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Systematic Safety Improvement Risk Factor Evaluation and Countermeasure Summary

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Final Report

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16. Abstract

The majority of crash fatalities in the United States occur along rural roadways. These roadways typically have low volumes and widespread crashes. In other words, no one location generally has an unexpectedly high number of crashes. Systemic safety tools/methodologies can be used in this type of situation because they evaluate and prioritize expected crash risk through the consideration of regional data patterns, research results, and engineering judgment. This project investigated two systemic safety tools/methodologies: the approach followed to produce Minnesota county road safety plans (and now described in the FHWA *Systemic Safety Project Selection Tool*) and usRAP. Both tools/methodologies were applied with data collected from two counties in Iowa and a sensitivity analyses completed on their results. It was concluded that changing the "weight" of the safety risk factors considered as part of Minnesota approach could have an impact on some of the locations in the "top 20" of the rankings and subsequent decision-making. However, the amount of that impact varied and a correlation analysis of the original and alternative rankings developed found a statistically insignificant difference. The change in acceptable benefit-cost ratio for the application of usRAP showed that it impacted the type and number of countermeasures, along with the benefit-cost ratio of the plan suggested by the software. It is recommended that additional research be completed to consider similar input variable changes on transportation systems with a higher level of variability in their characteristics.

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EXECUTIVE SUMMARY

The majority of the crash fatalities in the United States occur along rural roadways. However, the severe and majority injury crashes that occur on the rural roadway system are typically very widespread. In other words, there are very few traditional "hot spots" for these type of crashes. Systemic safety was introduced to address this situation. Systemic safety tools/methodologies generally use system-wide, regional, and local crash data; the current state-of-knowledge on relationships between roadway characteristics and severe crashes; and/or, engineering judgment to proactively identify and prioritize locations that may be at a higher "risk" for crashes. Unfortunately, very little research has been completed that investigates the impacts on the results of systemic safety tools/methodologies due to the changes in decisions made during their application. In addition, almost all the knowledge available about systemic safety is focused on paved roadway applications. This research project was completed to address some of this gap in the knowledge. Two systemic safety tools/methodologies were applied as part of this project, and a sensitivity analysis completed on their results due to changes in one or more of their input variables. A focus group that discussed potential safety risk factors for unpaved roadways was also convened.

The first task completed as part of this research project was a literature review of systemic safety tool and methodology documentation. The processes and approaches used by five systemic safety tools or methodologies were investigated. These tools/methodologies included the Minnesota County Road Safety Plan (CRSP) approach, the Federal Highway Administration (FHWA) Systemic Safety Project Selection Tool, United States Road Assessment Program (usRAP), the New Jersey systemic road safety tool, and the SafetyAnalyst™. Each of these tools or methodologies attempts to proactively identify and prioritize locations by estimating safety "risk". These five tools/methodologies were summarized and then compared through the consideration of five attributes. These attributes included general availability (e.g., cost, etc.), required input data, ease of use, basis of prioritization, and then potential to provide sensitivity analysis insight. In general, it was clear that data collection requirements and cost of these tools/methodologies varied widely. All of them, however, used "stars" (i.e., number of safety risk factors) and/or benefit-cost ratios used for the prioritization of locations. Most of the tools or methodologies evaluated, however, were relatively easy to apply and seemed likely to provide some insight if they were evaluated with a sensitivity analysis. A summary comparison matrix was used to select the Minnesota CRSP and usRAP approaches for further evaluation in this research project.

The second task completed as part of this research project was the data collection needed for the application of the Minnesota CRSP and usRAP approaches. Data were collected for 353 miles of paved secondary (i.e., county) roadway within two counties in Iowa. The data collected at the regional and county level to define the criteria for some of the safety risk factors used in the Minnesota CRSP approach. In addition, data were also collected at approximately 80 horizontal curves, 50 stop-controlled intersections, and 58 roadway segments in each county. These data were then compared to safety risk factor criteria and the number of criteria met at each location were recorded. Overall, there were five safety risk factors considered at each horizontal curve, seven at each stop-controlled intersection, and five at each roadway segment. The locations were then ranked by the number safety risk factors they met, and rules set to determine the rank of

those locations with the same amount. Finally, to apply the usRAP methodology data were collected that described 40 to 50 roadway characteristics for every 328 foot segment within the database.

A focus group that identified potential safety risk factors for unpaved roadways was also held as part of this project. Approximately 20 people attended that identified 24 potential safety risk factors for unpaved roadways. The factors that they suggested were related to the environment, roadway design or infrastructure, driver behavior and education, and roadway maintenance. In general, there were many potential safety risk factors suggested for unpaved roadways that also applied to paved roadways and others that did not (e.g., dust and surface characteristics). In addition, it is believed that the significance of the impact these factor may have on safety is likely to be different along paved and unpaved roadways.

The third task completed as part of project was a sensitivity analysis. One or more input variables were changed in each tool or methodology considered (e.g., Minnesota CRSP and usRAP) and then initial and alternative results compared. Three different approaches were used to adjust the coefficients, or "weight", of the safety risk factors applied within the Minnesota CRSP approach. Overall, a total 51 alternative rankings were produced and compared to the three initial rankings in each county. Two different comparison methodologies were used. First, the percentage change in the "top 20" locations ranked was noted. Then, a Kendall tau-b correlation coefficient was calculated and statistical comparison of the initial and alternative rankings completed. Overall, the percentage change in "top 20" locations ranged from zero to 50 percent (with a typical average of 10 to 20 percent (i.e., two to four locations)). It was concluded that this type of shift, in some cases, could impact the decision-making based on the Minnesota CRSP results. The Kendall tau-b correlation coefficient evaluation, however, found that the initial and alternative ranking lists were statistically correlated (i.e., similar) in all cases. This difference in results is not entirely surprising. The "top 20" shift only considered the changes that might have an impact on decision-making and the statistical comparison evaluated the entire ranking list. The usRAP results comparison was more straightforward. The type and number of countermeasures suggested by usRAP were compared for acceptable benefit-cost ratios of both one and two. Not surprisingly, the increase in acceptable benefit-cost ratio from one to two resulted in the suggestion of fewer countermeasures and produced a higher overall benefit-cost ratio for the group of countermeasures suggested. In addition, the number of sites or mileage suggested for the implementation of countermeasures decreased and some of those suggested changed (which was believed to be the result of the application of usRAP rules for competing countermeasures at one location).

The work completed as part of this project led to several recommendations. First, it was recommended that the approach followed with this research be expanded to counties with a higher variability in roadway characteristics. In addition, it was proposed that a wider range of "weights" and more specifically defined safety risk factors might be applied to the two counties considered in this research and others. Second, it was recommended that safety risk factors should meet two objectives. These objectives include the identification of locations with characteristics known to impact rural roadway safety and the differentiation of locations with relatively unique safety risk factors or safety risk factor combinations. The third recommendation suggested that the variability in roadway characteristics be considered when safety risk factors

are selected. In addition, it was recommended that another project be used to investigate an approach with more specific definitions of safety risk factor “weights”. In theory, this approach would use a method somewhere between the typical assumption of equal safety risk factor “weights” and full predictive modeling. It was also suggested that the impact of changing safety risk factor “weights” be evaluated when they are applied. It was hypothesized that the process might be not be necessary if the additional effort did not impact the final decision-making. Overall, it was also generally recommended that more research be completed on the selection and application of safety risk factors along gravel and/or rock roadways, the selection of safety risk factors for paved roadways, the development of ranking “tiebreakers”, and the proper evaluation of system safety program applications.

CHAPTER 1. INTRODUCTION

Systemic safety tools or methodologies are designed to assist in decisions that address crashes that occur in a widespread manner throughout a transportation system. They generally use system-wide crash and inventory data, along with research results and engineering judgment, to identify safety risk factors and potential locations of safety concern that would not normally be identified as traditional "hotspots" (i.e., specific locations with more than an expected number of crashes). Systemic safety approaches generally rank locations by quantifying their number roadway characteristic safety-based risk factors. Then, low-cost safety improvement measures are then typically proposed (*1*).

Safety along rural roadways is a widespread concern throughout the United States. In addition, in 2012 more than 70 percent of the fatal crashes in Iowa occurred along secondary (i.e., county) rural roadways (*2*). Traditionally, the identification of "hotspot" crash locations for improvement has been through a ranking based on crash rate, frequency, and/or severity. However, when the focus of safety improvements is to reduce severe crashes only (e.g., fatalities and serious injuries) or there is a lack of "hotspots" (which is typical in rural areas) a different prioritization methodology is needed. Systemic safety methodologies use an approach based on "risk factors" defined by system-wide crash data, research results, roadway characteristic information, and/or engineering judgment. . In recent years several approaches and tools have been proposed to accomplish this task. This research summarizes, evaluates, and investigates two of these tools/methodologies and completes a sensitivity analysis and/or comparison of the impact changes in one or more of their inputs may have on their results. The results of this research should be helpful to state and local transportation safety personnel as they apply the systemic safety tools/methodologies currently available.

Problem Addressed

More than half of the crash fatalities in the United States occur along rural roadways (*3*). Many of the roadways also have relatively low volume traffic volumes. The fatal or severe injury crashes that occur along these roadways are typically widespread (i.e., they occur along many miles of roadway) and may occur during a period of many years. A lack of crashes at a particular location, however, is not an indicator of low safety risk. Therefore, the traditional reactive "hotspot" method of location identification and safety improvement is not applicable to this type of crash pattern. Several tools and/or methodologies that take a proactive and systemic approach to roadway safety improvements are available. They are designed to address the need to improve the safety improvement decision-making process and locational prioritization along low-volume and/or rural roadways. This research describes several of these tools and/or methodologies and then investigates how changing one or more of their input variables required for two of them might alter the results they produce. A descriptive and/or statistical analysis is also completed to summarize the significance of any changes that may occur. The results of this research are expected to provide additional guidance to the users of these tools/methods and improve the efficiency and effectiveness of their implementation.

Project Objectives

The tools and/or methodologies considered in this research identify and incorporate roadway and/or roadside safety risk factors (e.g., horizontal curve radius, access density, etc.) to estimate potential concerns at particular locations. The first objective of this research project was to investigate, summarize, and compare the proactive systemic safety improvement tools/methodologies currently available and the research related to them. In addition, the results of research that focused on similar approaches along unpaved roadways are described. The second objective of this project was to compare, select, and then apply one or two systemic safety tools/methodologies to a sample of local rural roadway mileage. The results of these activities are then evaluated through a sensitivity analysis and/or comparison focused on changes to one or more of the primary inputs for the tool/methodology. The significance of the sensitivity analysis and/or comparison results will be summarized with descriptive statistics and/or a statistical evaluation. Finally, a focus group was convened to identify safety risk factors that might be used in similar systemic safety tools/methodologies along unpaved rural roadways. The results of this focus group are summarized in this document. Previous research in this subject area has focused only on the application of these tools/methodologies along paved roadways. Lastly, an informational website that includes summaries about the potential impacts of several rural roadway safety improvements was created.

Report Organization

This report includes five chapters. The first chapter includes a general description of the problem addressed by this research project and its objectives. The second chapter is a summary of the relevant literature that focuses on systemic safety tools/methodologies and systemic safety research projects that considered unpaved roadways. The systemic safety tools/methodologies summarized in Chapter 2 are also compared (using various factors) and two are selected for further investigation. The two tools/methodologies selected are identified in Chapter 2. The third chapter of this document includes a description of the data collected to apply the two systemic safety tools/methodologies selected. The input data collected is summarized in detail. The results of a gravel or rock roadway safety risk factor focus group are also described. Chapter 4 documents the results of the two systemic safety tools/methodologies and describes the different approaches taken to evaluate the potential impacts to their results due to alterations in one or more of their input variables. Descriptive statistics are calculated and/or a statistical comparison completed of any differences in their results that might be produced. Finally, Information about a website developed as part of this project that contains summary information about potential rural roadway safety improvements are also noted in Chapter 4. Chapter 5 includes the conclusions and recommendations reached with the completion of the research tasks described in this report.

CHAPTER 2. LITERATURE SUMMARY

As noted in Chapter 1, the widespread nature of crashes along low-volume rural roadways has resulted in the introduction of a systemic roadway safety evaluation process that is considered complementary to the traditional "hot spot" reactive approach. The systemic approach to safety management uses various roadway and roadside characteristics to estimate the safety risk and/or rank roadway locations for potential safety improvements. This chapter summarizes and compares several systemic safety tools and/or methodologies. Several factors are used to make the comparison and two approaches are selected for additional consideration during this research project (See Chapters 3 and 4). The results of that comparison are shared at the end of this chapter. Research that has considered something close to a systematic analysis on unpaved roadways is also summarized.

Systemic Safety Tools/Methodologies

The following tools/methodologies are summarized in this chapter:

- Minnesota County Roadway Safety Plan (CRSP) Approach (*4*)
- Federal Highway Administration (FHWA) Systematic Safety Project Selection Tool (*5*)
- United States Roadway Assessment Program (usRAP) Safer Road Investment Plans (*6, 7, 8*)
- New Jersey Systemic Road Safety Analysis Tool – Roadway Departure Crashes at Bridges (*9*)
- SafetyAnalyst™ (*10*)

This project is interested in several characteristics of the tools and/or methodologies listed above. These characteristics include general availability, level of input data required, ease of use, basis of prioritization, and potential for prioritization sensitivity analysis insight.

Minnesota County Roadway Safety Plan Approach

Minnesota County Roadway Safety Plans (CRSPs) have been prepared for each county in that state (*4*). The main objective of these local agency plans was to identify locations for and prioritize various safety measures to reduce the number of fatal and serious injury crashes. The format of these county safety plans are generally the same throughout the state. The Otter Tail county plan is the document used for this summary (*4*). The methodology used to identify and prioritize locations was focused on the use of crash data combined with safety surrogates to develop a star ranking system for roadway segments, horizontal cures, and stop-controlled intersections. The crash information, surrogates or risk factors, and countermeasures considered during the process for each of these parts of the county roadway network are summarized below.

Rural Roadway Segments

There are 193 rural roadway segments within the 1,004 miles of Otter Tail County rural roadway network. These segments were defined by a consistency in speed limits, average daily traffic, and geometrics (i.e., where the cross section changed a new segment was defined). The most significant crashes occurring on these segment were related to vehicles running off the roadway. The segments identified were prioritized through the use of a five star ranking system related to the following five safety risk factors. These five safety risk factors, which generally have a focus on roadway departure crashes, included:

1. Average daily traffic (ADT): A star was assigned to a roadway segment if it had an ADT between 600 and 1,200.
2. Access density: A star was assigned to a roadway segment if it had an access density greater than 10.8 access point per mile (i.e., the estimated average of the local rural roadway highways in Otter Tail County).
3. Road departure crash density: A star was assigned to a roadway segment if its road departure crash density was higher than 0.08 road departure crashes per mile per year (the estimated average of the rural roadway segments in Otter Tail County).
4. Critical radius horizontal curve density: Any segment with a density greater than the county rural roadway segment average value of 0.35 horizontal curves per mile with a radius between 500 and 1,200 feet was awarded a star. There is some confusion, however, in the interpretation of the document text with regard to whether this is a statewide, regional, or county average (*4*).
5. Edge risk assessment: A level of risk related to the possibility of vehicles leaving the travel lane was also assigned to each roadway segment. Each segment received a ranking of one to three. The edge risk assessment rating was defined in the following manner:
   a) One – roadways with a usable shoulder and a reasonable clear zone
   b) Two – roadways with little or no usable shoulder but a reasonable clear zone. Or, roadways with a usable shoulder but fixed objects in the clear zone
   c) Three – roadways with no usable shoulder and fixed objects in the clear zone

A roadway segment was awarded a star if the edge risk assessment was rated a two or a three.

It the county safety plan reviewed the five safety risk factors listed above were generally identified as surrogate safety measures through national and regional research (*4*). Data that defines each of these risk factors needs to be collected for each of the roadway segments considered in this process. The segments evaluated within each county were then ranked by the number of stars they received. Safety improvements were also identified for each roadway segment and the cost estimated. If two segments received the same star rating the edge risk assessment level and then the roadway departure crash density were used to break the tie. The countermeasures considered for application at the prioritized segments are noted in the concluding paragraph of this chapter section (*4*).

Rural Roadway Horizontal Curves

A prioritization approach similar to that described for roadway segments was also completed for each of the horizontal curves on the county roadway system (*4*). The safety risk factors used to "star rank" the horizontal curves were identified from previous research, engineering judgment, and the characteristics of horizontal curves with recorded crashes within the specific county of interest and its surrounding counties or region from 2005 to 2009. The five roadway features that were used to rank the horizontal curves included the following:

1. Horizontal curve radius: a star was assigned to horizontal curves with a radius between 500 and 1,200 feet.
2. ADT: a star was assigned to horizontal curves with an ADT between 200 and 600 vehicles per day.
3. Intersection within the horizontal curve: a star was assigned to horizontal curves with an intersection within it.
4. Visual trap: It has been observed that the presence of a visual trap increases the risk of being involved in a crash and these curves received a star rating. Visual traps usually exist when a minor obstacle or object continues on a tangent but the roadway curves. The existence of a crest vertical curve before a horizontal curve may also introduce or exacerbate the impact of a visual trap.
5. Crash experience: A star was assigned to curves that had at least one severe crash during a five-year study period (i.e., 2005 to 2009 for Otter Tail County).

Rural Stop-Controlled Intersections

The county safety plans also included the prioritization of rural stop-controlled intersection locations. A process similar to the approach described above for rural roadway segments and horizontal curves was followed. A sample of intersections on the county roadway system were ranked through the process of assigning stars related to seven risk factors. The risk factors appear to have been identified through the summary of data collected on the roadway system, research, and engineering judgment. The intersections with the greatest number of stars has the highest priority. A crash cost calculation was used as a "tie breaker" during the ranking or prioritization of locations when two or more intersections had the same number of stars. The seven roadway features involved in the rural stop-controlled intersection prioritization process included:

1. Skew: A star was assigned if the intersection skew was greater than 15 degrees.
2. Intersection on/near curve: A star was assigned if the intersection was on or next to a horizontal curve.
3. Commercial development: A star was assigned if the intersection had a commercial development in one or more of its quadrants.
4. Distance to previous stop sign: A star was assigned if an intersection had a minor roadway leg that did not have another stop sign within five miles.
5. ADT ratio: A star was assigned if an intersection had a minor to major roadway ADT ratio between 0.4 and 0.8.
6. Railroad crossing on minor approach: A star was assigned if an intersection had a railroad

crossing on one of its minor leg approaches.

7. Crash history: A star was assigned if a severe crash occurred at an intersection during a five-year period (e.g., 2005 to 2009).

CRSP Summary

The Minnesota CRSP systemic safety approach results in a prioritized list or roadway segments, horizontal curves, and stop-controlled intersection locations. After the prioritization was completed a series of infrastructure-based safety improvements were proposed for those locations determined to be higher priority. The safety improvements proposed for a location were based on the crashes to be addressed and the characteristics of the location. An application form for funding was also completed as part CRSP (*4*). This form included a description of the location, crash history, deficiency list, a picture of the location, and the proposed safety improvement.

