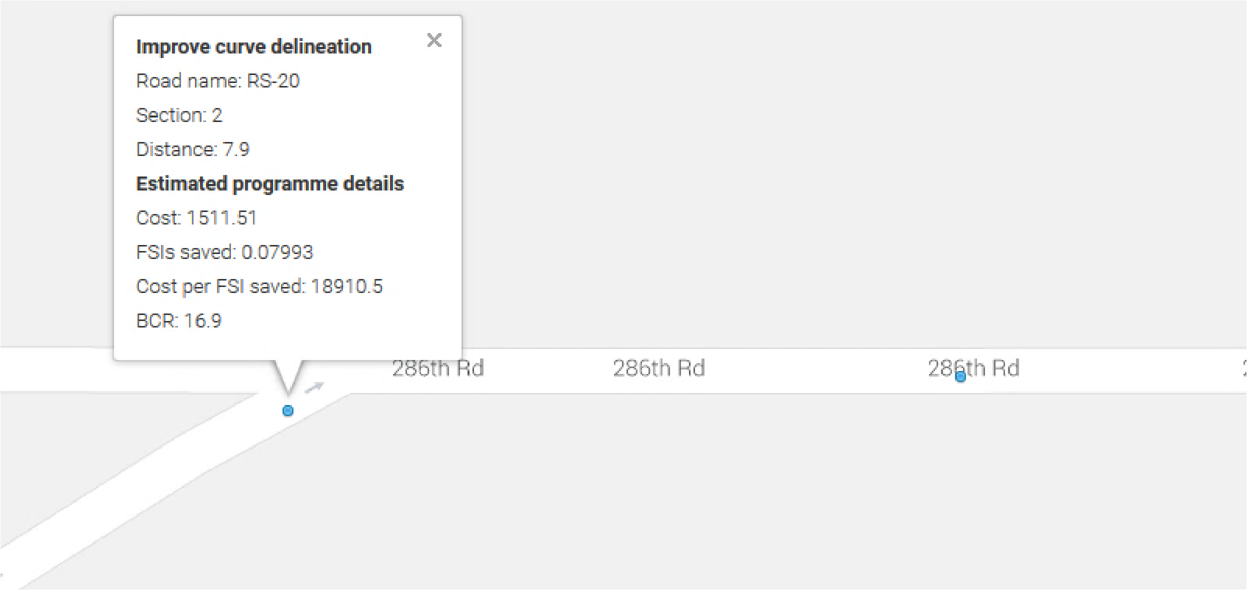

Figure 5.27: Recommended Locations of "Improve Curve Delineation" for RS 20 and RS 25

As shown in Figure 5.27, the two recommended locations were prior to the horizontal curve (advance warning) and within the curve. A third location in advance of the horizontal curve in the opposite direction (direction not coded) was also expected for the opposing direction of travel. The location selected to have the highest benefit-cost ratio was within the horizontal curve, which had a benefit-cost ratio of 16.9 and estimated cost of $1,511.51. Figure 5.28 shows the horizontal curve connecting RS 20 and RS 25.

Figure 5.28: Horizontal Curve (Westbound) Connecting RS 20 and RS 25

As shown in Figure 5.28, multiple horizontal curve countermeasures could be implemented to increase safety, including replacing various directional object markers with chevrons, adding pavement markings, increasing the superelevation, adding a gravel or paved shoulder, and adding advance warning to drivers. Similar to outputs of the previous two corridors, after-countermeasure star ratings were developed for RS 20 and RS 25 for vehicle occupants, motorcycles, and pedestrians, as shown in Figures 5.29 through 5.31.