There were eight types of safety improvements considered at each high priority rural roadway segment. These safety improvements included two foot shoulder paving/safety wedge/rumble strip, rumble strip, centerline rumble strips, rumble stripe, six inch wet reflective epoxy in grooves, six inch latex marking, chevrons/two foot shoulder paving in critical radius curves, and field access removal/consolidation. The improvements at each location were based on a decision tree that included factors related to roadway characteristics (e.g., paved shoulder, lane width) traffic volume and adjacent land use. High priority roadway segments were those that had been assigned three or four stars or segments with two stars and an edge risk assessment of two or three.

The improvements considered for horizontal curves that were high priority included a combination of two foot shoulder paving/safety wedge/rumble strip and chevrons/arrow boards. The horizontal curves suggested for improvements were those identified as high priority (i.e., a three or more stars) and those in close proximity to these (for uniformity and cost effectiveness), those on high priority segments and a radius of 500 to 1,200 feet, and those that need updated signs. A project form was completed for each high priority roadway segments identified.

High priority stop-controlled intersection locations (i.e., three or more stars rating) were considered for several safety improvements. The improvements consider included roundabouts, directional medians, mainline dynamic warning sign(s), street lights, updated signs/markings, and clearing/grubbing. The decision tree used to choose a suggested project for a particular location included the following roadway and crash characteristics: traffic volume; roadway surface; and the existence of severe right-angle crashes, street lighting, and a median. A typical cost was provided for each of the improvements noted above.

Overall, the process used to develop the CRSPs was the initial reason for this project. The star rating used essentially “weight” each star equally. This process can be used, requires a reasonable amount of data to be collected, it is free, easy to use, its basis of prioritization is a star rating but not “weighted” in any manner, and it has great potential for sensitivity analysis insight.

FHWA Systemic Safety Project Selection Tool

The FHWA funded a project designed to produce a systemic safety project selection tool (*5*). This tool was developed while this project was happening and was in draft form when this literature review as completed. Since that time the tool has been completed (*5*). This document generally contains additional information and more detail about the systemic process used for the Minnesota CRSP approach along with some case studies/examples of the steps in the process. It consists of a general description of the process or steps involved with the systemic safety improvement approach, a framework for balancing systemic and traditional approaches, and suggestions for evaluating the systemic safety process with particular performance measures (*5*).

As noted, the overall process described in the FHWA tool was essentially equivalent to that followed for the Minnesota CRSPs and described in the previous section of this document (*4, 5*). However, it includes some important information and additional details about the steps involved with the systemic approach and also defines systemic safety. It also guides the user through the process. In addition, it is emphasized that the systemic approach to safety improvement is proposed to complement the traditional reactive site analysis approach. The systemic safety planning process is defined as an approach that uses system-wide crash data to identify focus crash types and risk factors; screens and prioritizes candidate locations; selects countermeasures, and prioritizes projects (*5*). Overall, the process evaluates a network of roadways and prioritizes locations through the use of safety risk factors that might include roadway and roadside characteristics in addition to crashes (See the previous Minnesota CRSP discussion). The document is divided into chapters that focus on the three elements of systemic safety. Element one is the systemic safety project selection process. This element describes how safety professionals should identify key crash types and safety risk factors; evaluate countermeasures; and prioritize locations for safety improvement projects. Element two describes methods of how to balance and fund systemic and traditional site analysis improvements. The final element then generally describes how the benefits of a systemic safety project plan might be evaluated (*5*).

Tool Summary

The general approach described by the FHWA *Systemic Safety Project Selection Tool* document is that followed by the Minnesota CRSP approach previously described (*4, 5*). The document is guidance for those entities considering the application of systemic safety approach and offers insights into the process. The document defines systemic safety; describes the steps in the systemic safety project selection, funding, and evaluation cycle; and the appendix lists some existing tools and resources that could be used in the process (e.g., the AASHTO Strategic Highway Safety Plan, FARS, roadway departure and intersection safety implementation plans, CMF clearinghouse, NCHRP Report 500 and the FHWA nine proven safety countermeasures, the Highway Safety Manual, Safety Analyst , and the Interactive Highway Safety Design Model). In general, this tool is a process description document and offers new insights, but no new tool or approach to systemic safety.

United States Road Assessment Program (usRAP)

The United States Road Assessment Program (usRAP) was introduced in 2004 (*6, 7, 8*). The general objective of usRAP is to investigate and quantify the relative safety of roadways through the use of roadway and crash data. The process and models within the usRAP approach had been used by the program in Europe and Australia. In general, the usRAP approach determines a road protection score (RPS) to identify segments that its multiplicative modeling concludes have a higher risk of a crash. The RPS is based on whether roadway inventory elements that have been shown to impact or have a relationship with the occurrence serious crashes exist or not. The process produces a star ranking (one to five stars) based on this modeling. The details of the research or modeling used for each risk factor is not widely shared, but the relationship between the star ratings and safety was verified in the United States was done by Harwood, et al. in 2010 (*11*).

Approximately 40 to 50 elemental inputs need to be provided for each 328 foot roadway segment when usRAP is applied. The usRAP approach, however, can be applied with a relatively small amount of fatal and/or serious injury crash data. The process followed by usRAP generally distributes the crash totals to the roadway segments in a manner proportional to their calculated safety risk level. The RPSs that are produced are also used to create a Safer Roads Investment Plan (*6, 7, 8*). These plans are a prioritized list of safety improvements that might be applied along the roadway segments identified. It is a network level ranking of countermeasures by benefit-cost ratio. Approximately 70 countermeasures are considered and they are proposed for consideration along segments when they meet a one or more requirements defined within the usRAP process or by the user of the software.

The development of the RPS and star ratings, along with the Safer Roads Investment Plan prioritization are described in more detail below. usRAP awards up to five stars to each 328 foot roadway segment. Within the usRAP approach a ranking of four or five stars indicates a safer roadway than a roadway with one or two stars. The basis of a ranking is the existence or absence of particular roadway design features. The road infrastructure elements of a highly ranked roadway segment might include the following:

- Separation of opposing traffic by a wide median or barrier
- Good pavment marking and intersection design
- Wide lanes and paved shoulders
- Roadside free of unprotected hazards such as poles
- Good provision for bicyclists and pedestrians such as dedicated paths and crossings

Roadway segments that are assigned a star rating of one or two, on the other hand, are typically characterized by less sutiable roadway characteristics. These types of road infrastructure elements might include two-lane undivided roadways with the following:

- Relatively high posted speed limits
- Frequent curves and intersections

- Narrow lanes
- Unpaved shoulders
- Poor line markings
- Hidden intersections
- Unprotected roadside hazards such as trees, poles and steep embankments close to the side of the road
- Unlikely ability to accommodate bicyclists and pedestrians

The roadway characteristic data necessary to apply the usRAP tool is collected for each 328 foot segment through various means. However, for the most part, the data can generally be collected through the use of the streetview mechanism of Google StreetView™. A system has been developed that allows the collection of the information needed on approximately 40 to 50 roadway, roadside, and intersection charactistics. The general estimate is that about three miles of data can be collected in this manner within an hour. The information collected is then used to develop a RPS and then a star rating. The geometrics for which data is collected and used in this process are those generally known to have the largest impact on fatal and serious injury crashes and their severity. This elements collected are related to the safety of car occupants, motorcyclists, bicyclists, and pedestrians.

The RPSs created by the usRAP process is a measure of both the likelihood of a crash and its severity. It is based on models that estimate the expected roadway safety impacts or risks to various roadway users from specific roadway characteristics and elements. The basis of the risk estimated is the research that exists and the RPS is developed for car occupants, motorcyclists, bicyclists and pedestrians. Each roadway segment RPS is then assigned a star rating and these can be smoothed for longer segments when shown in map form. In general, one star is the worst rating and five stars the best. A range of RPS scores is contained in each star ranking. The methodology used to develop a RPS was purposefully designed to not require detailed historic crash data. The lack of detailed crash data is often a characteristic of systems in developing countries and along local agency roadways.

As noted, the usRAP tool or approach produces a RPS and star rating for each of roadway segment and it also proposes potential countermeasures to improve these safety measures. The network level countermeasure proposals provided are essentially provided in a Safer Roads Investment Plan (*6, 7, 8*). The development of Safer Roads Investment Plans include consideration of the existing roadway elements (e.g., the RPS or star rating), estimates of crash fatalities and serious injuries, and the impact of the proposed application of proven countermeasures. The cost of implementing the proposed countermeasure is compared to the benefit provided by the reduction in crash costs they produce. The resultant benefit-cost ratio is compared to a threshold set by the jurisdiction using the usRAP tool. If the benefit-cost ratio is above the threshold (e.g., one) then the countermeasure is included in the Safer Roads Investment Plan.

The methodology used to create a Safer Roads Investment Plan includes several steps. First, the number of fatal and serious injury crashes that occur on each roadway section is estimated (if necessary) The RSP, traffic volume, length of segment, and a calibration fatality factor is used in

this calculation. In addition, if data are available the ratio of fatality to serious injury crashes may be applied. The calibration fatality factor is used to ensure that the overall estimated fatalities and serious injuries for the network equal the actual number of fatalities (and serious injuries if available). The fatalities and serious injuries are then allocated to each 328 foot segments throughout the network (for all four road users if possible). In addition, if the information is available the number of fatalities (and serious injuries) by crash type and other specifics of the crashes can also be used in the calibration.

The process of producing a safety roads investment plan also includes the consideration of approximately 70 countermeasures for each roadway segment. The proposed use of a countermeasure is applied or proposed for each 328 foot roadway segment through a series of triggers typically related to the star rating or RSP, road characteristics and conditions, and traffic volume. Overall, there are 300 different triggers that are used to assess the relevancy of a countermeasure on a particular segment. A series of rules is also applied so that any countermeasure that is suggested for a roadway segment makes sense from an engineering point of view (e.g., added lanes must be a certain length). In addition, there is a hierarchy for suggested countermeasures that might apply to an individual roadway segment. This hierarchy is used to avoid the application of two countermeasures addressing the same issue along a roadway element. For example, if there is a proposal to re-align a horizontal curve, a recommendation to improve signing and pavement marking along that curve may no longer be relevant. The benefit of the implementation of each countermeasure is then calculated by determining what the RPS is before and after the implementation and the estimated number of fatalities and injuries prevented. The cost of the improvement is then applied along with the value of the fatalities and injuries prevented. A benefit-cost ratio is calculated and a list is produced that includes countermeasures that results in situations with a benefit-cost ratio above the threshold identified. This is the Safer Roads Investment Plan. Overall, a 20 year timeframe is considered and the user is warned that specific engineering planning and design at each location are still needed. The Safer Roads Investment Plan should be considered a planning level starting point of recommended measures.

usRAP Summary

The usRAP approach essentially estimates the safety risk along roadway segments through the consideration and use of the current state-of-the-knowledge about the crash impacts connected to approximately 40 to 50 roadway characteristics. The risk or star ratings produced by the process has been shown to relate to crash levels. The data is relatively easy to collect and it is free. The prioritization of the segments for improvement is connected to the allocation of the known level of fatalities and injuries to each segment and the cost and crash reduction effectiveness of the countermeasures proposed. In addition, segments are assigned a star rating that is a function of the roadway condition or characteristics. For this project, one or more primary condition inputs could be adjusted to determine how the usRAP results change and/or when the benefit-cost causes a countermeasure or location(s) to enter or leave the Safer Roads Investment Plan. The benefit-cost threshold could be adjusted (with limited value but would show results sensitivity), and/or a limited number of countermeasures (e.g., curve delineation improvement) could be considered. A combination of the latter with adjustments to the acceptable benefit-cost input

value might have value and assist in the determination of implementation. There is some potential here for sensitivity analysis insight.

New Jersey Systemic Road Safety Analysis Tool – Roadway Departure Crashes at Bridges

Researchers from Rutgers University Center for Advanced Infrastructure and Transportation (CAIT) Center recently completed a project to develop a systemic road safety analysis tool in order to examine roadway departure crashes at bridges in Salem County, New Jersey (*9*). At the time this literature review was completed this work was ongoing, but the project report was recently finalized (*9*). Overall, the CAIT authors indicated that the basis of the approach used in the analysis tool is a version of the roadway safety management process described in the Highway Safety Manual (*9*). In fact, the steps followed in the New Jersey safety analysis tool included a network screening for crash locations, diagnosis or identification of high-risk road features, countermeasure selection to treat roadway departure crashes, economic appraisal or benefit-cost analysis based on expected crash reduction benefits, and the justification and prioritization of projects (i.e., the grouping and prioritizing of projects). The researchers, as part of the last step noted, also did a sensitivity analysis of the tool and identified what inputs had the most impact on the results. They also concluded that benefit-cost ratios can be used for budgeting purposes to focus limited funding on locations where the countermeasures may have the largest impact. It was also found that sites with similar characteristics produced similar benefit-cost ratios and also needed similar countermeasures. The CAIT researchers could not evaluate the safety impact of the countermeasures proposed by the tool they produced because they not been implemented. The text below summarizes the location identification, data input, and location prioritization process proposed by the CAIT project team.

As noted above, there was a five step process followed in the systemic road safety analysis tool developed by the Rutgers University researchers to address roadway departure crashes at bridges. First, they collected roadway departure crash data within 0.1 miles of minor bridges along county roadways. Crash data from 2007 to 2011 were considered. In addition, the light conditions, crash severity, total number of injuries, contributing circumstances, and sequence of events were summarized. The locations that were identified in this crash analysis were also prioritized for a site visit (not all the sites could be visited due to funding and time constraints). The objective of the site visit prioritization was to identify those sites that appeared to have the highest risk of roadway departure crashes. The grading process used was limited to assigning a one, two, or three to the alternatives for lighting, severity, contributing circumstances, and the sequence of events during the crashes identified. The number of crashes and injuries were also combined with the ratings provided and the location ranked.

The second and third steps in the systemic road safety analysis tool developed as part of the CAIT project included diagnosis and countermeasure selection. Seven of the 16 locations ranked in the previous step were visited and cross section, pavement, signage, abutment condition, geometry, speed limit, and other information collected. The locations visited were based on the rating they received in the first step of this process and others were visited because they were close to those selected. In addition, it appears that several other bridges outside the scope of the crash data and project were considered. The researchers considered the characteristics of these

sites to identify those geometrics that may cause roadway departure crashes. Any of the characteristics that showed a trend at the sites were believed to be a "high-risk" roadway feature. The characteristics the researchers labeled as "high-risk" for roadway departure crashes at bridges included:

- Pavement width less than 22 feet
- Shoulder width less than 1.5 feet
- Lane width less than 10.5 feet
- Pavement condition fair or poor
- Superelevation is minimal or non-existent for a horizontal curve
- Friction is fair or poor
- Striping is fair or poor
- Advance warning signs are minimal or non-existent
- Object markers are in poor condition or non-existent
- Abutment is in fair or poor condition
- Vertical curve exists
- Horizontal curve exists

All these features were provided a ranking of one if they occurred at a location and then the sum of those was multiplied by the number of crashes that occurred in the time period considered. The features that accumulated the largest number of points were identified as those most likely to produce roadway departure crashes (based on the locations and data considered). The top five risk factors were a pavement condition of fair or poor, striping in fair or poor condition, advance warning signs minimal or non-existent, object markers in poor condition or non-existent, and the existence of a vertical curve. The researchers also decided to include the existence of a horizontal curve based on past research results. In addition, they appear to have included bridges with parapets and/or substandard or non-existent guardrail as high-risk features. The third step was to select the countermeasures to address the high-risk features in an effort to reduce the number and/or severity of roadway departure crashes. The "proven" safety countermeasures identified for consideration included the installation of guardrail, rumble strips, rumble stripes, new pavement markings, advance warning signs and/or horizontal curve delineation, and the resurfacing of the pavement (including high friction surfacing).

The fourth step in the process followed in the CAIT project was economic appraisal. The economic appraisal used the *Highway Safety Manual* (HSM) approach of calculating expected crashes and crash reductions at each site with the installation of the countermeasures identified (*9*, *12*). A benefit-cost ratio was calculated by estimating the cost of installing each countermeasure and the benefits were estimated by calculating (if possible) the expected reduction in all crashes, fatalities, and property damage. The cost of implementing the countermeasures were collected from bid reports for the New Jersey Department of the Transportation, service life from some guidelines of the Illinois Department of Transportation, and the crash modification factors (CMFs) of the countermeasures were from the CMF Clearinghouse (www.cmfclearinghouse.org). The authors noted that their signing countermeasure did not have a reliable CMF and that their process would not show it as being effective at reducing roadway departures. Where CMFs were unavailable the factor was set to

one (meaning no effect) or equal to the CMF for total crashes. Overall, it would appear that economic analysis was done for guiderail, rumble strips, signage (see above for why it won't be shown as effective), pavement resurfacing, and high friction surfacing. The impact of these countermeasures were calculated using the process proposed in the HSM. The rural two-lane two-way roadway safety performance function in Chapter 10 in the HSM was used for the study sites to determine expected crashes and then the expected change in crashes after the installation of a countermeasure was estimated with the application of CMFs. In this case the CMFs for total crashes, property damage only crashes, and fatality/injury crashes (if they are all available) were applied to particular sites annually for the service life assumed for the initial countermeasure installation (i.e., no reinstallation costs were considered). A benefit-cost ratio was calculated and those installations at a site with a ratio greater than one were considered beneficial.

The fifth step in the process followed in the CAIT project was the justification and prioritization of projects. There were three primary activities completed as part of this step. First, a sensitivity analysis was completed to determine which inputs to the process had the most impact on the benefit-cost ratio results. During this project 11 different input factors were altered in a sensitivity analysis for a guiderail installation at one study site. The benefit-cost ratios produced were compared when extreme values of various inputs (while holding all others equal) were used. The first approach considered the overall range of inputs. However, these ranges were much different (e.g., a range of several thousand for volume, but only a few points for lane width) and this impacted the results. The second approach limited the changes in inputs to 20 percent to reduce the impacts of these differences. This approach only considered the seven input factors that were continuous in nature. However, the results were relatively comparable. Overall, traffic volumes and lane widths appear to have one of the bigger impacts on the benefit-cost ratio. Horizontal curve radius and roadside hazard ratings, on the other hand, had medium impacts, and shoulder width and segment length had little impact. The second activity in this step was the determination of a threshold to justify projects. First, benefit-cost ratios of various individual countermeasures were considered. Second, the annual average daily traffic (AADT) that would produce benefit-cost ratios of one for various countermeasures were calculated as a potential threshold. This would identify those countermeasures that only require a small amount of volume and might be implemented in a widespread manner. Finally, the last activity in this step was to propose methods of project prioritization. Two methods were described. The first approach described was a simple ranking and implementation of projects by their benefit-cost ratio. This approach is sometimes followed but may also not be the most efficient (e.g., an improvement may be proposed that, if combined with another site, could be more economic). The second approach described was to group projects with similar benefit-cost ratios and also consider the location of the projects in relationship to each other. This approach would likely result in similar countermeasures being installed at the same time particularly if they were in close proximity to each other. In general, the authors concluded that a prioritized list of projects should only be a starting point and will need to take other factors into account for the choice of order. This conclusion is similar to that made for the usRAP lists.

NJ Approach Summary

The methodology developed by the CAIT research team was essentially an application of the HSM using the equations, etc. noted within that document. An excel sheet was developed as part

of the project and could be used for other areas of safety focus. The overall approach uses the CMFs in the HSM to apply and calculate (when possible) the benefit-cost ratios for different measures at each site. The research team that developed this approach did do a sensitivity analysis as part of the project and any additional analysis would likely show similar results. In addition, there were a number of assumptions made in the application of this process because of the gaps in the CMF research.

SafetyAnalyst™

SafetyAnalyst™ is a set of software tools to assist local and state highway agencies with the management of their highway safety program (*10*). The software can be used to program site-specific safety improvements. It is a software that applies currently accepted safety data analysis techniques to assist the user with the identification of safety improvement needs and the programming of projects. In general, it incorporates the safety analysis processes and approaches described in the *Highway Safety Manual* (*12*). The software includes six safety management tools that are combined in four modules. The six management tools include the following:

- Network Screening Tool: applied to identify locations that have the potential for safety improvement
- Diagnosis Tool: used to evaluate crash patterns at individual sites
- Countermeasure Selection Tool: assists with the selection of countermeasures to reduce the frequency and severity of crashes at specific locations
- Economic Appraisal Tool: can perform economic analyses to evaluate the implementation of countermeasure(s) at one or more locations
- Priority Ranking Tool: ranks the sites and proposed improvement projects with the benefit-cost analyses done in the economic appraisal tool
- Countermeasure Evaluation Tool: used to perform evaluations before and after the implementation of safety improvements

The process or steps followed in the software is similar to many of the efforts described previously in this document. The focus of this research project, however, is the evaluation of how sensitive the prioritization results of these tools are to varying input data. Therefore, this summary focuses on the details of the SafetyAnalyst™ most relevant to this project. More specifically, the input requirements, the selection process for countermeasures, and the selection or priority ranking of improvement or projects are described below.

The *Highway Safety Manual* has, as one of its focal points, safety performance functions (SPFs). SPFs are regression models that are used to predict expected crash frequencies and severities at specific locations. SafetyAnalyst™ includes SPFs for a range of roadway segments, intersections, and ramps. These SPFs are calibrated to the data that the user enters and the SPFs can be changed to those developed by a user if that is preferred. The SafetyAnalyst™ also uses crash modification factors (CMFs) in its analysis. The approach used incorporates SPFs, CMFs and observed crash frequencies and severities in their estimations of expected crash frequencies and severities at a study site.

The data or input required by SafetyAnalyst™ is generally considered to be significant. It requires data that describes roadway characteristics, traffic volumes, and crashes. The minimum amount of data listed in the final report for the SafetyAnalyst™ includes 29 pieces of descriptive information related to roadway segments, intersections, ramps, and crashes. This minimum amount of data is required to assign crashes to specific sites, define the site subtype (e.g., the type of segment, intersection, or ramp), compute expected crash frequencies at each site, and describe the crash experience at each site. There are also other non-site-specific inputs that have default values.

A countermeasure selection tool is available in the SafetyAnalyst™ software. It allows the user to select from a wide range of countermeasures to address the particular types of crashes occurring at a site. The software also suggests countermeasures based on the type of site, crash patterns, and specific safety concerns identified by the diagnosis tool. In general, the diagnosis tool is used to identify predominant crash patterns and higher-than-expected crash frequencies. One or more countermeasures can be selected for a particular site and the economic analysis tool and priority ranking tool can then be used to determine the more appropriate option. SafetyAnalyst™ uses the information available at the time it was created with regard to the safety improvement effectiveness of the countermeasures selected, but the user can add in new information as it is made available. The software is a tool that assists the user with the selection of the countermeasure, but ultimately the user selects the countermeasures to be considered in the economic analysis and priority ranking tools.

Lastly, the countermeasure(s) selected by the user of SafetyAnalyst™ are economically evaluated and the projects prioritized. This part of the software can be used to compare alternatives at a particular site and prioritize projects within the network. The tool allows users to maximum safety benefits for the funding they have available. SafetyAnalyst™ provides default construction cost estimates for countermeasures that can also be changed by the user. There are three types of analysis that the software can complete. The user can select a cost effectiveness analysis (i.e., countermeasure costs per crash reduced), a benefit-cost ratio analysis (i.e., the ratio of crash reduction benefits to countermeasure costs), or a net present value analysis (i.e., the excess benefits over countermeasure costs). The benefits, of course, are calculated based on use of observed, expected, and/or predicted crash frequencies and severities at a site with and without the countermeasure being evaluated. The CMFs represent the safety improvement potential offered by a countermeasure. The analyses applied also take into account service life and the value of money. They also meet all Federal Highway Administration Highway Safety Improvement Program (HSIP) requirements. Projects throughout the network are then ranked in the SafetyAnalyst™ with the results from the economic analysis. The software can also assist the user in the selection of an optimal set of projects that will maximize safety benefits.

SafetyAnalyst™ Summary

The SafetyAnalyst™ is a detailed safety improvement management tool. It does have some significant data requirements, but the data could be collected if needed. The effort needed, however, to collect this data was considered to be beyond the scope of this project. The cost of this software is also significant. Finally, the value of considering the SafetyAnalyst™ in this

project was limited because the similar types of approaches could be adjusted in the usRAP and/or the New Jersey tools (which is based on the *Highway Safety Manual*) previously described (*12*). Changes to the input variables for a sensitivity analysis of SafetyAnalyst™ results would likely focus on its benefit-cost analysis.

Unpaved Roadway Systemic Safety Projects

Another objective of this research project was the identification of safety risk factors that might be of interest if the systemic safety improvement approach was applied along gravel or unpaved roadways. Some of tools or approaches described previously could be applied to gravel roadways, but none of them were developed with information or data from these type of roadways. In addition, most of the research that has been completed (e.g., to develop CMFs) has been on paved and/or higher volume roadways. Some of the ideas or projects that focused on the prioritization of projects along gravel roads are summarized below. Few resources are available for this type of application and most are primarily based on a combination of data and research or expert judgment. The approaches proposed for gravel roadways may be relevant to low volume paved roadways in some cases.

South Dakota Rural Road Safety Index

In 2011, Mahgoub, Selim, and Pramod of South Dakota State University presented a paper at the Transportation Research Board Annual Meeting on the development of a rural road safety index (RRSI) (*13*). The RRSI was to be used to rank roadway network locations by their safety features to identify deficiencies. It was proposed that it could be used to support roadway safety reviews. The authors summarized the crash characteristics in South Dakota and discuss roadway departure crash characteristics in detail (*13*). Their research team also conducted field visits on 26 gravel rural roadways with an ADT between 50 and 400 vehicle per day and speed limits between 30 and 55 miles per hour. They used a safety issue and question list during these field visits. The subjects and questions in the list included:

- Road Overview: Are there changes in land use and/or traffic or other environmental challenges such as terrain?
- Crash History: Is there a history of crashes that points to specific problems areas?
- Road Alignment and Cross Section: How well does the roadway serve current and future traffic? Are lane width, shoulders, and sight distances adequate?
- Roadside Features: Are there steep slopes, drainage features, narrow shoulders or clear zones, or fixed objects (narrow bridges, mailboxes, utility poles)? Are guardrails adequate and meet standards?
- Gravel Road Surface Conditions: Are road surfaces well maintained (proper shape, smooth surfaces, loose gravel, or edge drop-offs)?
- Paved Road Surface Conditions: Is surface smooth, adequate skid resistance, free of edge drop-offs?
- Signing and Pavement Marking: Are signs and pavement markings well maintained and meet the requirements of the MUTCD, including night time visibility?
- Intersections and Approaches: Are there sight restrictions (vegetation or other) that limit

visibility? And is signing adequate?

- Railroad Crossings: Are crossings properly signed and free of sight restrictions?
- Pedestrians and Bicycles: Are crossings clearly signed and marked, and are there areas of pedestrian activity (schools, playgrounds, parks) in need of special considerations?
- Provisions for Heavy Vehicles: Are there operational issues due to the presence of heavy commercial or agricultural vehicles?

The question list is intended to be a starting point to encourage the consideration of particular issues that have been found to be safety issues along rural roadways. It is not intended to be all-inclusive and is somewhat similar in approach to the prompt list approach in the road safety audit guidelines and software of the FHWA (*14*). Particular roadway characteristics or areas of interest from a safety point of view are identified in these prompt lists (*14*).

A discussion of risk was also included in the South Dakota State University paper (*13*). The authors proposed that risk is an important concept to consider, particularly when crash history is not available. They defined risk as the combination of the likelihood of a crash and the severity of a crash if it occurs. The data in South Dakota showed that rollover and fixed object crashes represented 43 percent of the crashes and 71 percent of the injuries and fatalities on local rural roadways (*13*). The authors proposed that the factors that influenced the likelihood of these crashes included:

- History of the crash
- Existing speed on the road
- Volume of traffic on the road
- Hazard location

The risk at the study sites were subjectively evaluated with a Safety Priority Evaluation Matrix form. The form included a description of the issue or hazard; the location; a matrix of exposure/probability and consequence; a space to comment on safety risk; and, an area to make a recommendation. The matrix also allowed exposure, probability, and consequence to be ranked in very low, low, medium, high, and very high categories. The term “exposure” is related to the number of opportunities for an event and was proposed to be generally in proportion to traffic volume. The “probability” term was related to the likelihood of a crash, and the “consequence” was in reference to the severity of a crash (*13*).

The paper concluded with a description of the proposed RRSI (*13*). The objective was to assign a quantitative value to the potential safety issues along a segment. The process proposed assigned deduction points to particular situations that were likely to occur along a rural gravel roadway. Four specific situations were listed within each general category. The general categories included roadside obstacles, signs and delineation, cross section, alignment and access, and roadway surface and maintenance. Each of the specific situations described in the general categories was assigned a deduction point value and the least safe situation (in the opinion of the research team) was given the highest deduction and the situation that was considered desirable was assigned a deduction of zero. The number of points assigned to the general categories and the situations in each category were selected by the research team (*13*). For example, in the cross section category

a lane width greater than 10 feet with sufficient shoulders was assigned zero deduction points, but a lane width of less than 9 feet and no shoulder was assigned 20 deduction points. The research team proposed that the sum of deduction points every 500 feet at each study site should be subtracted from 100 and the resulting number was the RRSI (*13*). The RRSI could then be used as a priority ranking methodology by local agencies.

Unpaved Roadway Safety Project - Wyoming

In the mid- to late-1990s several documents were published that describe work that appears to have been led by a research team based in the state of Wyoming (*15, 16, 17, 18, 19*). These documents summarize one or more projects that were completed. The projects focused on the evaluation of safety on unpaved roadways. The following papers and documents were reviewed:

- Variable Safety Improvements for Unpaved Roads (*15*)
- Incremental Safety Improvements for Unpaved Rural Roads (*16, 17*)
- Starting a Safety Improvement Program for Rural Unpaved Roads (*18*)
- Development of a Field Evaluation Guide for Unpaved Rural Roads (*19*)

Several of the documents above discussed similar subjects. In the *Variable Safety Improvement for Unpaved Roads* paper Caldwell and Wilson described the need for a different approach to safety improvements along unpaved roadways (*15*). They proposed that local agencies face a dilemma with regard to safety improvements along these roadways. Funding for improvements and potential tort liability require reconstruction to current policy standards, but this approach can be costly. They conclude that this may be causing many local agencies to take the "do nothing" approach. The study they summarize used a survey of a steering committee to collect information about safety on unpaved roadways. First, the steering committee was asked about roadway safety audits. The committee recommended that the road safety audit procedure should include a group severity index, implementation costs, crash data considerations, and a ranking of deficiencies that is done roadway section by roadway section (*15*). They also proposed that a roadway classification system should be used for unpaved roadways that is based on traffic volume and type of user or driver. They identified 12 roadway elements that should be the focus of unpaved road safety audits. These elements included surface width, consistency, sight distance, signage, surface condition, prudent speed, horizontal curves, percent trucks, bridges, railroad crossings, vertical curves, foreslope, clear zone, and pedestrians/bicyclists (*15*). Finally, the committee strongly recommended the consideration of incremental safety improvements. Incremental safety improvements are those that could be done to increase the safety of the roadway while not bringing the entire segment up to current policy design standards. It was proposed that this approach could be followed while working toward a final design standard (*15*).

The document described above was likely completed while the *Incremental Safety Improvement for Unpaved Rural Roads* project was being completed at the University of Wyoming (*16, 17*). The project report was published in 1997 and a *Transportation Research Record* article that summarizes that project were reviewed as part of this task (*16, 17*). The research summarized in these documents developed a rating or prioritization system for low volume roadways that would

benefit from the incremental safety improvement process described previously. As part of the project they completed a survey to determine what sub-groups of functional classification were being used to apply reduced design standards. They found that many different traffic volumes were being used and the research team proposed the use of the following: 0 to 50 vehicles per day (vpd), 50 to 250 vpd, 250 to 400 vpd, and 400 to 1,500 vpd. They also chose to focus on horizontal curve (see below).

A national focus group of individuals was surveyed about the validity of the traffic volume sub-groups described above (with an assumed type of vehicle use, traffic volumes, travel way widths, operating speed, surface material, ride quality, opposing traffic influence, and surface drainage) and the acceptability of particular incremental safety improvements for each of the functional class sub-groups (*16, 17*). Overall, 17 different safety improvements for a deficient horizontal curve were included in the survey for each sub-group. The safety improvements ranged from a "do-nothing" alternative to a complete reconstruction. Not all the improvements suggested were found to be acceptable for on some of the roadways. An analysis and evaluation of the results was completed. Overall, it was concluded that a functional classification for rural local roadways was needed and that improvement guidelines for those classifications was needed. In addition, it was concluded that incremental improvements were important if the objective was to increase the safety of these roadways (i.e., something more than "local rural"). More specifically the researchers proposed that traffic volumes (as noted above) and road user characteristics were critical to the establishment of the local roadway sub-group functional classifications. They also proposed that these sub-groups should be accepted on a national basis (and additional research be done to determine the volumes to use for the sub-groups) and design guidelines need to be developed that account for incremental or staged construction and provide local agencies with more flexibility. Finally, they recommended that any incremental improvements along a roadway needed to ensure the consistency in the driving environment and they proposed a six step incremental safety improvement program. The six steps included the following:

1. Establish a functional subclassification for the roadway
2. Identify the site deficiencies
3. Review the incremental improvement alternatives
4. Analyze the effect of the improvements on driver expectancy
5. Implement the improvement program
6. Monitor and evaluate the effectiveness of the improvements

Caldwell and Wilson also authored an article entitled *Starting a Safety Improvement Program for Rural Unpaved Roads* (*18*). In this article they described their proposed methodology to develop a safety improvement program (SIP) for unpaved rural roadways (*18*). The process they proposed prioritizes roadway segments for safety analysis and identifies their safety needs. It also included partnering with road users in the completion of the process. In general the research project used a focus group of transportation professional and experts to identify critical roadway characteristics and to develop the safety analysis procedure for unpaved rural roadways. The Delphi survey method was used and the initial survey focused on the examination of issues related to SIPs for unpaved roadways. The findings from that survey included:

- The output from the SIP should be a group index versus an item by item prioritization
- The safety analysis should be done section by section
- Incremental improvements should be encouraged and a change in policy and practice is needed on local low volume roadways
- Crash data should be included in the SIP to identify high frequency locations and assist in the determination of the causation factors of the crash
- A classification by traffic volume and roadway user expectation is recommended

A second Delphi survey was also completed. This second survey focused on a prototype SIP developed by the research team. The recommended SIP included five steps:

1. System-wide prioritization of unpaved roadway sections
2. Identification of safety improvements on prioritized roadway sections
3. Prioritization of safety improvements
4. Scheduling and implementing safety improvements
5. Program evaluation and update

The first and second steps were the focus of the *Transportation Research Record* article (*18*). It is proposed that the prioritization of unpaved roadways is done section by section and that each section is given a "primary rating factor" related to low, average, and high traffic volumes and different types of roadway users (e.g., local, recreation, and tourist). Different combinations of these two characteristics are assigned a grade from A (low volume and local roadway users) to E (high volume and a combination of all three roadway users). A matrix of the combinations is provided in the *Transportation Research Record* article (*18*). The "primary rating factor" is then adjusted up or down by factors that account for operating speed, heavy vehicles, and terrain. Adjustments for different levels of these three factors are also provided in the *Transportation Research Record* article (*18*). For example, the "primary rating factor" is reduced by one level if there is high level of operating speed variability and moved up if there is a low level of variability in operating speed. A number of focus group members suggested that there may also be a need to weight the impact of the different adjustment factors. The second part a SIP identifies specific safety improvement needs. The researchers proposed that this should involve surveying local roadway users (e.g., property owners, residents, route drivers, sheriff's deputies, and roadway/bridge personnel). Nine of the 10 focus group members agreed with this approach. Of course, as noted above, there are also three steps that follow the prioritization of the unpaved roadway sections and the identification of safety improvements. The research project team concluded that the prioritization of safety improvements along rural unpaved roadways should not be data or resource intensive, will be difficult until safety improvements on higher priority roadways have been identified and planned, and that determining all the improvements needed on all the sections of roadways would be beyond the resources of the majority of local agencies (*18*). The last two steps in the process included scheduling improvements (it is proposed that they should be done to maximize the benefit-cost ratios and involve professional judgment) and the evaluation of the program effectiveness (for long term success and adjustments) (*18*). The researchers concluded that most local roadway agencies do not have a SIP for unpaved roadways, and that the development of a SIP for unpaved roadways needed to recognize the limits of local roadway funding and crash data (*18*). They also suggested that roadway user

assessments were useful to the identification of safety needs along unpaved roadways (*18*). Finally, they proposed that changes were needed to current policies and practice for prioritizing and evaluating the safety needs along unpaved roadways (*18*).