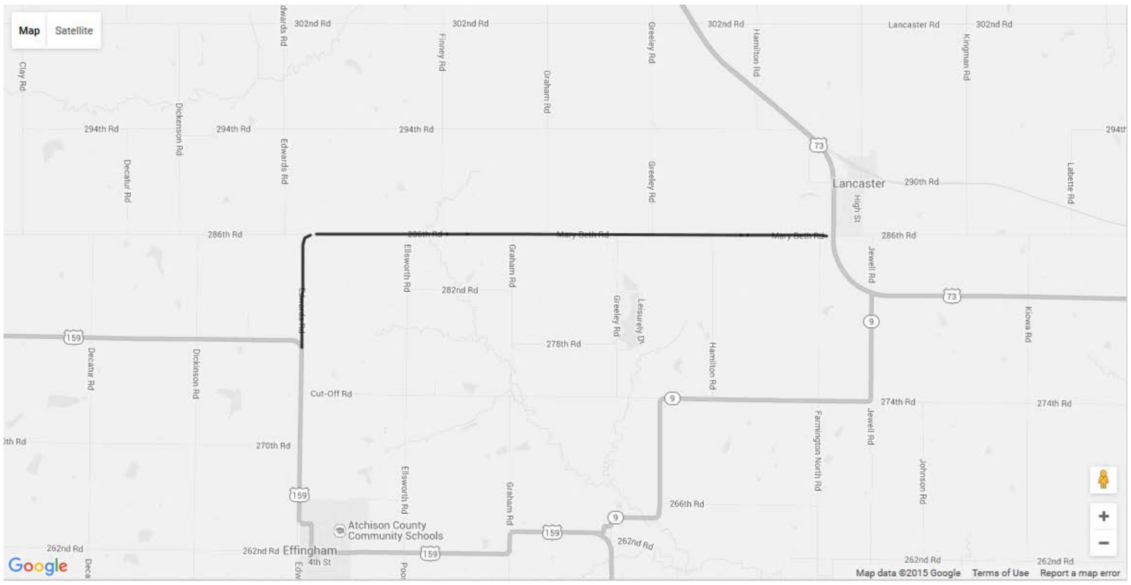

Figure 5.29: Predicted Star Ratings for RS 20 and RS 25 for Vehicle Occupants after All Countermeasures were Implemented

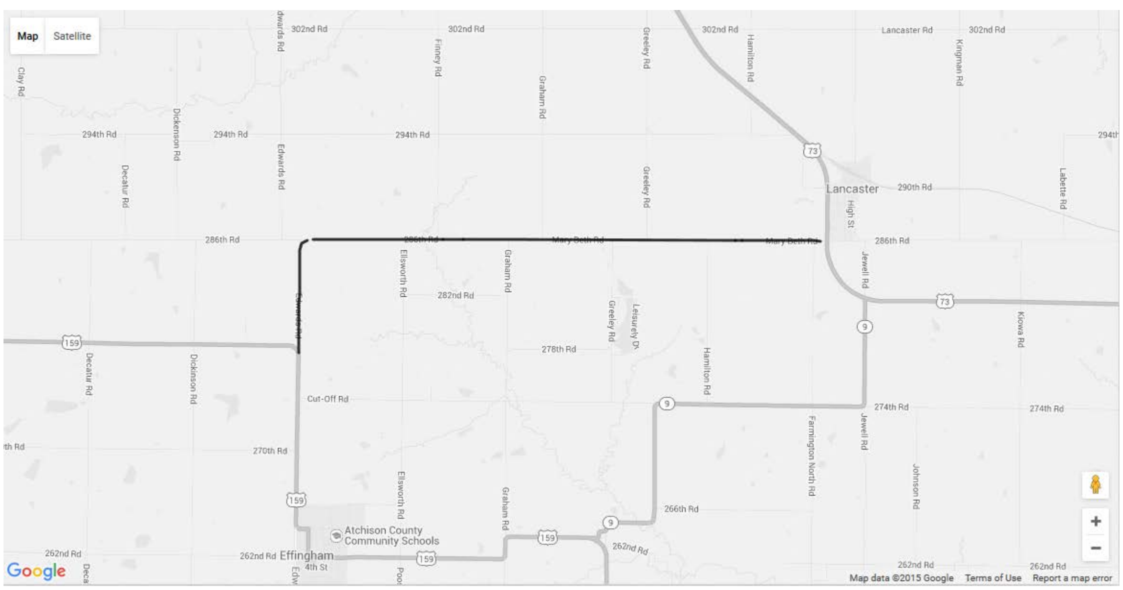

Figure 5.30: Predicted Star Ratings for RS 20 and RS 25 for Motorcycles after All Countermeasures were Implemented

Figure 5.31: Predicted Star Ratings for RS 20 and RS 25 for Pedestrians after All Countermeasures were Implemented

No change in star ratings were found for Figures 5.29 through 5.31 as confirmed in Table 5.12, which compares star ratings for vehicle occupants and motorcycles on RS 20 and RS 25.

Table 5.12: Before-and-After Countermeasure Implementation Star Ratings, Lengths, and Percentages for Vehicle Occupants and Motorcycles for RS 20 and RS 25

	Vehicle Occupants				Motorcycles			
	Before		After		Before		After	
	Length (km)	Percent	Length (km)	Percent	Length (km)	Percent	Length (km)	Percent
5 Stars	0.00	0%	0.00	0%	0.00	0%	0.00	0%
4 Stars	0.00	0%	0.00	0%	0.00	0%	0.00	0%
3 Stars	0.00	0%	0.00	0%	0.00	0%	0.00	0%
2 Stars	0.00	0%	0.00	0%	0.00	0%	0.00	0%
1 Star	**9.80**	**100%**	**9.80**	**100%**	**9.80**	**100%**	**9.80**	**100%**
N/A	0.00	0%	0.00	0%	0.00	0%	0.00	0%
Totals	**9.80**	**100%**	**9.80**	**100%**	**9.80**	**100%**	**9.80**	**100%**

However, Table 5.12 can be misleading based on presented results. Although the usRAP software provided countermeasures (Table 5.10) and program benefit-cost information (Table 5.11) and recommended countermeasures would increase roadway safety by reducing fatal and serious injury crashes, the roadway would need to be completely upgraded to the standards of a two-lane undivided highway or higher in order to enhance the star ratings.