In the 1990s the Wyoming Technology Transfer Center also developed a "Field Guide for Unpaved Rural Roads" (*19, 20*). The development of this field guide included two surveys of a national focus group that considered the identification and prioritization of safety issues along rural unpaved roadways (*19*). The focus group consisted of 34 people from 19 states and the District of Columbia that had worked with unpaved roadways in their state or nationally. In addition, they all had a background in transportation safety. Overall, 10 of the focus group members came from federal agencies, 5 from state departments of transportation, 6 from academic or Local Technical Assistance Program organizations, 8 from counties or parishes, and 5 from private consultants or professional societies. First, the focus group was asked to identify five safety issues related to unpaved rural roadways and also the standards or guidelines for the safety management of these roadway. This survey led to a list of 30 safety issues and the identification of 78 reference documents. The second survey asked the focus group members to prioritize the safety issues for possible inclusion in the field guide. The focus group was told that only the most critical issues would be considered and that the field guide should address those topics that were not already in existing and readily available references. The overall ranking of the 30 safety issues was based on a combination of focus group rankings. These ranking are shown below:

1. Proper installation of traffic control signs
2. Delineation of sharp curves, bridges, and culverts
3. Geometric design and alignment related to terrain
4. Evaluation of intersection sight distance
5. Geometric design and alignment related to driver expectancy
6. Consideration for consistent signing to enhance expectancy
7. Evaluation of roadside clear zones and obstructions
8. Procedures for surface maintenance including grading
9. Proper roadway crown and superelevation
10. Considerations and signing for obstacles along roadway
11. Evaluation of roadway surface conditions and structural capacity
12. Identify required roadway lane and shoulder width
13. Considerations for intersection location
14. Proper installation of bridge rails and approach rails
15. Inspection and inventory of traffic control signs
16. Sign maintenance procedures
17. Procedures to enhance surface drainage
18. Identifying restricted roadway width caused by erosion, etc.
19. Work area traffic control for maintenance work
20. Determination of stopping and sight distance for signing
21. Identify proper side slopes and back slopes
22. Control of dust and mud
23. Procedures to enhance the safety of railroad crossings
24. Consideration for turnouts on one lane roadways

25. Layout of guardrail and crash cushions
26. Procedures for winter maintenance
27. Procedures to conduct speed studies and establish speed limits
28. Cattle guard placement and maintenance
29. Considerations for pedestrian and bicycle usage along road
30. Placement of acceleration and deceleration lanes

Only about the first 15 of these items were addressed in the field guide. It was also concluded that many of them were related to driver expectancy. The field guide was published in 1997 and updated in 2004 and 2013 (*20*). Its table of contents includes sections on traffic control devices, railroad crossings, horizontal and vertical curves, intersections, intersection sight distance, delineation, clear zone, bridges and culverts, guardrail, tools, and road surface management (*20*). The safety issues listed above may be of value to this research project.

Summary of Findings

The literature related to a series of systemic safety tools/methodologies was summarized in this chapter. The documents reviewed showed that the five tools/methodologies considered have a wide variety of needs and approaches. The characteristics of the tools/methodologies described in this chapter were compared through the consideration of several factors. These factors included:

- General availability (including cost)
- Level of input data required
- Ease of use
- Basis of prioritization
- Potential for prioritization sensitivity analysis insight

A rating or ranking for these factors for each tool/methodology is shown in Table 1. A comparison of these factors resulted in the selection of the CRSP and usRAP approaches for further evaluation in this research project. These approaches will be applied to a sample of paved local roadways and their results investigated through a sensitivity analysis.

Table 1. Systemic safety tool/methodology comparison

	Factors of Consideration				
	General Availability	**Input Data Required**	**Ease of Use**	**Basis of Prioritization**	**Potential for Sensitivity Analysis Insight**
CRSP Approach	High	Low	Low	Star Rating	High
FHWA Tool	High	Low	Medium	Star Rating	High
usRAP Approach	High	Medium	Medium	Benefit-Cost	Medium
New Jersey Tool	Medium	Medium	Low	Benefit-Cost	Medium
SafetyAnalyst™	Low	High	Medium	Benefit-Cost	Medium

*CRSP = Minnesota County Roadway Safety Plan, FHWA = Federal Highway Administration, usRAP = United States Roadway Assessment Program

CHAPTER 3. DATA AND FOCUS GROUP RESULTS SUMMARY

In Chapter 2 several systemic safety tools/methodologies that could be used to evaluate the safety of paved low-volume rural roadway were summarized. A comparison matrix was also developed and used to select two of the tools/methodologies summarized for further consideration and application in this research. The two tools/methodologies selected included the Minnesota CRSP and the usRAP approaches. In this chapter the county selection and data collection processes used in this project are described and the data collected for both tools/methodologies summarized.

County Selection

Early in this research project two Iowa counties, Dallas and Buchanan, were considered potential sites for systemic safety data collection and evaluation. The engineers had expressed interest in the process and agreed to be involved. They are both also on the project technical advisory committee (TAC). The counties were approached before the Minnesota CRSP and usRAP tools/methodologies were selected for consideration. One of the primary factors in the selection of these counties was whether data could be easily collected or confirmed in the field. Both counties are within easy driving distance of the research team. Fortunately, field data was ultimately not necessary for either of the tools/methodologies selected. The counties are also different in their growth patterns. Buchanan County is in northeast Iowa and generally rural. Dallas County is west of the Des Moines metropolitan area and experiencing growth and/or suburbanization. Another factor considered in the county selection was whether the required input data would likely be available in electronic databases and whether a good portion of the secondary roadway system (the focus of this research) was available for review with Google Maps StreetView™.

Data Collection Process

Data were collected that defined the geometric, roadside, and crash data characteristics of the paved secondary rural roadway system in Dallas and Buchanan Counties. However, these data were only collected along those roadways for which visualization was possible using Google Maps Street View ™ and ArcMap 10.1™. These visualization capabilities were only available for a sample of the roadway mileage in each county (See Figures 1 and 2). Overall, a total of 197 miles of data were collected in Buchanan County and 156 miles in Dallas County. The Google Maps Street View™ software was used to collect much of the data needed for this research. Traffic volume, horizontal curve radius, and crash data, however, were also acquired from the Iowa Department of Transportation (DOT) Geographic Information Management System (GIMS), the *Horizontal Curve Identification and Evaluation* research project finished in September 2012, and the Iowa DOT statewide crash databases (*21*).

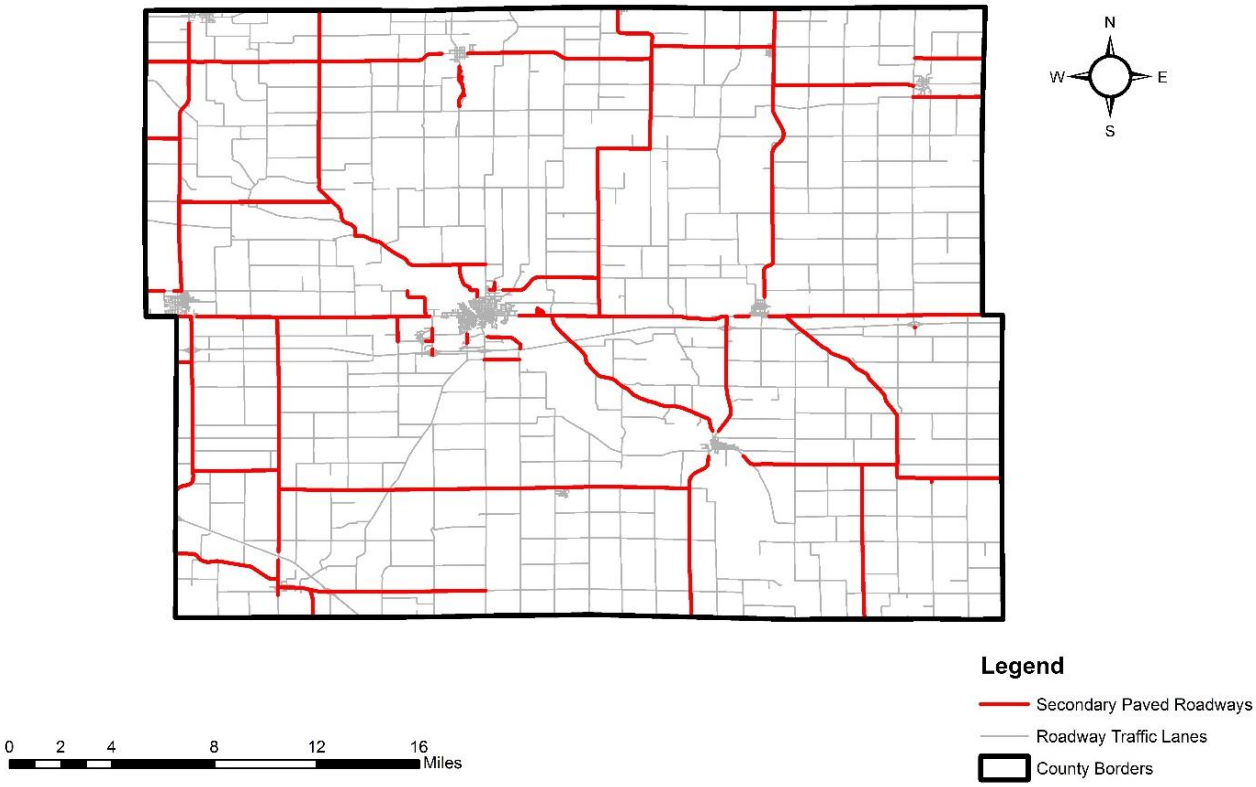

Figure 1. Buchanan County database roadways

Data Collected

Minnesota CRSP Approach

The systemic safety tools/methodologies selected for evaluation in this research project were described in Chapter 2. The application of each tool/methodology required the collection of data that are used to estimate the safety risk along the roadway mileage in the database (See Figures 1 and 2).

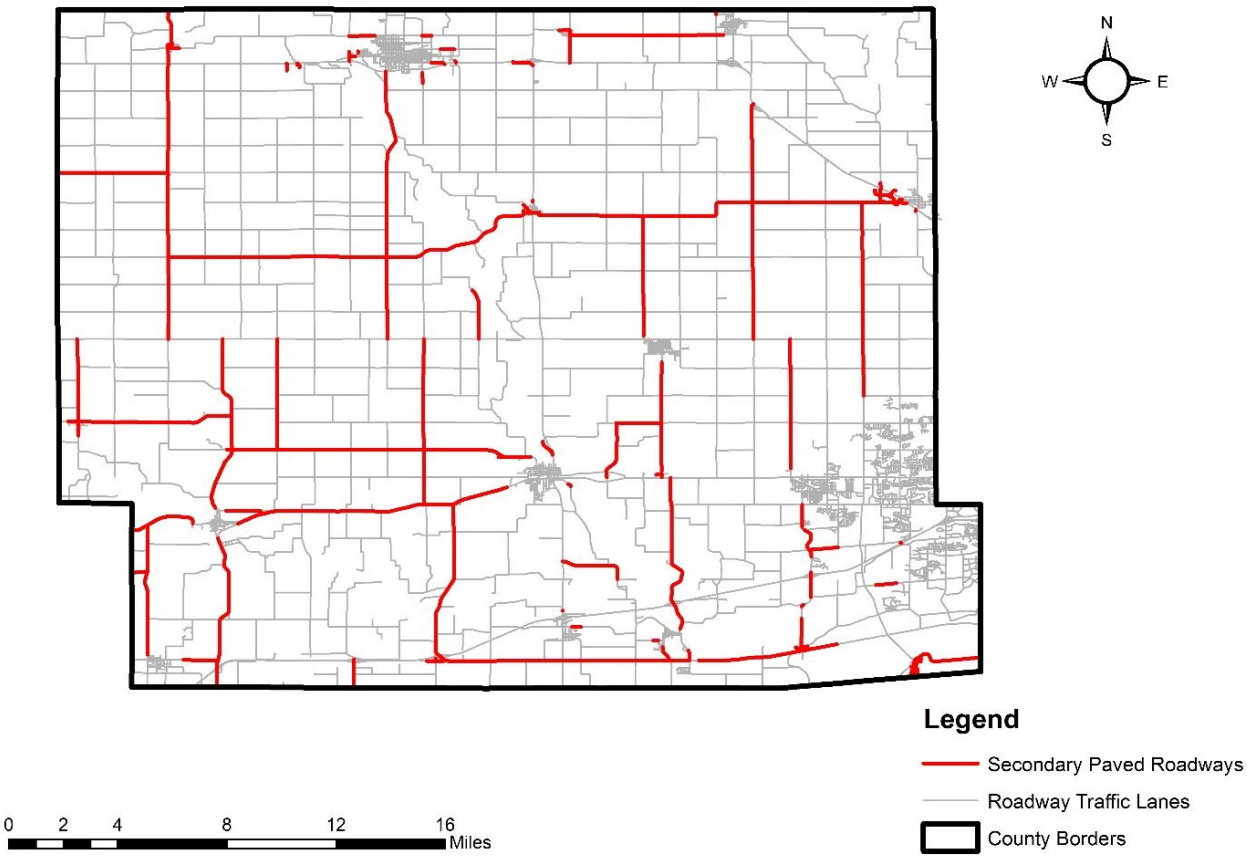

Figure 2. Dallas County database roadways

The data required is defined by each tool/methodology, but can generally be categorized as roadway geometrics, traffic flow (e.g., volumes), and roadside characteristics. Table 2 includes a list of the data collected to apply the Minnesota CRSP approach in Buchanan and Dallas County. As noted in Chapter 2 the data collected for the Minnesota CRSP approach are focused on the characteristics of horizontal curves, stop-controlled intersections, and roadway segments. However, the application of the Minnesota CRSP approach also required some data to be collected for a larger area than a county. In this case, data were collected for the Iowa DOT Districts within which Buchanan and Dallas counties are located (e.g., Iowa DOT Districts 6, and 4, respectively). The other data were collected for individual horizontal curves, stop-controlled intersections, and roadway segments along the highlighted corridors in Figures 1 and 2. The data indicated in Table 2 will be described in more detail within this chapter.

usRAP Approach

A large number of variables needed to be considered to apply the usRAP approach. More specifically, data had to be collected for almost 50 different locational, geometric, traffic flow, and roadside characteristics along the corridors highlighted in Figures 1 and 2. In addition, as noted in Chapter 2, these data were collected for every 328 foot segment along these corridors.

Fortunately, many of the factors remained consist for many, if not most, of the 328 foot segments. In addition, some of the data collected was relatively automated (e.g., latitude and longitude) and others relatively scarce and/or non-existent along the rural roadways considered. The factors collected for each segment are listed below:

Table 2. Minnesota CRSP approach data requirements

Transportation System Component	Data Required
Horizontal Curves	Horizontal curve radii (District)
	Severe Roadway Departure Crashes (District)
	Annual Average Daily Traffic (AADT) (County and District)
	Existence of an Intersection (County)
	Existence of a Visual Trap (County)
	Fatal and Major Injury Crash Information (County)
Stop-Controlled Intersections	Skew Angle (County)
	On or near a Curve (County)
	Existence of Commercial Development (County)
	Nearest Stop Sign Within 5 Miles (County)
	Minor/Major Roadway AADT Ratio (County)
	Railroad Crossing on Minor Approach (County)
	All Crash Information (County)
Roadway Segments	AADT (County and District)
	Severe Roadway Departure Crash Information (District)
	Number of Access Points (County)
	Roadway Departure Crash Information (County)
	Number of Horizontal Curves and Radii (County and District)
	Roadside Risk Assessment (County)

*All crash data used was from 2008 to 2012.

- Carriageway/roadway divided/undivided and direction
- Distance from the start of the road segment
- Length of the roadway section considered
- Latitude and Longitude for section start point
- Landmarks
- Traffic Flow
- Motorcycle Percentage
- Observed Bicycle Flow
- Pedestrian Flow – Crossing Road
- Pedestrian Flow – Along Road
- Area Type

- Number of Through Lanes
- One-Way/Two-Way Flow
- Speed
- Through Lane Width
- Paved Shoulder Width
- Unpaved Shoulder Width
- Existence of Shoulder Rumble Strips
- Horizontal Curvature and Advisory Posted Speed Limit
- Quality of Curve with Regard Driver Perception of Sharpness
- Overtaking Demand (typically done in pre-processing)
- Quality of Delineation
- Vertical Alignment Variation
- Road Condition with Regard to Skid Resistance
- Sidewalk Provision – Right
- Sidewalk Provision – Left
- Land Use – Right and Left
- Side Friction (e.g., Roadside and Traffic Interaction)
- Pedestrian Crossing Facilities
- Quality of Pedestrian Crossing Visibility
- Bicycle Facilities Availability
- Roadside Severity – Segregated Bicycle Path
- Motorcycle Facilities Availability
- Roadside Severity – Segregated Motorcycle Path
- Speed Limit – Segregated Motorcycle Path
- Median Type – Segregated Motorcycle Path
- Minor Access Point Density
- Roadside Severity – Right
- Roadside Severity – Left
- Intersection Type
- Intersection Quality with Regard to Traffic Control and Sight Distance
- Intersecting Road Volume: approach traffic volume
- Median Type – this is a notation of the median type (e.g., centerline, raised median, etc.)
- Major Upgrade Cost Impact (e.g., influence of situation on the cost of major developmental upgrade projects)
- Comments
- Presence of Roadwork (Work Zones)

All the factors listed above are defined in more detail within Appendix A and even more specifically in the reference "usRAP Coding Manual for Star Ratings and Safer Roads Investment Plans" (*8*). A number of the data entry decisions were relatively subjective and this document assisted in the definition of the different options for these variables. In addition, there was a quality control process in which the data entered were checked by more than one method. A sample of the data collected to apply usRAP is summarized in more detail later in this chapter.

Description of Data

Minnesota CRSP Approach District-Level

As noted in Table 2, the Minnesota CRSP approach required the collection and summary of some data for a larger regional area. More specifically, data were collected for the Iowa DOT Districts within which Dallas and Buchanan counties were located. The application of systemic safety approaches along low volume roadways requires these type of data to assist in the definition of most crash-based risk factors. These regional data were also required because there is not enough fatality and severe injury crash data along rural and/or low volume roadways within a typical county to show crash patterns. The data were collected to investigate these crash patterns and extrapolate that to the counties of interest. The Iowa DOT District 4 and 6 (Dallas and Buchanan County districts, respectively) data collected for the Minnesota CRSP approach are summarized below. These data include segment AADT, curve radius and AADT, and severe (i.e., fatal and major injury) roadway departure crashes.

Segment Volume

The Iowa DOT collects traffic flow on a regular basis throughout the entire transportation system within Iowa. One third of the Iowa transportation system has these data collected every year. The volume used for this secondary (i.e., county) roadway analysis was the most recent available from 2005 to 2012. These data are collected for roadway segments of various lengths (e.g., nine feet to more than 1.5 miles). The segments for which traffic flow was collected are defined by the Iowa DOT and are related to changes in various roadway characteristics (e.g., traffic flow, geometrics, speed limits, etc.). The total number of paved secondary roadway segments, and therefore the sample size for the AADT collected, was 5,736 in Iowa DOT District 4 and 7,964 in Iowa District 6. The descriptive statistics of the AADT database for each district are shown in Table 3. The distribution of paved secondary roadway segment AADT in each county is shown in Figure 3.