5.6 Comparison of RSA to usRAP

On May 12, 2014, KDOT performed an RSA for RS 20 and RS 25. The seven-member team included representatives from KDOT, FHWA, Kansas Local Technical Assistance Program (LTAP), Atchison County, and a KDOT Area Engineer. The group identified locations of eight "issues," or locations of risk to the driver or infrastructure needing critical improvement as shown in Figure 5.32.

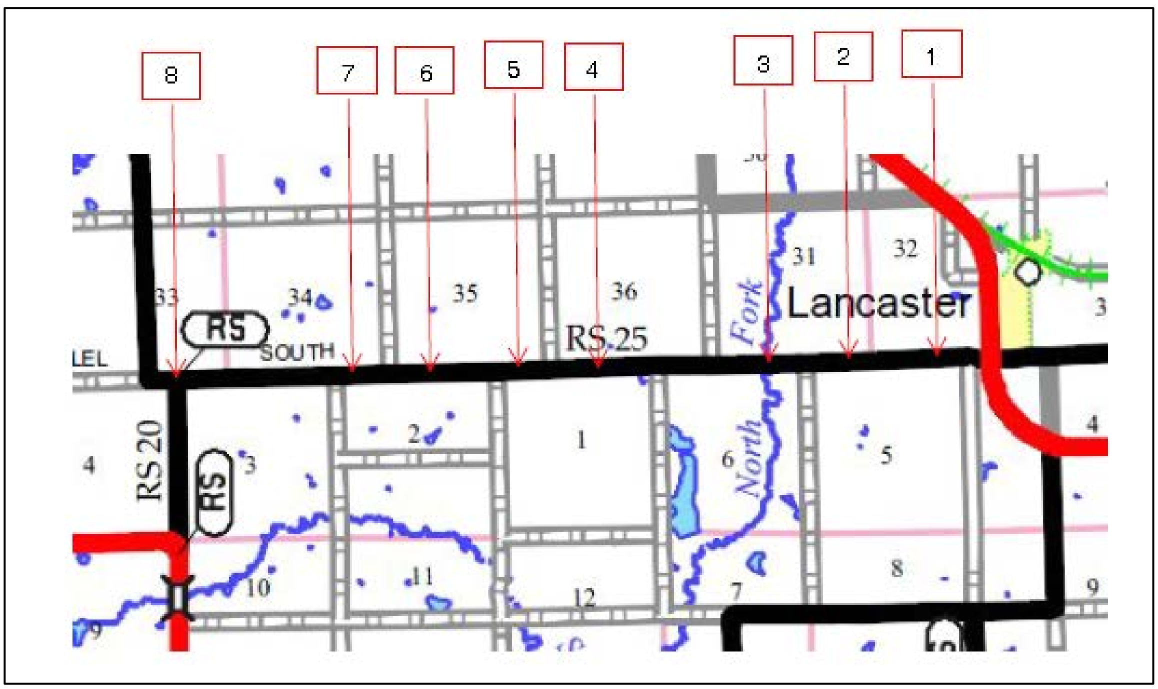

Figure 5.32: RS 25 Practical Road Safety Assessment Issue Locations

The following issues were identified for each location:

- Object marker located on one side of the road and culvert headwall close to roadway edge.
- Brush pile in the right-of-way and culvert ends and hazardous sideslopes within the clear zone.

- Culvert headwalls located 3–4 ft from the edge of the pavement, culvert rail missing, evidence of a vehicle hitting the hubguard on the culvert.
- Concrete pipe with a polyethylene pipe as a liner, sign knocked over, and steel sideslopes.
- Failed wingwall of culvert and undercutting at roadway edge.
- Steep sideslopes with heights from the roadway to the streambed between 6 and 15 ft.
- Bridge rail separated from the bridge and rusted and damaged object markers.
- Low-speed horizontal curve with reported fatality 12 years ago.

As shown in Table 5.10, the usRAP software identified similar concerns as a result of the RSA, including curve delineation (#8 on the RSA) and also "roadside barriers—passenger" and "driver" side (#1, #3, #5, and #7 on the RSA). However, the usRAP software and coders could not evaluate specific issues on the RSA, including issues involving wingwalls, culverts, and pipes, because the field of view did not allow evaluation. The research team concluded that the usRAP software similarly identified locations of concern or risk, and recommended countermeasures for many of the issues that the RSA identified based on visual inspection at the roadway site by safety professionals.

Chapter 6: Findings and Recommendations

6.1 Discussion of usRAP for Highway Safety in Kansas

Understanding the safety risks of rural highways in Kansas is critical since a significant percentage of the roadways are rural centerline miles. However, allocation of safety funding and implementation of appropriate safety countermeasures on rural roadways can be difficult due to limited data, limited expertise, and sometimes-unknown areas that pose a significant risk to drivers. A systemic tool that utilizes often limited information (specifically historical crashes) to identify risky areas or mass-action areas can greatly benefit a local jurisdiction and the State of Kansas if even one life is saved or one serious injury is prevented. Although many tools are currently available to highway safety engineers as described in the literature review, the research team selected usRAP, a program based on the iRAP, to demonstrate the capabilities in identifying areas of risk on two-lane roadways and to determine its effectiveness and further deployment for KDOT and Kansas counties.

The research team selected three corridors to test the usRAP software. US-40 between Topeka, KS, and Lawrence, KS, was chosen because it carries a considerable amount of commuter traffic. K-5 was selected because of its many horizontal curves, blind driveways, and sudden changes in vertical alignment, and because it is a well-known route between the Kansas City metropolitan area and Lansing, KS. Finally, RS 20 and RS 25 were selected for evaluation because both corridors are paved rural secondary roadways connected by a horizontal curve in Atchison County, KS.

The usRAP is a free software program that requires extensive data inputting based on Google Street View or manual data collection at every 100-m segment. Corridor baseline data is needed for system calibration (type of highway or roadway) including: AADT, posted and 85th percentile speed, system-wide centerline miles for each roadway type, system-wide historical crash analysis for types of transportation modes (vehicles, motorcycles, pedestrians, bicyclists), and typical Kansas countermeasure costs. One significant advantage of the usRAP program is that it does not require historical crash data for the road segment or corridor of interest. The usRAP software analysis is based on risky roadway characteristics, or characteristics directly related to crash experience.

The usRAP software outputs provide valuable information that can be easily interpreted for most levels of roadway design and/or supervision. Outputs include a star ranking for the corridor every 100 m, a table that provides a percentage of the roadway in each star ranking, countermeasure recommendation that includes location and expected benefit-cost ratio over a 20-year period, a program benefit-cost ratio (if all suggested countermeasures were implemented) over a 20-year period, the number of fatal and serious injuries prevented over a 20-year period for each countermeasure and the entire program, and star ratings for the corridor if all countermeasures were implemented. However, the software is not designed to replace a required engineering study before implementation of any major roadway countermeasure or geometric change. Rather, usRAP software output identifies potentially risky areas of a corridor to help guide a transportation study.

Star ratings developed for US-40 and K-5 found that none of the roadways were considered a 4-star or 5-star roadway. This made sense because these roadways were not interstates or divided highways where design standards included the highest safety benefits for high speeds and also standard safety countermeasures (large clear zones, wide medians, and paved shoulders). The three corridors also exhibited vast differences in horizontal and vertical alignments, in which these two-lane undivided roadways were narrow and many times had cluttered clear zones with fixed objects. Additionally, there were many private property driveways having direct access to the roadway and sometimes these were hidden. The lower star rating was also found for other mode analyses, including motorcycles, pedestrians, and bicycles where these roadways were not designed for these types of facilities.

The usRAP software provided a list of recommended countermeasures for each corridor based on inputted calibration data and coded data from visual inspection of the roadway. A common countermeasure in each corridor included clearing the roadside of hazards on both sides. Additionally, adding or enhancing curve delineation was another prominently recommended countermeasure. These countermeasures had a high benefit-cost ratio and were expected recommendations based on the roadway types that were investigated in this study.

In addition to the list of recommended countermeasures, the usRAP software also determined where the countermeasure should be implemented, as well as individual benefit-cost ratios. The usRAP software benefits counties with limited resources to invest in a countermeasure because it narrows down the location of countermeasure implementation and reduces time, money, and initial investigations for required engineering studies.

Finally, the usRAP software predicted a star rating for each corridor if all countermeasures were implemented. Although substantial improvement was predicted for US-40 and K-5 (higher volumes), RS 20 and RS 25 were predicted to remain constant because a full reconstruction was needed to upgrade the corridor to a two-lane undivided highway or in order to obtain significant overall safety improvement. For example, an investment in curve delineation at the connection of RS 20 and RS 25 may not improve the overall star rating, but it could save a life or prevent a serious injury.

6.2 usRAP Implementation Strategy for KDOT and Kansas Counties

As stated earlier, the usRAP program does not replace traditional highway safety engineering approaches such as road safety assessments and engineering studies. The usRAP program is designed to be a high-level planning tool to identify potentially risky locations based on calibration data, coded data, and often data that is not available for rural low-volume roadways.

The usRAP program would be a valuable tool for Kansas in mass deployment county by county. Although this research study evaluated only three corridors, utilization of the usRAP software would allow evaluation of an entire roadway network in a county. With a roadway database created for each county, mass-action areas, such as horizontal curves, could be identified. By identifying all horizontal curves in the usRAP roadway database, the usRAP software will determine locations requiring a countermeasure and then identify the location with the lowest star rating and highest potential benefit-cost ratio, resulting in an engineering study for countermeasure investment. The research team recommends the usRAP program to KDOT on a county-by-county basis and in conjunction with traditional road safety assessments in order to reduce fatal and serious injury crashes in rural areas.