Table 3. Paved secondary roadway segment AADT descriptive statistics

	Iowa DOT District 4	**Iowa DOT District 6**
Number of Segments	5,736	7,964
Minimum AADT (vpd)	5	5
Maximum AADT (vpd)	7,700	16,600
Average AADT (vpd)	583	955
Standard Deviation (vpd)	717	1,305

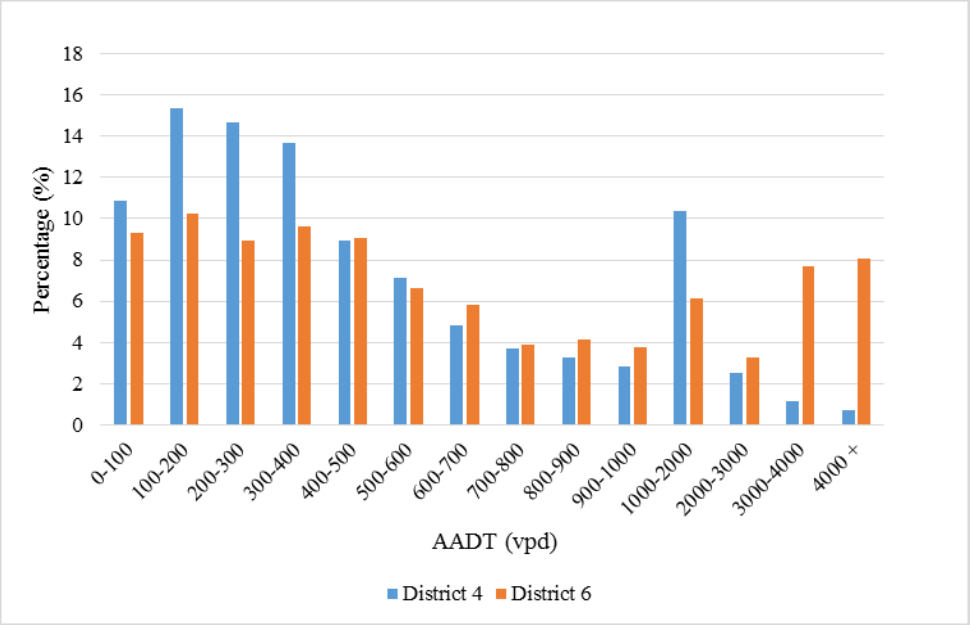

Figure 3. Paved secondary roadway segment AADT

Figure 3 shows that District 4 and 6 have different distributions of paved secondary roadway segment AADT. More than 50 percent of the paved secondary roadway segments in Iowa DOT Districts 4 and District 6 have an AADT less than 400 and 600 vpd, respectively. In addition, more than 75 percent of the segments in Iowa DOT Districts 4 and 6 have AADTs less than 700 and 1500 vpd. In other words, District 4 has more low volume paved secondary roadway segments than District 6. This result is not completely unexpected because there are a larger number of cities in District 6, it may be more suburban, and there is likely more commuting or traffic flow along county roadways. These AADT data were used with district level crash data to define safety patterns related to volume. The crash data and the plots created with AADT and crashes are described later in this document.

Horizontal Curve Radius and Volume

The second set of district data collected were horizontal curve radii and the AADT that occurred along those curves. The horizontal curve radii were estimated during another research project and two approaches were used (*21*). The first methodology estimated horizontal curve radii by using a circular regression. The second methodology estimated horizontal curve radii based on curve and chord length. More information about these estimation methodologies can be found in the *Horizontal Curve Identification and Evaluation* report (*21*). If both estimation methods are used on one horizontal curve, the average of the calculations was determined and applied

Descriptive statistics for the horizontal curves defined along the paved secondary roadways in Iowa DOT Districts 4 and 6 are included in Table 4.

Table 4. Paved secondary roadway horizontal curve radii and AADT descriptive statistics

	Iowa DOT District 4	Iowa DOT District 6
Number of Horizontal Curves	1,309	2,413
Minimum Radius (feet)	63	79
Maximum Radius (feet)	8,825	5,044
Average Radius (feet)	1,274	1,058
Radius Standard Deviation (feet)	993	652
Minimum AADT (vpd)	5	10
Maximum AADT (vpd)	5,600	9,200
Average AADT (vpd)	584	754
AADT Standard Deviation (vpd)	711	913

Overall, there were more than 2,400 horizontal curves in the data base for Iowa DOT District 6 and more than 1,300 in District 4. The range of horizontal curve radii was 0 to 8,825 feet in Iowa DOT District 4 and 79 to 5,044 feet in District 6. In addition, the average horizontal curve radii was 1,274 feet with a standard deviation of 711 feet in Iowa DOT District 4 and these descriptive statistics were 1,058 feet and 913 feet, respectively, in Iowa DOT District 6. The distributions of horizontal curve radii in each district are shown in Figure 4. The distributions are relatively similar, but Iowa DOT District 4 has a larger percentage of horizontal curves with very long radii (e.g., 2,000 feet or more).

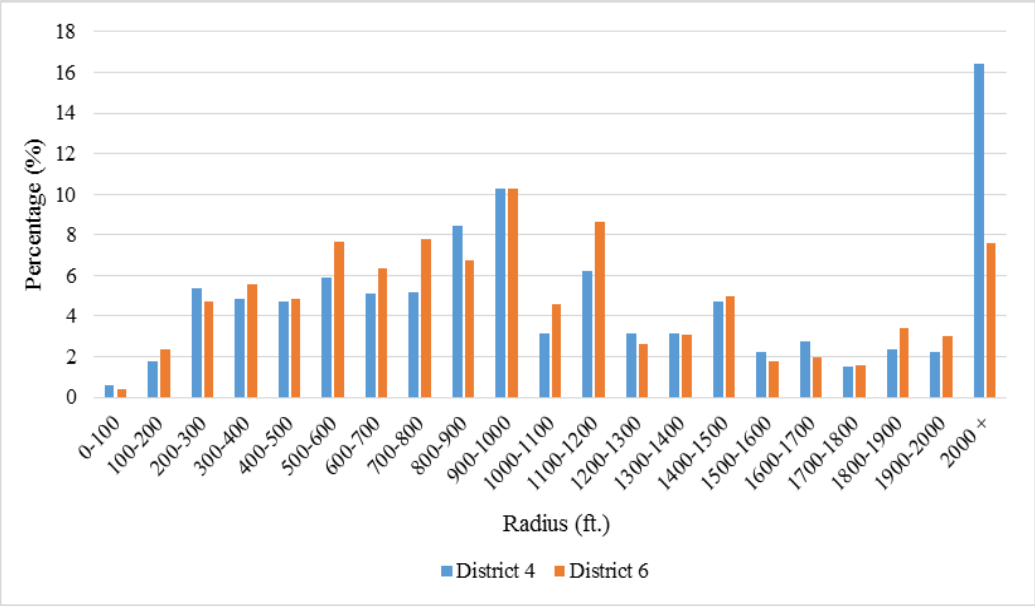

Figure 4. Distribution of paved secondary roadway horizontal curve radii

The descriptive statistics for the AADT that occurs along the horizontal curves summarized above are also provided in Table 4. Overall there was a range of AADT from 5 to 5,600 vpd in Iowa DOT District 4 and from 10 to 9,200 vpd in Iowa DOT District 6. The average AADT,

however, was only 584 and 754 vpd (with a standard deviation of 711 and 913) in Iowa DOT Districts 4, and 6, respectively. Figure 5 shows the horizontal curve AADT along paved secondary roadways within the two districts. Overall, approximately 52 and 57 percent of the horizontal curves in Iowa DOT Districts 4 and 6 had a radius of less than 1,000 feet. Bonneson, et al. indicated in their research that horizontal curves with a radius less than 1,000 feet can be expected to experience a sharp increase in crash rate (*22*). The distributions shown in Figure 5 are also relatively similar, but there was almost twice the percentage of horizontal curves with an AADT between 1,000 and 2,000 vpd in Iowa DOT District 6 than in Iowa DOT District 4. The distributions in Figure 5 also show that more than 57 and 42 percent of the horizontal curves in Districts 4 and 6, respectively, had AADT less than 400 vpd. In addition, approximately 80 and 90 percent of the horizontal curves in Iowa DOT Districts 4 and 6, respectively, had a radius of less than 2,000 feet.

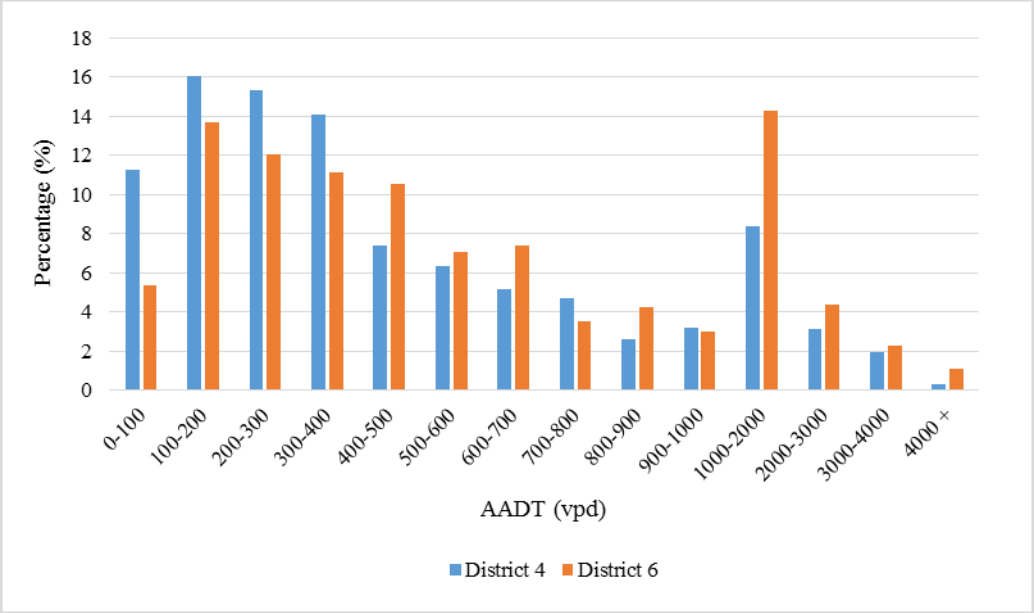

Figure 5. Distribution of horizontal curve AADT

Roadway Departure Crash and Locational Data

Roadway departures result in many of the crash fatalities within the United States. Iowa DOT District and horizontal curve severe (i.e., fatality and/or major injury) roadway departure crash and locational data along paved secondary roadways from 2008 to 2012 were collected and summarized for Iowa DOT Districts 4 and 6. Overall, a total of 28 and 27 roadway departure crash fatalities were recorded in Iowa DOT Districts 4 and 6, respectively, during the five year time period considered. In addition, 65 and 87 roadway departure crash major injuries occurred in Iowa DOT District 4 and 6, respectively. Along horizontal curves in these districts there were 14 roadway departure crash fatalities and 34 roadway departure crash major injuries in Iowa DOT District 4 from 2008 to 2012, and 10 roadway departure crash fatalities and 43 roadway departure crash major injuries in Iowa DOT District 6. In other words 50 and 37 percent of the roadway departure fatalities during this time period, within Iowa DOT Districts 4 and 6,

respectively, occurred along horizontal curves. The location of these crash data, along with the AADT and horizontal curve information previously described, were used in the application of the Minnesota CRSP approach to define two of the crash-based risk factors applied to the county roadway database of interest. This application is explained further in the next section of this report

Minnesota CRSP Approach Site Specific

In addition to the district level data previously described the application of the Minnesota CRSP approach also required the collection of a wide range of data to describe the characteristics of the paved secondary roadway systems shown in Figures 1 and 2. The data needed were essentially defined by the process and approach described along with the safety risk factors noted (See Chapter 2). Data were collected about the characteristics of horizontal curves, stop-controlled intersections, and roadway segments along the paved secondary roadways in Buchanan and Dallas counties (See Figures 1 and 2). The following section of this document summarizes the site specific data collected to apply the Minnesota CRSP tool/methodology.

Horizontal Curve Characteristics

There were five safety risk factors used in the Minnesota CRSP approach to systemically rank the horizontal curves along the county roadways of interest in this project. These safety risk factors included the following:

- Radius
- Traffic Volume
- Intersection Presence
- Visual Trap Presence
- Crash Experience

The existence of the first two safety risk factors listed above at a horizontal curve within along the county roadways of interest was defined using the district-level data previously described and site specific data. Their definition and application within the two counties of interest are described below. The other three safety risk factors above were identified through the collection of site specific data. Overall, data were collected about the characteristics of 82 and 83 horizontal curve curves in Buchanan and Dallas Counties, respectively. The number of these horizontal curves that included each of the five safety risk factors is noted below.

Radius. Radius was defined as one of the safety risk factors at horizontal curves. The existence of this factor at a particular curve was defined through the consideration of the district level horizontal radii and crash data previously described. Figures 6 and 7 show the percentage of horizontal curves and severe (i.e., fatal and/or major injury) roadway departure crashes on the horizontal curves within Iowa DOT Districts 4 and 6, respectively. This safety risk factor is defined as the range of horizontal curve radii that are overrepresented with severe roadway departure crashes.

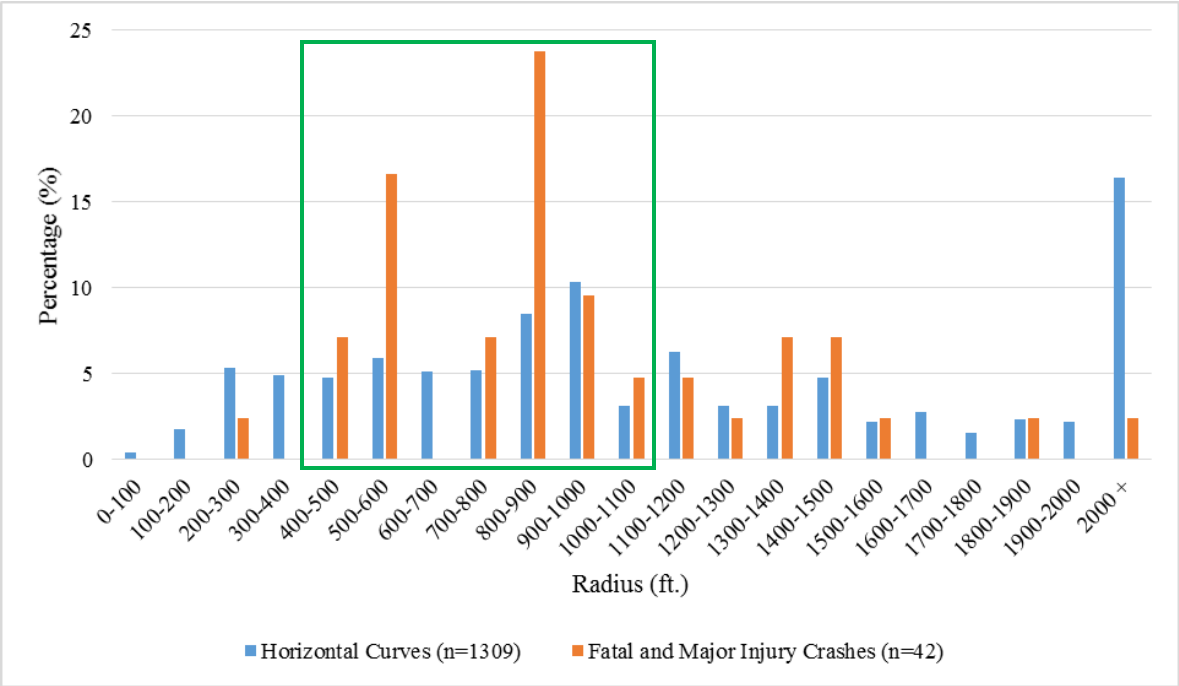

Figure 6. Iowa DOT District 4 horizontal curve severe roadway departure crash and radii distribution

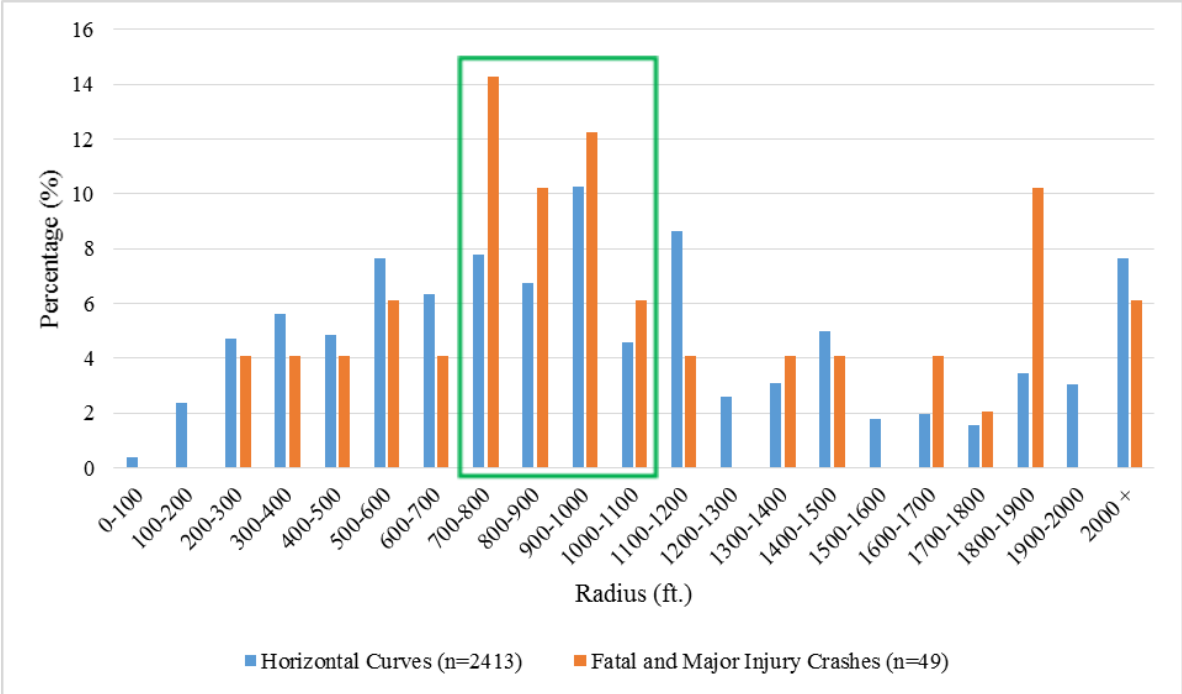

Figure 7. Iowa DOT District 6 horizontal curve severe roadway departure crash and radii distribution

The research team selected the range shown by the box in each figure. In Iowa DOT District 4 (which applies to Dallas County) a horizontal curve radius range of 400 to 1,100 feet was selected. Approximately 70 percent of the severe roadway departure crashes along horizontal curves occurred within this range, but only about 42 percent of the horizontal curves in the district have a radii within that range. In Iowa DOT District 6 (which applies to Buchanan County) a horizontal curve radius range of 700 to 1,100 feet was selected. Approximately 42 percent of the severe roadway departure crashes along horizontal curves occurred within this range, but only 30 percent of the radii were within that range. Clearly, the overrepresentation for the ranges selected is greater in Dallas County than Buchanan County.