6.3 Advantages and Disadvantages of usRAP for Kansas Counties

On October 6, 2015, the research team met with Mr. Norm Bowers of the Kansas Association of Counties in Topeka, KS. As part of this project, the research team wanted to solicit input from a former county engineer with experience working on the state highway system, who is an advocate for safer roads. The research team presented Mr. Bowers with an overview of the research project, the corridors selected for evaluation, and the coding methodology using the usRAP software. Additionally, the usRAP output was presented, including the star ratings, proposed countermeasures and locations for installation, and benefit-cost ratios. Mr. Bowers proposed the following questions, and the research team provided the following answers:

1. *What is the cost of usRAP to the counties?* The usRAP is free to counties to view once the data has been coded for a specified roadway network or corridor.
2. *Can county representatives adjust or input data into usRAP?* County representatives (engineers or road supervisors) have read-only access to the website and countermeasure information; however, coding and initial adjustments can only be accessed and modified by the research team, KDOT, or the project sponsor.
3. *Is crash data needed?* Crash data are not needed for usRAP. Four years of crash data were extracted from the KDOT database, including specific crashes for all Kansas highways, US highways, and rural secondary roads. Because usRAP is a planning tool, it predicts locations where crashes could occur based on coded roadway variables.

Overall, the meeting with Mr. Bowers provided an opportunity to present a systemic safety tool that could aid Kansas counties. After showing results of the corridor evaluation to Mr. Bowers, the research team noted that a visualization of safety risks in a Google Maps environment could increase understanding of the results and ease of use for the user.

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Appendix A: Countermeasure Costs

Shown in Table A.1 are the low, medium, and high countermeasure costs used for this research study. The research team validated the price of each countermeasure through projects recently completed by KDOT, RSAP software, and vendor information. The countermeasures highlighted in blue were ones that the research team adjusted the unit cost.

Table A.1: Countermeasure Costs for Rural Roadways

Countermeasure	C'way Code	Unit of Cost	Service Life (years)	Rural-Low Upgrade Cost	Rural-Medium Upgrade Cost	Rural-High Upgrade Cost
Improve delineation	i	lane mi	5	9410	12550	15690
Bicycle lane (on-road)	i	per mi	20	18830	25100	31380
Bicycle lane (off-road)	i	per mi	20	188250	251000	376510
Horizontal realignment	i	lane mi	20	251000	502010	753010
Improve curve delineation	i	per carriageway mi	5	9410	12550	15690
Lane widening (up to 1.5 ft)	i	lane mi	10	5020	100400	150600
Lane widening (>1.5 ft)	i	lane mi	10	125500	251000	376510
Protected turn lane (unsignalized 3 leg)	m	intersection	10	75000	112500	150000
Protected turn lane (unsignalized 4 leg)	m	intersection	10	75000	112500	150000
Delineation and signing (intersection)	m	intersection	5	5850	7800	9750
Protected turn provision at existing signalized site (3-leg)	m	intersection	10	75000	112500	150000
Protected turn provision at existing signalized site (4-leg)	m	intersection	10	75000	112500	150000
Signalize intersection (3-leg)	m	intersection	20	130000	150000	170000
Signalize intersection (4-leg)	m	intersection	20	200000	220000	240000

Replace intersection with grade separation	m	intersection	20	7800000	11700000	15600000
Rail crossing upgrade	m	unit	20	78000	109200	140400
Roundabout	m	intersection	20	3000000	3500000	4000000
Central hatching	u	per mi	10	12550	15690	18830
Centerline rumble strip / flexi-post	u	per mi	10	37650	50200	62750
Central turning lane (TWLTL)	m	per mi	10	188250	282380	37650
Central median barrier (undivided highway)	m	per mi	10	313760	407880	502010
Convert to divided highway with median barrier	u	per carriageway mi	20	1506020	3012050	4518070
Convert to divided highway - <3 ft median	u	per carriageway mi	20	112950	2259040	3388550
Convert to divided highway - 3 to 15 ft median	u	per carriageway mi	20	1506020	3012050	4518070
Convert to divided highway - 15 to 30 ft median median	u	per carriageway mi	20	1882530	3765060	5647590
Convert to divided highway - 30 to 65 ft median median	u	per carriageway mi	20	2259040	4518070	6777110
Convert to divided highway - >65 ft median	u	per carriageway mi	20	2635540	5271080	7906630
Add service road/frontage road	i	per mi	20	2635540	5271080	7906630
Additional lane (2 + 1 road with barrier)	i	per mi	20	502010	1004020	1506020
Implement one-way network	u	per carriageway mi	20	627510	941270	1255020
Upgrade pedestrian facility quality	i	unit	10	11700	23400	35100
Provide refuge Island for pedestrians	m	unit	10	7800	23400	39000
Unsignalized pedestrian crossing	m	unit	10	62400	78000	93600
Signalized pedestrian crossing	m	unit	20	60000	67500	75000
Grade separated pedestrian facility	m	unit	20	234000	468000	702000
Road surface rehabilitation	i	lane mi	10	12070	13520	15450
Clear roadside obstacles - right side	i	per linear mi	20	12550	25100	37650
Clear roadside obstacles - left side	i	per linear mi	20	12550	25100	37650

Sideslope improvement - right side	i	per linear mi	20	94130	188250	282380
Sideslope improvement - left side	i	per linear mi	20	94130	179730	282380
Roadside barriers - right side	i	per linear mi	20	313760	407880	502010
Roadside barriers - left side	i	per linear mi	20	313760	407880	502010
Shoulder paving right side (<3 ft)	i	per linear mi	20	62750	125500	188250
Shoulder paving right side (>3 ft)	i	per linear mi	20	125500	299270	376510
Restrict/combine direct access points	i	per mi	10	31380	62750	94130
Sidewalk provision right side (adjacent to road)	i	per linear mi	20	230760	288860	404500
Sidewalk provision right side (>10 ft from road)	i	per linear mi	20	245110	306380	428940
Traffic calming	i	per carriageway mi	10	37650	75300	112950
Vertical realignment (major)	i	lane mi	20	941270	1882530	2823800
Passing lane	i	per linear mi	20	627510	1255020	1882530
Median crossing upgrade	m	intersection	10	39000	97500	156000
Clear roadside obstacles (bike lane)	i	per mi	20	12550	25100	37650
Sideslope improvement (bike lane)	i	per mi	20	104590	209170	313760
Roadside barriers (bike lane)	i	per mi	20	313760	407880	502010
Skid resistance (paved road)	i	lane mi	10	75300	131780	196940
Skid resistance (unpaved road)	i	per carriageway mi	10	43750	54680	76560
Pave road surface (existing unpaved road)	i	lane mi	10	75300	131780	196940
Street lighting (midblock)	i	lane mi	20	200000	400000	600000
Street lighting (intersection)	i	intersection	20	50000	75000	100000
Street lighting (pedestrian crossing)	i	unit	20	64751	72606	88315
Shoulder rumble strips	i	per carriageway mi	10	75300	100400	125500
Parking improvements	i	per carriageway mi	20	31380	62750	94130
Sight distance (obstruction removal)	i	per linear mi	20	41590	52390	72920

Pedestrian fencing	i	per carriageway mi	20	252020	368660	548300
Side road grade separated pedestrian facility	i	intersection	20	3354000	5031000	6708000
Side road signalized pedestrian crossing	i	intersection	20	15600	31200	46800
Side road unsignalized pedestrian crossing	i	intersection	10	62400	78000	93600
Sidewalk provision right side (with barrier)	i	per linear mi	20	657030	821280	1109570
Sidewalk provision right side (informal path >3 ft)	i	per linear mi	10	209820	262680	367860
Shoulder paving left side (<3 ft)	i	per linear mi	20	62750	125500	188250
Shoulder paving left side (>3 ft)	i	per linear mi	20	125500	299270	376510
Sidewalk provision left side (adjacent to road)	i	per linear mi	20	37650	75300	112950
Sidewalk provision left side (>10 ft from road)	i	per linear mi	20	188250	251000	376510
Sidewalk provision left side (with barrier)	i	per linear mi	20	150380	247410	348200
Sidewalk provision left side (informal path >3 ft)	i	per linear mi	10	75170	108940	142720
Realignment (sight distance improvement)	i	lane mi	20	150600	451810	753010
Central median barrier (1+1)	u	per mi	20	313760	407880	502010
Wide centerline	u	per linear mi	20	9410	12550	15690
School zone warning - signs and markings	i	lane mi	5	15100	16300	16300
School zone warning - flashing beacon	i	unit	20	19425	21782	26494
School zone - crossing guard or supervisor	m	unit	1	18767	20260	20260

Appendix B: Roadway Inventories

Table B.1: Detailed Road Conditions US-40: Roadside

Roadside severity - driver-side distance	km	%
0 to <1 m	0.80	3
1 to <5 m	7.10	26
5 to <10 m	9.00	33
> = 10 m	10.60	39
Roadside severity - driver-side object		
Safety barrier - metal	0.60	2
Safety barrier - concrete	0.10	0
Aggressive vertical face	0.10	0
Upwards slope - rollover gradient	0.90	3
Deep drainage ditch	1.00	4
Downwards slope	1.70	6
Tree > = 10 cm dia.	14.00	51
Sign, post, or pole > = 10 cm dia.	3.20	12
Semirigid structure or building	0.10	0
Unprotected safety barrier	0.80	3
None	5.00	18
Roadside severity - passenger-side distance		
0 to <1 m	0.70	3
1 to <5 m	8.00	29
5 to <10 m	9.40	34
> = 10 m	9.40	34
Roadside severity - passenger-side object		
Safety barrier - metal	0.80	3
Safety barrier - concrete	0.10	0
Upwards slope - rollover gradient	1.30	5
Deep drainage ditch	0.50	2
Downwards slope	1.10	4
Tree > = 10 cm dia.	10.10	37
Sign, post, or pole > = 10 cm dia.	8.90	32
Rigid structure/bridge or building	0.30	1
Semirigid structure or building	0.10	0
Unprotected safety barrier	0.20	1
Large boulders > = 20 cm high	0.10	0
None	4.00	15
Shoulder rumble strips		
Not present	27.00	98
Present	0.50	2
Paved shoulder - driver-side		
Wide (> = 2.4 m)	0.20	1
Medium (> = 1.0 m to < 2.4 m)	2.60	9
Narrow (> = 0 m to < 1.0 m)	0.70	3
None	24.00	87
Paved shoulder - passenger-side		
Wide (> = 2.4 m)	0.20	1
Medium (> = 1.0 m to < 2.4 m)	2.60	9
Narrow (> = 0 m to < 1.0 m)	1.30	5
None	23.40	85