Radius data were also collected for the horizontal curves in Buchanan and Dallas counties and compared to the ranges shown in Figures 6 and 7. If a horizontal curve had a radius that was included in the range identified it was concluded that it met the radius safety risk factor. There were 82 horizontal curves in Buchanan County with a range of radii from 197 to 3,746 feet. The average and standard deviation of the horizontal curve radii in Buchanan County were 1,361 feet and 722 feet, respectively. Overall, it was found that 12 (or 15 percent) of these horizontal curves met the criteria for this safety risk factor. Eight-three horizontal curves were evaluated in Dallas County and they had a range of radii from 186 to 4,868 feet, an average of 1,537 feet, and a standard deviation of 857 feet. A total of 20 (or 24 percent) horizontal curves in Dallas County were found to meet the criteria for this safety risk factor.

Traffic Volume. An approach similar to that followed for the horizontal curve radius safety risk factor was also followed to define the horizontal curve traffic volume risk factor. Horizontal curve AADT and severe roadway departure crash data were collected for Iowa DOT Districts 4 and 6 (described previously). Figures 8 and 9 show the percentage of horizontal curves with a particular AADT and the percentage of severe (i.e., fatal and/or major injury) roadway departure crashes that occurred along them.

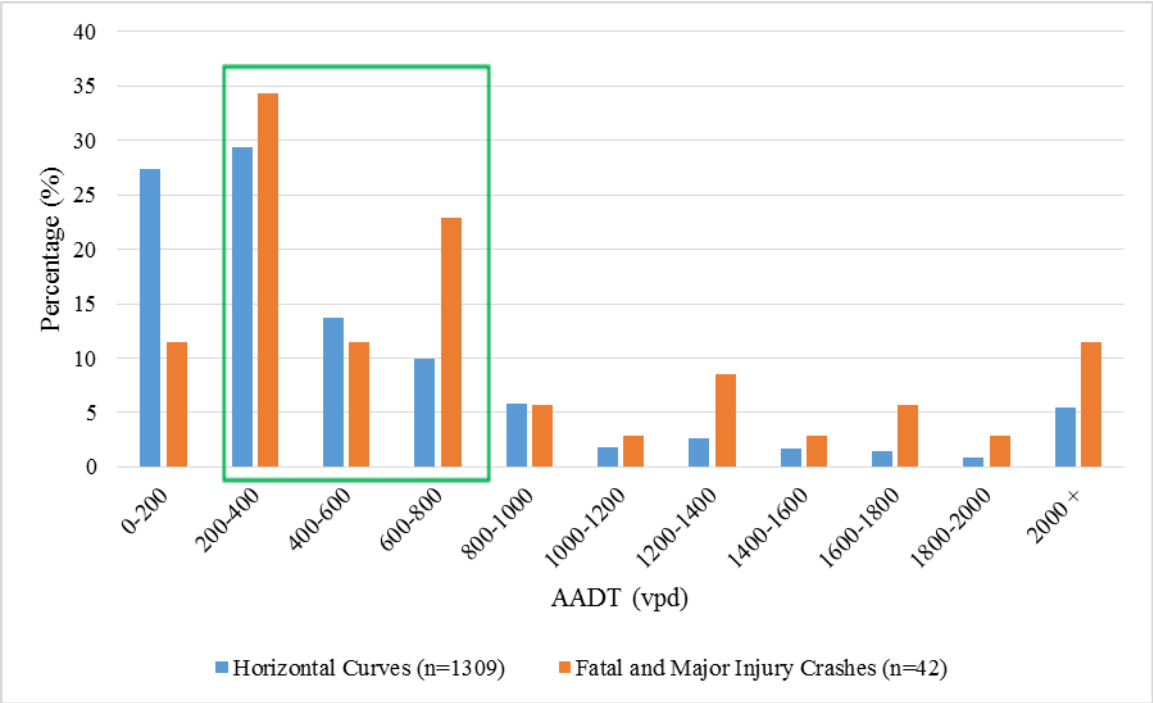

Figure 8. Iowa DOT District 4 horizontal curve severe roadway departure crash and AADT distribution

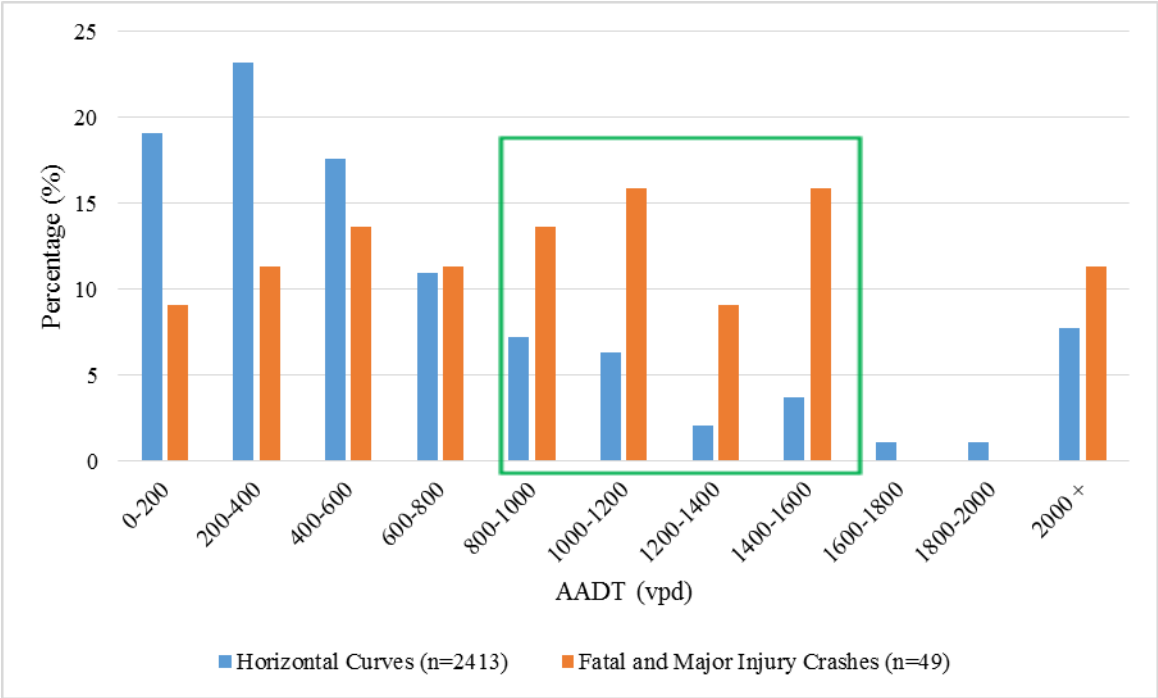

Figure 9. Iowa DOT District 6 horizontal curve severe roadway departure crash and AADT distribution

The research team selected 200 to 800 feet for Iowa DOT District 4 and 800 to 1,600 feet for Iowa DOT District 6 (See Figures 8 and 9) as the "over-represented" AADT range. In Iowa DOT District 4 (which applies to Dallas County) approximately 52 percent of the horizontal curves had an AADT volume in the range selected but about 68 percent of severe roadway departure crashes occurred there. In Iowa DOT District 6 (which applies to Buchanan County) only approximately 18 percent of horizontal curves occurred in the range selected, but approximately 55 percent of the severe roadway departure crashes occurred there. In this case, the overrepresentation occurring is greater in Buchanan County for the ranges selected.

Volume data were collected for the horizontal curves in Buchanan and Dallas Counties and compared to the ranges shown in Figures 7 and 8. If a horizontal curve had an AADT that was included in the range identified it was concluded that it met the traffic volume safety risk factor. There were 82 horizontal curves in Buchanan County with a range of traffic volumes from 200 to 1,540 vpd. The average and standard deviation of the horizontal curve AADT in Buchanan County were 769 and 358 vpd, respectively. Overall, it was found that 43 (or 52 percent) of these horizontal curves met the criteria for this safety risk factor. Eight-three horizontal curves were evaluated in Dallas County and they had a range of traffic volumes from 210 to 4,430 vpd, an average of 1,261 feet, and a standard deviation of 893 feet. A total of 37 (or 45 percent) horizontal curves in Dallas County were found to meet the criteria for this safety risk factor.

Intersection Presence. The third risk factor considered for horizontal curves was the presence of a paved roadway intersection within 150 feet. The visualization tools, such as Google StreetView™ or ArcMap™, were used to draw a circle with a radius of 150 feet that was located at each intersection in the database (described in the next section of this report) to determine the number of horizontal curves within that range. One paved intersection, therefore, could be within a 150 feet of multiple horizontal curves. Overall, it was determined that 43 and 37 (or 52 and 46 percent) of the horizontal curves evaluated in Buchanan and Dallas counties, respectively, met the criteria of this safety risk factor.

Visual Trap Presence. It has been speculated that the presence of a visual trap may increase the risk of being involved in a crash at a horizontal curve. A visual trap is essentially the appearance (to the driver) that a roadway continues in a straight alignment when in reality it curves left or right. This situation may occur, for example, when roadways have been realigned and there are tangent intersections at the point or curvature or tangency of the horizontal curve, and/or a line of trees or telephone continue straight rather than follow the alignment of the curving roadway. The existence of a visual trap in one or both directions at the horizontal curves in the database were collected using Google StreetView™ images. Overall, it was found that only 2 (or approximately 2 percent) of the horizontal curves evaluated in both Buchanan and Dallas had what appeared to be a visual trap and met the criteria for this risk factor.

Crash Experience. The fifth safety risk factor considered for horizontal curves was crash experience. The criteria for this safety risk factor was met at a horizontal curve if it experienced a severe (i.e., fatal and/or major injury) crash during the five year period considered (i.e., 2008 to 2012). Overall, Buchanan County and Dallas County experienced 17 and 33 fatal and major injury crashes, respectively from 2008 to 2012. However, only 8 and 10 of these crashes

occurred in Buchanan and Dallas County, respectively, along horizontal curves. The number of horizontal curves in the research project databases that experienced at least one these crashes was seven in both counties. Therefore, these seven horizontal curves met the criteria for this safety risk factor. The number of severe crashes occurring along horizontal curves represented about 47 percent of the total number of severe crashes in Buchanan County and approximately 30 percent of the severe crashes in Dallas County. However, the seven curves in each county that experience one or more severe crashes only represent about 8 percent of the horizontal curves considered in this research.

Stop-Controlled Intersection Characteristics

The second transportation system component considered by the Minnesota CRSP approach was stop-controlled intersections. Data for seven safety risk factors were collected these intersections and they included:

- Skew Angle
- Intersection On/Near a Horizontal Curve
- Commercial Development
- Distance to Nearest Stop Sign
- AADT Ratio
- Railroad Crossing on Minor Approach
- Crash History

The data that defined the safety risk factors above were all site specific. No comparison to the district-level data previously described was needed. Overall, safety risk factor data were collected for 52 stop-controlled intersections in Buchanan County and 47 stop-controlled intersections in Dallas County. The intersections considered were between two paved secondary roadways, and also between paved secondary roadway and United States highways, interstate ramps, and other paved local roadways. The data collected to determine if these stop-controlled intersections met the criteria of each safety risk factor listed above are described below.

Skew Angle. The skew angle of an intersection has been shown to impact safety (*12*). The skew angle at each of the stop-controlled intersections in Buchanan and Dallas County databases were measured using the measurement tool available in ArcMap™. In this research, stop-controlled intersections with a skew that was 15 degrees or more from a right angle were considered to meet the criteria for this safety risk factor. This data collection activity only consisted of determining whether an intersection was or was not skewed by 15 degrees or more. Overall, 16 and 17 (or 31 and 36 percent) stop-controlled intersections in Buchanan and Dallas Counties were identified as having a skew of 15 degrees or more and, therefore, met the criteria for this safety risk factor.

Intersection On/Near a Horizontal Curve. The second risk factor considered for stop-controlled intersections was whether they were near or within a horizontal curve. An intersection was considered to meet the criteria for this safety risk factor if it was located within 150 feet of the ends of a horizontal curve. This data was collected by defining a circle with a 150 foot radius

around each intersection. Overall, a determination was made that a total of five stop-controlled intersections (or 10 percent) were near or within horizontal curves in Buchanan County and 11 stop-controlled intersections (or 23 percent) had the same characteristic in Dallas County.

Commercial Development. The third intersection safety risk factor for which data were collected was the existence or presence of commercial development (other than a residence or a farm) in any quadrant. Several different types of commercial development were identified using the visualization tools previously described. Overall, four of the stop-controlled intersections (or 8 percent) considered in Buchanan County had commercial development in one or more quadrants and seven stop-controlled intersections (or 15 percent) with the same characteristic were identified in Dallas County. These stop-controlled intersections were determined to meet the criteria for this safety risk factor.

Distance to Nearest Stop Sign. Another safety risk factor considered in the Minnesota CRSP approach was the distance between stop signs. This factor was believed to be a measure of safety risk related to the increased likelihood of running a stop sign at an intersection that was relatively isolated. Data were collected about whether a stop sign on any paved roadway approach to each stop-controlled intersection in the database had another stop sign within five miles of its location. These data were collected with Google StreetView™. If the adjacent stop signs were greater than five miles from the stop-controlled intersection it was considered to meet this criteria. A total of 26 stop-controlled intersections (or 27 percent) were found to meet the criteria for this safety risk factor in Buchanan County and 14 of the of the stop-controlled intersections (or 30 percent) in Dallas County also did not have a stop sign within five miles.

AADT Ratio. The fifth stop-controlled intersection safety risk factor for which data were collected was AADT ratio. The AADT ratio was computed for each of the stop-controlled intersections in the two county databases. It was defined as the minor intersection roadway AADT divided by the major intersection roadway AADT. The minor intersection roadway was always the one with the smallest AADT. An average AADT was used if they varied on the different intersection approaches. In a few cases one of the intersection legs may also have a one-way operation. The approach was not adjusted for these situations. An intersection was determined to meet the criteria for this safety risk factor if it had a ratio between 0.4 and 0.8 (*4*). This was the same criteria used in Minnesota (*4*). Unfortunately, it was not possible to do a similar AADT ratio calculation for Iowa DOT Districts 4 and 6 as part of this research project. A total of 16 stop-controlled intersections (or 31 percent) in the Buchanan County database were determined to meet the AADT ratio safety risk factor criteria. In addition, 10 of the stop-controlled intersections (or 21 percent) in the Dallas County database also met the same criteria. The ADT ratios calculated in both counties ranged from approximately zero to almost one.

Railroad Crossing on Minor Approach. The sixth safety risk factor considered in this research was whether a railroad crossing was within 500 feet of the stop-controlled intersection on its minor approaches. These data were collected using ArcMap™. In general, it was found that none of the stop-controlled intersections considered in Buchanan County met the criteria for this safety risk factor, but two of stop-controlled intersections (or 4 percent) in Dallas County did have a nearby railroad crossing.

Crash History. The Minnesota CRSP approach used crash history as the seventh stop-controlled intersection safety risk factor. If a stop-controlled intersection experienced any type of crash within the five year period (i.e., 2008 to 2012) considered it was considered to meet the criteria for this safety risk factor. The crash data collected as part of this project found that 25 and 28 of the intersections (or 48 and 60 percent) in Buchanan and Dallas Counties, respectively, experienced at least one crash in the five years considered.

Segment Characteristics

The third transportation system component considered in the Minnesota CRSP approach was roadway segments. These segments incorporate the intersections and horizontal curves described previously along with the tangent sections that connect them. As noted at the beginning of this chapter, data were collected along 197 and 156 miles of paved secondary roadways in Buchanan and Dallas Counties, respectively. This mileage was divided into 58 segments in each county for purposes of this research. These segments were defined by similarities in AADT, speed limits, and geometric features. Segment lengths below 0.5 miles were not used and ranged from approximately 0.50 to 9.7 miles in Buchanan County. These segments also had an average length of about 3.3 miles and a standard deviation of approximately 2.1 miles. The length of the segments in Dallas County, on the other hand, ranged from approximately 0.50 to 10.4 miles, and had an average length of about 2.6 miles and a standard deviation of approximately 2.0 miles. Data were collected for these segments to determine if they met the criteria defined for five safety risk factors. These safety risk factors included the following:

- AADT
- Access Density
- Roadway Departure Crash Density
- Critical Radius Curve Density
- Edge Risk

The existence of the first safety risk factor along the roadway segments were based on both district-level data (previously described) and site specific data. The definitions for these criteria are described below. The other four safety risk factors above were defined by the data collected of data within the counties.

AADT. At the beginning of this chapter the AADT and severe (i.e., fatal and major injury) roadway departure crash data collected and summarized for the paved secondary roadway system within Iowa DOT Districts 4 and 6 were described. The criteria for this safety risk factor was defined by the range of AADT collected in each district that appears to be overrepresented with severe (i.e., fatal and major injury) roadway departure crashes. The percentage of paved secondary roadway mileage and percentage of severe roadway departure crashes for different AADTs are plotted in Figures 10 and 11 for Iowa Districts 4 and 6, respectively.