Table B.2: Detailed Road Conditions US-40: Mid-block

Carriageway label	**km**	**%**
Undivided road	27.50	100
Upgrade cost		
Low	25.20	92
Medium	0.90	3
High	1.40	5
Median type		
Physical median width > = 1.0 m to < 5.0 m	0.30	1
Central hatching (>1 m)	0.70	3
Centerline	26.50	96
Centerline rumble strips		
Not present	10.40	38
Present	17.10	62
Number of lanes		
One	29.50	96
Two	0.80	3
Two and one	0.20	1
Lane width		
Wide (> = 3.25 m)	27.50	100
Curvature		
Straight or gently curving	22.20	81
Moderate	5.30	19
Quality of curve		
Adequate	5.30	19
Not applicable	22.20	81
Grade		
> = 0% to < 7.5%	27.50	100
Road condition		
Good	27.50	100
Skid resistance/grip		
Sealed - adequate	27.50	100
Delineation		
Adequate	27.50	100
Street lighting		
Not present	27.20	99
Present	0.30	1
Vehicle parking		
Low	27.50	100
Service road		
Not present	27.50	100
Roadworks		
No road works	27.50	100
Sight distance		
Adequate	27.50	100

Table B.3: Detailed Road Conditions US-40: Intersections

Intersection type	Points	%
3-legged (unsignalized) with protected turn lane	5	2
3-legged (unsignalized) with no protected turn lane	26	9
4-legged (unsignalized) with protected turn lane	1	0
4-legged (unsignalized) with no protected turn lane	5	2
None	238	87
Intersecting road volume		
5,000 to 10,000 vehicles	2	1
1,000 to 5,000 vehicles	3	1
100 to 1,000 vehicles	7	3
1 to 100 vehicles	25	8
None	238	87
Intersection channelization		
Not present	274	100
Present	1	0
Intersection quality		
Adequate	35	13
Poor	2	1
Not applicable	238	87
Property access points	**km**	**%**
Commercial access 1+	1.20	4
Residential access 3+	1.30	5
Residential access 1 or 2	9.20	33
None	15.80	57

Table B.4: Detailed Road Conditions K-5: Roadside

Roadside severity - driver-side distance	km	%
0 to <1 m	0.80	5
1 to <5 m	11.90	73
5 to <10 m	1.90	12
> = 10 m	1.60	10
Roadside severity - driver-side object		
Safety barrier - metal	0.60	4
Safety barrier - concrete	0.10	1
Aggressive vertical face	0.30	2
Upwards slope - rollover gradient	0.70	4
Upwards slope - no rollover gradient	0.50	3
Deep drainage ditch	0.30	2
Downwards slope	0.90	6
Tree > = 10 cm dia.	6.50	40
Sign, post or pole > = 10 cm dia.	4.80	30
Rigid structure/bridge or building	0.20	1
Semirigid structure or building	0.20	1
Unprotected safety barrier	0.30	2
Large boulders > = 20 cm high	0.10	1
None	0.70	4
Roadside severity - passenger-side distance		
0 to <1 m	1.00	6
1 to <5 m	9.50	59
5 to <10 m	3.10	19
> = 10 m	2.60	16
Roadside severity - passenger-side object		
Safety barrier - metal	1.00	6
Safety barrier - concrete	0.10	1
Aggressive vertical face	0.10	1
Upwards slope - rollover gradient	1.90	12
Upwards slope - no rollover gradient	0.10	1
Deep drainage ditch	0.10	1
Downwards slope	1.20	7
Tree > = 10 cm dia.	5.70	35
Sign, post, or pole > = 10 cm dia.	4.00	25
Rigid structure/bridge or building	0.20	1
Semirigid structure or building	0.60	4
Unprotected safety barrier	0.20	1
Large boulders > = 20 cm high	0.10	1
None	0.90	6
Shoulder rumble strips		
Not present	16.20	100
Paved shoulder - driver-side		
Medium (> = 1.0 m to < 2.4 m)	0.90	6
Narrow (> = 0 m to < 1.0 m)	0.20	1
None	15.10	93
Paved shoulder - passenger-side		
Medium (> = 1.0 m to < 2.4 m)	1.10	7
Narrow (> = 0 m to < 1.0 m)	0.20	1
None	14.90	92