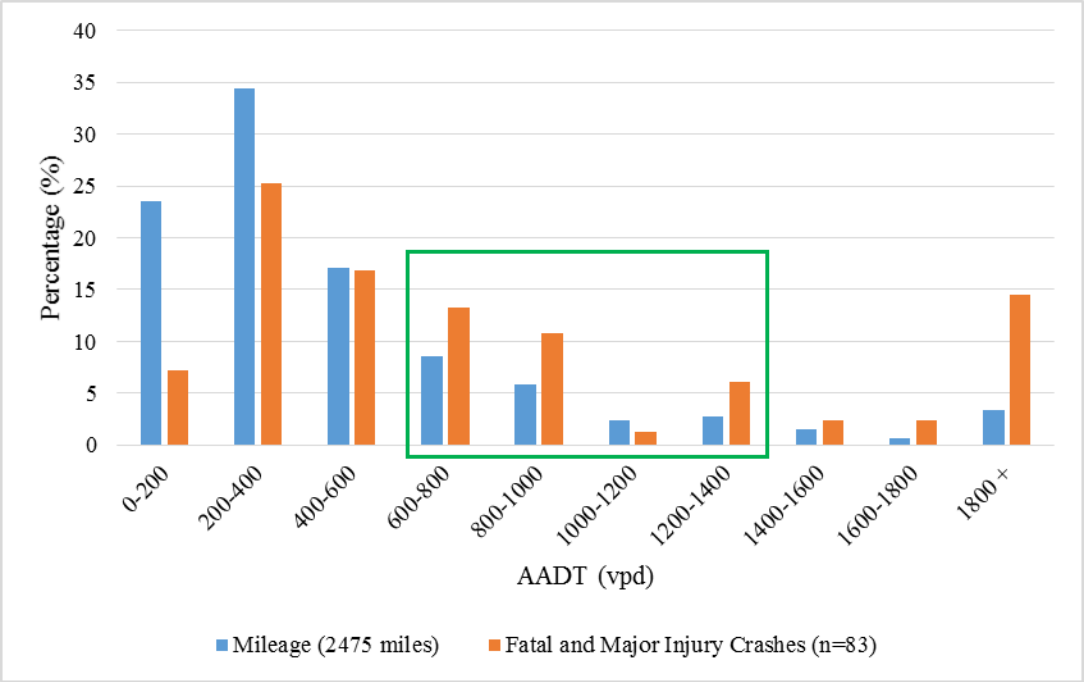

Figure 10. Iowa DOT District 4 severe roadway departure crash and AADT distribution

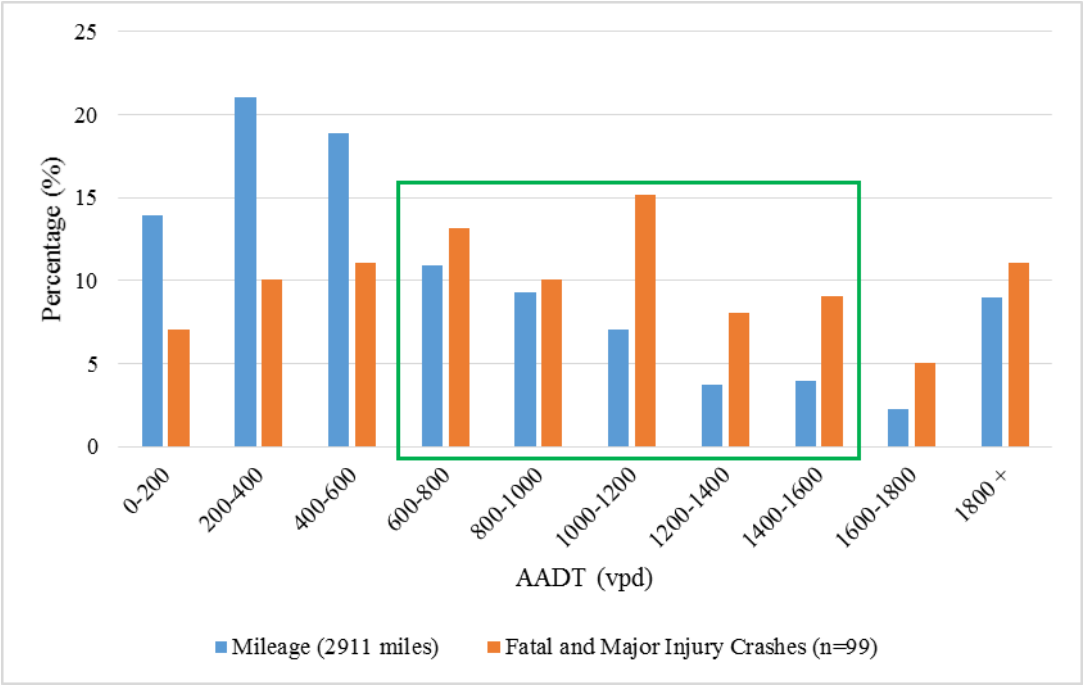

Figure 11. Iowa DOT District 6 severe roadway departure crash and AADT distribution

The boxes noted in each of the figures were selected by the project team as the range of AADT within which it appeared there was an overrepresentation of severe (i.e., fatal and major injury) roadway departure crashes. In Iowa DOT District 4 (which applies to Dallas County) this range was from 600 to 1,400 vpd and in Iowa DOT District 6 (which applies to Buchanan County) it

was 600 to 1,600 vpd. Overall, only about 20 percent of the roadway mileage in Iowa DOT District 4 had an AADT between 600 and l,400 vpd, but 31 percent of the severe (i.e., fatal and major injury) roadway departure crashes occurred along them. Similarly, in Iowa District 6 only about 35 percent of the roadway mileage had an AADT from 600 to 1,600 vpd, but they experienced about 55 percent of the severe (fatal and major injury) roadway departure crashes in the district.

The roadway segment AADT in Buchanan and Dallas Counties, respectively, ranged from 30 to 3,620 and 60 to 4,040 vpd. The average AADT was 864 and 1,123 in Buchanan and Dallas County, respectively, and the data had a standard deviation of 688 and 936. In general, it was determined that a total of 27 and 20 (or 47 and 34 percent) of the roadway segments in the Buchanan and Dallas County databases, respectively, met the criteria for this safety risk factor.

Access Density. The second segment-related safety risk factor for which data were collected was access density. It has been shown that access density has an impact on the safety of roadways (12). The number of access points (including intersections) along each of the roadway segments considered was summed and divided by the segment length to calculate access density. The range of access points per mile for the segments defined in Buchanan and Dallas Counties was 1.8 to 34.2 and 0 to 45.1, respectively. In addition, the average access density for Buchanan and Dallas Counties was 8.9 and 12.9 access points per mile, respectively (and the data had a standard deviation of 6.9 and 9.2 access points per mile). A segment was determined to meet the criteria for this safety risk factor if it had an access density greater than the county average. Overall, 19 and 22 segments (or 33 and 38 percent) of the segments in Buchanan and Dallas Counties, respectively, met this criteria.

Roadway Departure Crash Density. Roadway departure crash density was the third safety risk factor considered for roadway segments. First, the average number of roadway departure crashes per mile per year (i.e., the roadway departure crash density) was calculated for each of the segments considered. In other words, the total number of roadway departure crashes (of any severity level) from 2008 to 2012 were summed for each segment and divided by its length in miles and then by 5 (for the number of data years). The range of roadway departure crash density calculated for Buchanan County was 0 to 0.33 crashes per mile per year and 0 to 0.54 in Dallas County. The average roadway departure crash density in both Buchanan and Dallas Counties was 0.058 crashes per mile per year, but the standard deviation was 0.078 and 0.115 crashes per mile per year, respectively. A segment was determined to meet the criteria for this safety risk factor if its roadway departure crash density was greater than the county average. Overall, 24 and 17 of the segments (or 41 and 29 percent) in Buchanan and Dallas counties, respectively, were identified as meeting this criteria.

Critical Radius Curve (CRC) Density. The fourth risk factor considered in the Minnesota CRSP approach for roadway segments was CRC density. This density was calculated using the Iowa DOT District 4 and 6 data previously described. The average CRC density for each districts was calculated by summing the number of horizontal curves within the “critical” range of radii previously selected as overrepresented with severe (i.e., fatal and major injury) roadway departure crashes (See Figures 6 and 7) and dividing that by the roadway length in the database.

The average CRC for Iowa DOT Districts 4 and 6 were calculated to be 0.14 and 0.08 horizontal curves per mile, respectively. This characteristic ranged from 0 to 0.89 horizontal curves per mile in Buchanan County, had an average of 0.08 horizontal curves per mile, and a standard deviation of 0.21 horizontal curves per mile. In Dallas County, on the other hand, the CRC density had a range of 0 to 3.39 horizontal curves per mile, had an average of 0.25 horizontal curves per mile, and a standard deviation of 0.65 horizontal curves per mile. Overall, it was found that 10 and 13 roadway segments (or 17 and 22 percent) in Buchanan and Dallas Counties, respectively, were above the average Iowa DOT District CRC density and, therefore, met the criteria for this safety risk factor.

Edge Risk. The final safety risk factor evaluated for roadway segments in Buchanan and Dallas Counties was roadside edge risk. This edge risk assessment was intended to measure the potential negative consequences that could occur when vehicles leave the travel lane. The rating system used was developed for the Minnesota CRSP approach and is defined in Chapter 2 (*4*). A roadway segment was determined to meet the criteria for this safety risk factor if it was assigned an edge risk rating of two or three by the research team. Segments that were assigned a two had little or no usable shoulder, but a reasonable clear zone; or, they had a usable shoulder but with fixed objects in the clear zone. Segments assigned a three had no usable shoulder and also had fixed objects within the clear zone. Overall, only two (or 3 percent) of the segments in Buchanan County were assigned a two, but there were 24 segments (or 41 percent) in Dallas County that were given this designation. None of the segments considered were assigned a three.

usRAP Approach

One of the objectives of this research project was to evaluate the results from more than one systemic safety tool or methodology. The second tool/methodology selected for further consideration in this research project was the usRAP approach. As noted previously, the application of the usRAP approach requires the collection of data about approximately 40 to 50 roadway characteristics for every 328 foot roadway segment. These characteristics were listed previously and are defined in more detail in Appendix A and the reference document for usRAP coding (*8*). The data needed to apply usRAP were relatively easy to collect through the use of Google StreetView™ and the number of crash fatalities and/or serious injuries from 2008 to 2012 in Buchanan and Dallas Counties were acquired from the Iowa DOT statewide crash database. These crash data were used for calibration purposes in the usRAP approach (but usRAP could have been applied without them). The process used by usRAP to determine the potential safety risk, safety improvement countermeasures, and countermeasure implementation benefit to cost ratio along each 328 foot segment was described in Chapter 2.

usRAP data were collected for the paved secondary roadway systems shown in Figures 1 and 2. This is the same database of roadways for which data were collected for the Minnesota CRSP approach. In Buchanan County there were 197 miles of roadway in the database and in Dallas County there were 156 miles. The usRAP software produces a detailed condition report for each county that summarizes the data collected for approximately 40 to 50 different roadway characteristics defined. A brief synopsis of some characteristics on the condition report that showed some variation are included in Table 5 for Buchanan and Dallas Counties.

Table 5 shows that there is very little variability in the roadway characteristics for which usRAP data were collected. The variability in the characteristics included in Table 5, however, was somewhat higher in Dallas County than those in Buchanan County.

usRAP Data Quality Control

Following the collection of data for usRAP a vigorous quality assurance review was also completed to ensure consistency, reliability and accuracy within the information gathered. The quality assurance process involved a check of 29 variables to validate the coded data prior uploading the files for processing.

Focus Group Meeting Results

Systemic safety approaches have primarily, if not entirely, been applied along paved roadways. The data, research, and/or expert judgment used to apply the systemic safety approaches available are also primarily based on our knowledge of safety along paved roadways. One of the tasks included in this research project was to explore what, if any, factors might be considered in a systemic safety analysis of unpaved roadways.

On August 23, 2013 a focus group was held in Ames, Iowa that worked to identify factors that may impact the safety along gravel and/or rock roadways. Approximately 20 people from the research team and local or state agencies attended the focus group. They all primarily had a background in transportation engineering. The attendees were asked, without any limitations, to identify and discuss those factors they believed impacted gravel and/or rock roadway safety. The general categories that were noted to the attendees that might include safety risk factors included geometrics, traffic control, human behavior/traffic flow/demographics, maintenance and operations, educational issues, and enforcement. The safety risk factors suggested for gravel and/or rock roadways during this focus group are listed below:

- Good signing
- Enforcement Levels

Table 5. Sample of usRAP input data summary

Roadway Characteristic	Percentage of Buchanan County Paved Secondary Roadways	Percentage of Dallas County Paved Secondary Roadways
Vehicles per Day		
< 1000 vpd	75	59
1,000 to 5, 000 vpd	25	41
Road Condition		
Good	94	86
Medium	5	10
Poor	1	5
Land Use Left/Right		
Undeveloped	88/90	81/80
Residential	9/7	15/16
Area Type		
Rural	98	99
Semi-Urban	2	1
Speed		
55 mph	91	95
35 mph	5	1
Unpaved Shoulder Width		
>= 7.9 feet	8	17
3 to 7.9 feet	90	69
0 to <= 3 feet (1 meter)	1	10
Bicycle Flow		
None Recorded	98	95
Low	2	5
Roadside Severity Left/Right		
Distance to Object > 30 feet	90/91	85/84
Distance to Object = 15 to 30 feet	6/6	9/9
Distance to Object = 0 to 15 feet	1/1	3/3
Curvature		
Straight or Gently Curving	94	92
Moderate Curvature	4	7
Delineation		
Adequate	98	96
Poor	2	4
Vertical Alignment Variation		
Flat	96	80
Undulating/Rolling	4	19

*Not all characteristics or characteristic variables are shown. Conversions based on usRAP reference document (*8*).

- Ditch Design (Secondary Ditches for Heavy Rains)
- Driveway Location and Slopes
- Narrow Unprotected Guardrail

- Traffic Volumes
- Percentage of Teen Drivers & Education
- Horizontal Curve Radius
- Intersection Sight Distance
- Dust Levels
- Grading Windrows (i.e., Presence of Rock or Stock)
- Vertical Design
- Statuary Speed Legislation
- Obstructions
- Animals
- Narrow Bridges (some may have no guardrail/barriers)
- Surface Characteristics (e.g., tight/loose rock, rumbles/washboards, and variability of factors that impact surface)
- Vehicle Type (e.g., slow moving, ATVs, etc.)
- Unfamiliar Drivers (possibly on roadway due to online mapping shortest path suggestions)
- Vehicle Positioning
- Ex-Urban Development (i.e., roadway expectations and feelings of safety)
- Winter Maintenance (and approach difference in rural areas)
- Superelevation and Typical/Actual Cross Section
- Driver Distractions

The list of factors above includes a wide variety of roadway characteristics that the focus group attendees believed impacts safety along gravel or rock roadways. Of course, many of them are also believed to impact safety along paved roadways. The list of factors above, therefore, may be of value to those considering the application of systemic safety analysis on both paved and unpaved roadways. It should be noted, however, that the method used to define the criteria for these safety risk factors and/or their significance of their safety impacts could be different for paved and unpaved roadways. In addition, there are some factors listed above that would only be applicable for consideration when systemic safety approaches are applied along unpaved roadway systems (e.g., surface characteristics and dust levels).

Summary of Findings

This chapter described and summarized the data collected for the two systemic safety tools/methodologies selected for investigation in this research project. A wide variety of data had to be collected in order to apply both the Minnesota CRSP and usRAP approaches. The data collected for the Minnesota CRSP approach focused on horizontal curves, stop-controlled intersections, and roadways segments. In addition, the type of data that needed to be collected was determined by the defining criteria of the safety risk factors considered for these three transportation system components. The Minnesota CRSP approach required the collection of data within two Iowa DOT districts and the counties of interest. Overall, data were generally collected to assist in the definition of the criteria for five horizontal curve safety risk factors, seven stop-controlled intersection safety risk factors, and five roadway segment safety risk factors. The characteristics of the individual horizontal curves, stop-controlled intersections, and

roadway segments in the database were then compared to the safety risk factor criteria to determine if they met them or not. The number percentage of specific sites in each county that met these criteria are listed in Table 6. More information about the data collected at these sites is included in this chapter. The usRAP approach to systemic safety analysis, on the other hand, also required the collection of data to describe about 40 to 50 roadway characteristics for every 328 foot roadway segment in the database. Some of these data are summarized in Table 5 and they are defined in more detail in Appendix A. Finally, a list of safety risk factors that could be applied along gravel and/or rock roadways was provided in this chapter. These factors are the result of a focus group meeting. Some of them overlap with what might be considered for safety risk factors along a paved roadway and others do not.

Table 6. Number of sites meeting safety risk factor criteria

Transportation Element	Safety Risk Factor	Buchanan County	Dallas County
Rural Horizontal Curves	Radius	12 (15%)	20 (24%)
	Traffic Volume	43 (52%)	37 (45%)
	Intersection Presence	37 (45%)	47 (57%)
	Visual Trap Presence	2 (2%)	2 (2%)
	Crash Experience	7 (9%)	7 (8%)
Rural Stop-Controlled Intersections	Skew Angle	16 (31%)	17 (36%)
	Intersection On/Near a Horizontal Curve	5 (10%)	11 (23%)
	Commercial Development	4 (8%)	7 (15%)
	Distance to Nearest Stop Sign	26 (50%)	14 (30%)
	AADT Ratio	16 (31%)	10 (21%)
	Railroad Crossing on Minor Approach	0 (0%)	2 (4%)
	Crash History	25 (48%)	28 (60%)
Rural Segments	AADT	27 (47%)	19 (33%)
	Access Density	19 (33%)	22 (38%)
	Roadway Departure Crash Density	24 (41%)	17 (29%)
	Critical Radius Curve Density	10 (17%)	13 (22%)
	Edge Risk	2 (3%)	24 (41%)

Chapter 4 includes a summary or description of the ranking results from the Minnesota CRSP and usRAP approaches. A sensitivity analysis of the impact on their results due to changes in some of their input variables is also completed and a summary of their results provided.

CHAPTER 4. RESULTS AND SENSITIVITY ANALYSIS

Chapter 3 summarized the data collected for the application of the Minnesota CRSP and usRAP systemic safety approaches to the paved secondary roadway systems in two counties in Iowa. Initial and alternative ranking results from these tools/methodologies for Buchanan and Dallas Counties are described in this chapter. In addition, the application of a sensitivity analysis on the ranking results produced by the Minnesota CRSP approach is summarized. More specifically, the impact on the ranking results due to various changes in the "weights" (i.e., coefficients) assigned to one or more safety risk factors are statistically evaluated. Similarly, the changes in the type and number of countermeasures suggested by the usRAP approach due to an alteration in its acceptable benefit-cost ratio input variable are described. It is hypothesized that the impacts, if any, shown by these sensitivity analyses on the results of these two approaches could influence how they are applied. In other words, it may provide more insight into the level of effort or specificity involved in the selection and/or application of the input variables analyzed. This chapter summarizes the initial and alternative rankings produced by the application of Minnesota CRSP and usRAP data described in Chapter 3, describes the sensitivity analysis approach(es) used, and provides the comparison results.

Minnesota CRSP Approach – Initial Ranking Results

The Minnesota CRSP systemic safety approach was used to determine the horizontal curves, stop-controlled intersections, and roadway segments in the database that met the criteria for the safety risk factors identified in Chapter 3. These safety risk factors, their criteria, and the number of horizontal curves, stop-controlled intersections, and segments that met the criteria were also identified in Chapter 3. The locational rankings produced by the Minnesota CRSP approach for specific horizontal curves, stop-controlled intersections, and roadway segments are primarily based on a sum of the safety risk factors for which the criteria are met. The safety risk factor assignment, ranking process, and Minnesota CRSP approach results are described below for Buchanan and Dallas counties.

Horizontal Curves

A total of 82 horizontal curves were assigned up to five safety risk factors in Buchanan County and a similar process was followed for 83 horizontal curves in Dallas County. The five horizontal curve safety risk factors considered were radius, traffic volume, intersection presence, and visual trap presence. Table 7 shows the number of horizontal curves in Buchanan and Dallas Counties that met the criteria for zero to five of these safety risk factors.

Table 7. Number of horizontal curves by safety risk factors assigned

	Number of Horizontal Curves	
Number of Safety Risk Factor Criteria Met	Buchanan County	Dallas County
0	21	11
1	31	38
2	20	27
3	10	7
4	0	0
5	0	0
Total	82	83

Table 7 shows none of the horizontal curves evaluated meet the criteria for four or five safety risk factors. In addition, 21 and 11 (26 and 13 percent) of horizontal curves in Buchanan and Dallas Counties, respectively, met the criteria for none of the safety risk factors included in the approach. However, 10 and seven of the horizontal curves (or 12 and 8 percent) in Buchanan and Dallas Counties, respectively, met the criteria for three of the safety risk factors and might be considered higher priority (according to the Minnesota CRSP approach reference document) (*4*). The weighted average number of horizontal curve safety risk factors at a location was 1.23 and 1.36 in Buchanan and Dallas Counties, respectively. The standard deviation of this same characteristic in each county was 0.97 and 0.82, respectively.