Table B.5: Detailed Road Conditions K-5: Mid-Block

Carriageway label	km	%
Undivided road	16.20	100
Upgrade cost		
Low	9.90	61
Medium	5.40	33
High	0.90	6
Median type		
Physical median width > = 5.0 m to < 10.0 m	0.40	2
Physical median width > = 1.0 m to < 5.0 m	0.10	1
Centerline	15.70	97
Centerline rumble strips		
Not present	16.20	100
Number of lanes		
One	16.00	99
Two	0.20	1
Lane width		
Wide (> = 3.25 m)	1.20	7
Medium (> = 2.75 m to <3.25 m)	15.00	93
Curvature		
Straight or gently curving	12.20	75
Moderate	1.50	9
Sharp	2.40	15
Very Sharp	0.10	1
Quality of curve		
Adequate	3.60	22
Poor	0.40	2
Not applicable	12.20	75
Grade		
> = 0% to < 7.5%	16.20	100
Road condition		
Good	16.20	100
Skid resistance/grip		
Sealed - adequate	16.20	100
Delineation		
Adequate	27.50	100
Street lighting		
Not present	15.50	96
Present	0.70	4
Vehicle parking		
Low	16.20	100
Service road		
Not present	16.20	100
Roadworks		
No road works	16.20	100
Sight distance		
Adequate	16.20	100

Table B.6: Detailed Road Conditions K-5:Intersections

Intersection type	Points	%
3-legged (unsignalized) with protected turn lane	21	13
4-legged (unsignalized) with protected turn lane	1	1
4-legged (unsignalized) with no protected turn lane	2	1
4-legged (signalized) with protected turn lane	3	2
None	135	83
Intersecting road volume		
5,000 to 10,000 vehicles	2	1
1,000 to 5,000 vehicles	3	2
100 to 1,000 vehicles	16	10
1 to 100 vehicles	6	4
None	135	83
Intersection channelization		
Not present	160	99
Present	2	1
Intersection quality		
Adequate	25	15
Poor	2	1
Not applicable	135	83
Property access points	km	%
Commercial access 1+	1.20	7
Residential access 3+	1.80	11
Residential access 1 or 2	3.80	23
None	9.40	58

Table B.7: Detailed Road Conditions RS 20 and 25: Roadside

Roadside severity - driver-side distance	km	%
0 to <1 m	0.50	5
1 to <5 m	9.20	94
5 to <10 m	0.10	1
Roadside severity - driver-side object		
Upwards slope - rollover gradient	0.10	1
Deep drainage ditch	0.10	1
Downwards slope	0.10	1
Cliff	0.30	3
Tree > = 10 cm dia.	0.20	2
Sign, post, or pole > = 10 cm dia.	8.90	91
Unprotected safety barrier end	0.10	1
Roadside severity - passenger-side distance		
0 to <1 m	0.50	5
1 to <5 m	4.90	50
5 to <10 m	2.70	28
> = 10 m	1.70	17
Roadside severity - passenger-side object		
Upwards slope - rollover gradient	0.30	3
Deep drainage ditch	4.30	44
Downwards slope	0.10	1
Cliff	0.30	3
Tree > = 10 cm dia.	0.70	7
Sign, post, or pole > = 10 cm dia.	2.30	23
Unprotected safety barrier end	0.10	1
None	1.70	17
Shoulder rumble strips		
Not present	9.80	100
Paved shoulder - driver-side		
None	9.80	100
Paved shoulder - passenger-side		
None	9.80	100

Table B.8: Detailed Road Conditions RS 20 and 25: Mid-block

Carriageway Label	km	%
Undivided road	9.80	100
Upgrade cost		
Low	9.80	100
Median type		
Centerline	9.80	100
Centerline rumble strips		
Not present	9.80	100
Number of lanes		
One	9.80	100
Lane width		
Medium (> = 2.75 m to <3.25 m)	9.80	100
Curvature		
Straight or gently curving	9.60	98
Sharp	0.20	2
Quality of curve		
Poor	0.20	2
Not applicable	9.60	75
Grade		
> = 0% to < 7.5%	9.80	100
Road condition		
Medium	9.80	100
Skid resistance/grip		
Sealed - medium	9.80	100
Delineation		
Poor	9.80	100
Street lighting		
Not present	9.80	100
Vehicle parking		
Low	9.80	100
Service road		
Not present	9.80	100
Roadworks		
No road works	9.80	100
Sight distance		
Adequate	9.80	100

Table B.9: Detailed Road Conditions RS 20 and 25: Intersections

Intersection type	Points	%
3-legged (unsignalized) with protected turn lane	11	11
None	87	89
Intersecting road volume		
1,000 to 5,000 vehicles	1	1
1 to 100 vehicles	10	10
None	87	89
Intersection channelization		
Not present	98	100
Intersection quality		
Adequate	11	11
Not applicable	87	89
Property access points	**km**	**%**
Residential access 1 or 2	1.10	11
None	8.70	89

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