The horizontal curves in the Buchanan and Dallas County databases were ranked according to the number of safety risk factor criteria they met. When the same number of criteria were met by different horizontal curves (See Table 7) it was decided by the research team that the horizontal curve radius would be used to determine the rank. The horizontal curves with a shorter radius were assigned the higher rank and if the radii of the horizontal curves were the same an average ranking was assigned. The top 20 ranked horizontal curves in Buchanan and Dallas Counties are shown in Table 8. The horizontal curve labels used in Table 8 are generic in nature because the focus of this research was on the changes in the rankings that may occur when some of the inputs to the methodology used (i.e., the Minnesota CRSP approach) were altered. The results of the sensitivity analysis completed to accomplish this task are described later in this chapter. Overall, it should be noted from Table 7 that the horizontal curves listed in Table 8 all met the criteria of either two or three of the safety risk factors.

Stop Controlled Intersections

A total of 52 stop-controlled intersections were assigned up to seven safety risk factors in Buchanan County and a similar process was followed for 47 stop-controlled intersections in Dallas County. The five stop-controlled intersection safety risk factors were skew, intersection on/near a horizontal curve, commercial development, distance to nearest stop sign, AADT ratio,

railroad crossing on minor approach, and crash history. Table 9 shows the number of stop-controlled intersections in Buchanan and Dallas counties that met the criteria for zero to seven of the risk factors. In general, none of the stop-controlled intersections evaluated met the criteria for six or seven safety risk factors. In addition, nine and five (17 and 11 percent) stop-controlled intersections in Buchanan and Dallas Counties, respectively, met the criteria for none of the safety risk factors included in the approach. However, 14 of the stop-controlled intersections in Buchanan and Dallas counties (27 and 30 percent, respectively) met the criteria for three or more of the safety risk factors and might be considered higher priority (according to the Minnesota CRSP reference document) used for this project (*4*). The weighted average number of stop-

Table 8. Initial horizontal curve, stop-controlled intersection, and roadway segment rankings

Ranking	Horizontal Curves		Stop-Controlled Intersections		Roadway Segments	
	Buchanan County	Dallas County	Buchanan County	Dallas County	Buchanan County	Dallas County
1	Curve 70	Curve 44	Intersection 21	Intersection 39	Segment 44	Segment 54
2	Curve 14	Curve 79	Intersection 8	Intersection 45	Segment 18	Segment 30
3	Curve 4	Curve 54	Intersection 10	Intersection 14	Segment 54	Segment 20
4	Curve 65	Curve 29	Intersection 35	Intersection 29	Segment 55	Segment 17
5	Curve 1	Curve 51	Intersection 38	Intersection 10	Segment 17	Segment 47
6	Curve 50	Curve 42	Intersection 11	Intersection 18	Segment 13	Segment 23
7	Curve 38	Curve 6	Intersection 47	Intersection 19	Segment 3	Segment 55
8	Curve 61	Curve 16	Intersection 36	Intersection 28	Segment 31	Segment 7
9	Curve 57	Curve 40	Intersection 12	Intersection 42	Segment 41	Segment 28
10	Curve 82	Curve 62	Intersection 17	Intersection 25	Segment 20	Segment 41
11	Curve 39	Curve 37	Intersection 2	Intersection 30	Segment 45	Segment 33
12	Curve 40	Curve 28	Intersection 14	Intersection 31	Segment 46	Segment 43
13	Curve 56	Curve 43	Intersection 9	Intersection 16	Segment 14	Segment 31
14	Curve 76	Curve 69	Intersection 29	Intersection 26	Segment 57	Segment 26
15	Curve 12	Curve 47	Intersection 16	Intersection 6	Segment 58	Segment 51
16	Curve 26	Curve 4	Intersection 4	Intersection 11	Segment 56	Segment 53
17	Curve 58	Curve 75	Intersection 18	Intersection 38	Segment 39	Segment 19
18	Curve 2	Curve 71	Intersection 42	Intersection 46	Segment 5	Segment 42
19	Curve 24	Curve 13	Intersection 43	Intersection 1	Segment 38	Segment 34
20	Curve 11	Curve 17	Intersection 44	Intersection 8	Segment 30	Segment 5

controlled intersection safety risk factors at a location was 1.77 and 1.89 in Buchanan and Dallas Counties, respectively. The standard deviation for this same characteristic in each county was 1.23 and 1.22, respectively.

The stop-controlled intersections in the Buchanan and Dallas county database were ranked according to the number of safety risk factor criteria they met. When the same number of criteria were met by different stop-controlled intersections (See Table 9) it was decided by the research team that the AADT ratio of the intersections would be used to determine the rank.

Table 9. Number of stop-controlled intersections by safety risk factors assigned

	Number of Stop-Controlled Intersections	
Number of Safety Risk Factor Criteria Met	Buchanan County	Dallas County
0	9	5
1	13	15
2	16	13
3	10	9
4	3	4
5	1	1
6	0	0
7	0	0
Total	52	47

The stop-controlled intersections with the higher ratio were assigned the higher rank and if the ratio of the stop-controlled intersections were the same an average ranking was assigned. The reference document for the Minnesota CRSP approach suggested crash cost to complete this same activity (*4*). The top 20 ranked stop-controlled intersections in Buchanan and Dallas Counties are shown in Table 8. The stop-controlled intersection labels used in Table 8 are generic in nature because the focus of this research was on the changes in the rankings that may occur when some of the inputs to the methodology used (i.e., the Minnesota CRSP approach) were altered. The results of the sensitivity analysis completed to accomplish this task are described later in this chapter. Overall, it should be noted from Table 9 that the stop-controlled intersections listed in Table 8 all met the criteria of either two, three, four, or five of the safety risk factors.

Roadway Segments

A total of 58 roadway segments were assigned up to five safety risk factors in both Buchanan County and Dallas County. The five roadway segment safety risk factors were AADT, access density, roadway departure crash density, critical radius curve density, and edge risk. Table 10

shows the number of roadway segments in Buchanan and Dallas Counties that met the criteria for zero to five of the risk factors.

Table 10. Number of roadway segments by safety risk factors assigned

	Number of Roadway Segments	
Number of Safety Risk Factor Criteria Met	Buchanan County	Dallas County
0	15	5
1	16	19
2	19	27
3	4	6
4	4	1
5	0	0
Total	58	58

In general, none of the roadway segments evaluated met the criteria for all five safety risk factors. In addition, 15 and 5 (26 and 9 percent) of roadway segments in Buchanan and Dallas Counties, respectively, met the criteria for none of the safety risk factors included in the approach. However, 8 and 7 (or 14 and 12 percent) of the roadway segments in Buchanan and Dallas Counties, respectively, met the criteria for three or more of the safety risk factors and might be considered higher priority (according to the Minnesota CRSP reference document) (*4*). The weighted average number of roadway segment safety risk factors at a location was 1.41 and 1.64 in Buchanan and Dallas Counties, respectively. The standard deviation for the same characteristics in each county was 1.16 and 0.85, respectively.

The roadway segments in the Buchanan and Dallas county database were ranked according to the number of safety risk factor criteria they met. When the same number of criteria were met by different roadway segments (See Table 10) it was decided by the research team that AADT would be used to determine the rank. The roadway segment with the higher AADT was assigned the higher rank and if the two segment AADT were the same an average ranking was assigned. The reference document for the Minnesota CRSP approach suggested edge risk and roadway departure density to complete this same activity (*4*). The top 20 ranked roadway segments in Buchanan and Dallas Counties are shown in Table 8. The roadway segment labels used in Table 8 are generic in nature because the focus of this research was on the changes in the rankings that may occur when some of the inputs to the methodology used (i.e., the Minnesota CRSP approach) were altered. The results of the sensitivity analysis completed to accomplish this task are described later in this chapter. Overall, it should be noted from Table 10 that the roadway segments listed in Table 8 all met the criteria of either two, three, or four of the safety risk factors.

Minnesota CRSP Approach – Sensitivity Analysis

As previously noted, a sensitivity analysis of the rankings produced by the application of the Minnesota CRSP approach was completed as part of this project. The focus of this sensitivity analysis was the impacts, if any, an alteration of the "weight" assigned to one or more of the safety risk factors might have on the rankings produced. The safety risk factors used to create the initial ranking results described previously were weighted equally (i.e., they each had a coefficient value of one). The ability to alter the impact of meeting the criteria of a safety risk factor within the Minnesota CRSP approach, however, has always been possible. A general process describing this type of alteration is now available in the FHWA *Systemic Safety Project Selection Tool* report (*5*). The typical objective of these alterations is to more closely approximate the impact and/or importance of a safety risk factor.

The design of a sensitivity analysis is generally based on the number and possible "weight" range of the factors being evaluated. In this case, there were five safety risk factors for horizontal curves, seven safety risk factors for stop-controlled intersections, and five safety risk factors for roadway segments. The consideration of a change in the "weight" of every potential safety risk factor combination possible (189 permutations per county) was not possible as part of this project. A more calculated or focused approach to the sensitivity analysis was designed and is discussed below. In addition, the range of safety risk factor "weights" currently found in the literature and practice generally appears to be between 0.5 to 1.5 (*5*). Therefore, the sensitivity analysis applied for this research project, only considered changes from 1.0 to 2.0 (i.e., a doubling of the "weight" or significance of the safety risk factor). The three sensitivity analysis applications completed as part of this research are described below. Overall, a total of 57 rankings were produced as part of this task.

Alternative Ranking Methodologies

Three different sensitivity analysis methodologies were applied as part of this research. First, a typical, but abbreviated, sensitivity analysis design was applied (i.e., the basic application). Then, an engineering judgment case study approach was designed. This approach was considered representative of the type of alterations a practitioner might apply. Finally, a data focused case study approach was used. This approach altered the Minnesota CRSP more significantly than the engineering judgment case study and also used new data. The third sensitivity analysis approach might be considered representative of a systemic safety methodology that uses the data available to more specifically relate the significance of safety risk factor to the characteristics of a particular location (e.g., horizontal curve, stop-controlled intersection, or roadway segment). The specifics of the three sensitivity analysis methodologies applied are described below.

Basic Application

The first sensitivity analysis approach applied had a typical, but abbreviated, design. The approach had two parts to it. First, the "weight" of each horizontal curve, stop-controlled intersection, and roadway segment safety risk factor was individually doubled (i.e., the "weight" of the risk factor went from one to two) and alternative rankings were produced. Then, the

combinations of safety risk factors that, if they had their "weight" altered, would impact the most horizontal curves, stop-controlled intersections, and roadway segments in the database were identified. The "weight" of the safety risk factors in these combinations were doubled and three additional alternative ranking were produced. The combinations considered in this sensitivity analysis were the following:

- Horizontal Curves (Buchanan County): Traffic Volume and Intersection Presence
- Horizontal Curves (Dallas County): Radius, Traffic Volume, and Intersection Presence
- Stop-Controlled Intersections (Buchanan County): Skew Angle, Commercial Development, Distance to Nearest Stop Sign, and Crash History
- Stop Controlled Intersections (Dallas County): Intersection On/Near a Horizontal Curve, Distance to Nearest Stop Sign, AADT Ratio, and Crash History
- Roadway Segments (Buchanan County): AADT, Access Density, and Critical Radius Curve Density
- Roadway Segments (Dallas County): AADT, Roadway Departure Crash Density, and Edge Risk

Finally, all 39 of the rankings produced by each of the shifts noted above were compared to the initial rankings (previously described) using the two methodologies described in the next section of this chapter. The results of these comparisons are summarized later in this chapter.

Engineering Judgment Case Study

The second sensitivity analysis approach applied was an engineering judgment case study. This approach, as noted above, was intended be an example of what a practitioner might do if he/she wanted to change the "weights" of some safety risk factors within the parameters previously described (e.g., a "weight" shift of one to two). The following changes were made to the Minnesota CRSP approach as part of this sensitivity analysis case study:

- Horizontal Curves
  1. Radius and traffic volume safety risk factors: double the "weight" of the locations that previously met these safety risk factor criteria and assume the risk factor is also met (i.e., assign a "weight" of one) by those locations that previously did not.
  2. Intersection presence and crash experience safety risk factors: double the "weight" of the locations that previously met this safety risk factor criteria.
- Stop-Controlled Intersections
  1. AADT ratio safety risk factor: double the "weight" of the locations that previously met these safety risk factor criteria and assume the risk factor is also met (i.e., assign a "weight" of one) by those locations that previously did not.
  2. Skew angle, intersection on/near horizontal curve, and crash history safety risk factors: double the "weight" of the locations that previously met this safety risk factor criteria.

- Roadway Segments
  1. AADT safety risk factor: double the "weight" of the locations that previously met these safety risk factor criteria and assume the risk factor is also met (i.e., assign a "weight" of one) by those locations that previously did not.
  2. Access density, roadway departure crash density, and critical radius curve density safety risk factors: double the "weight" of the locations that previously met this safety risk factor criteria.

The changes listed above redefine the criteria for meeting all the radius and volume based safety risk factors. The "weight" of these safety risk factors for those locations that met their criteria when the initial rankings were produced is doubled and all the other locations in the database are assumed to also meet the criteria (i.e., have a safety risk factor "weight" of one). This approach was followed because radii and traffic volume are known to always have some type of influence on roadway safety. In other words, there is some level of safety risk related to these factors at all locations and this approach attempts to account for that. Then, the "weight" of several other risk factors listed above were doubled. Those not listed were considered to be of less importance and their "weighted" remained the same as that used to create the initial ranking. It should be noted that a wide range of safety risk factor approaches and combinations could have been considered for this case study.

The six rankings produced by this sensitivity analysis were compared to the initial rankings (previously described) using the two methodologies described in the next section of this chapter. The results of these comparisons are also summarized later in this chapter.

Data Focused Case Study

The third sensitivity analysis approach applied changes the Minnesota CRSP safety risk factor criteria even more than the engineering judgment case study described above. It also introduced new county level data. This case study is intended to be representative of an approach that uses the data available to more specifically define the "weight" of the safety risk factors used. The following changes were made to the Minnesota CRSP approach as part of this sensitivity analysis case study:

- Horizontal Curves
  1. Radius and traffic volume safety risk factors: consider the Iowa DOT District data used to define the criteria for these safety risk factors (See Figures 6 to 9). Use the percentage of severe roadway departure crashes to percentage of horizontal curve ratio for each range of radius or AADT plotted to reassign the "weights" for these safety risk factors. Assign safety risk factor "weights" of 2, 1, and 0 to those horizontal curves within ranges of radius or AADT that have percentage ratios greater than one, less than one, and equal to zero, respectively.
  2. Intersection presence, visual trap, and crash experience safety risk factors: double the "weight" of the locations that previously met this safety risk factor criteria.

- Stop-Controlled Intersections
  1. AADT ratio safety risk factor: for each county paved secondary roadway database, plot the percentage of stop-controlled intersections and percentage of stop-controlled intersection crash (all severities) data for different ranges of AADT ratio (See Figures 12 and 13). Use the percentage of stop-controlled intersection crashes to percentage of stop-controlled intersections ratio for the ranges of AADT ratio plotted to reassign the "weights" for this safety risk factor. Assign safety risk factor "weights" of 2, 1, and 0 to those stop-controlled intersections within ranges of AADT ratios that have percentage ratios greater than one, less than one, and equal to zero, respectively.
  2. Skew angle, intersection on/near horizontal curve, commercial development, distance to nearest stop sign, railroad crossing on minor approach, and crash history safety risk factors: double the "weight" of the locations that previously met this safety risk factor criteria.
- Roadway Segments
  1. AADT safety risk factor: consider the Iowa DOT District data used to define the criteria for this safety risk factor (See Figures 10 and 11). Use the percentage of severe roadway departure crashes to percentage of roadway mileage ratio for each range of AADT plotted to reassign the "weights" for this safety risk factor. Assign safety risk factor "weights" of 2, 1, and 0 to those roadway segments within a ranges of AADT that have percentage ratios greater than one, less than one, and equal to zero, respectively.
  2. Access density, roadway departure crash density, critical radius curve density, and edge risk safety risk factors: double the "weight" of the locations that previously met this safety risk factor criteria.

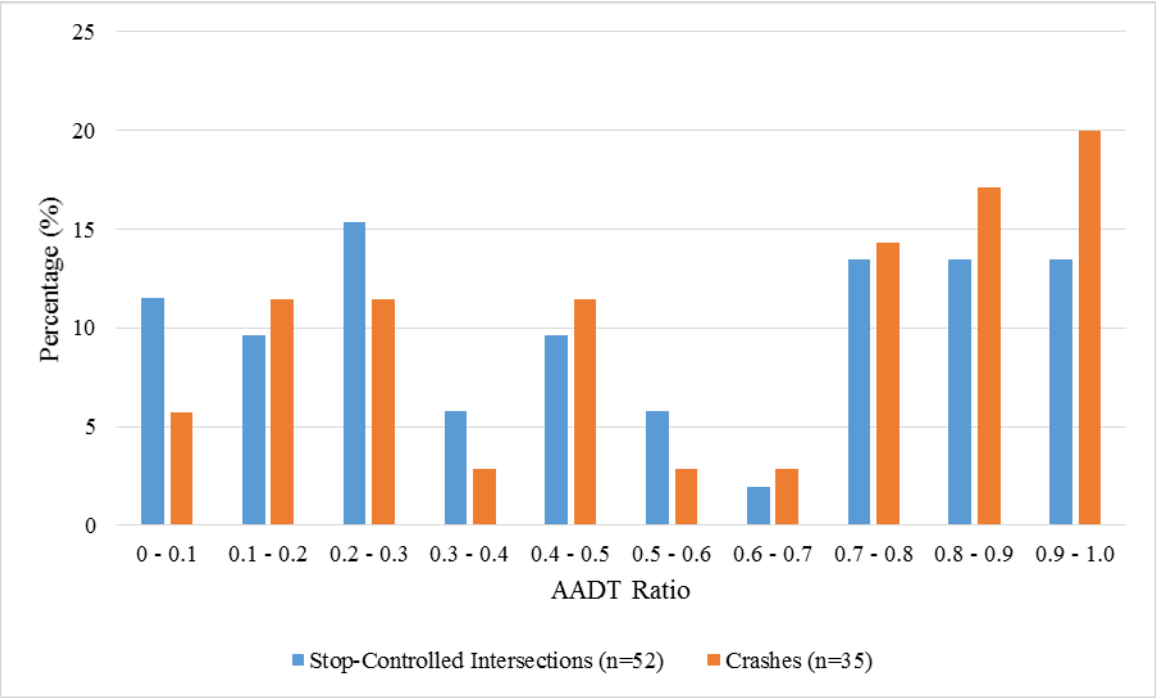

Figure 12. Buchanan County stop-controlled intersection and intersection crash distribution

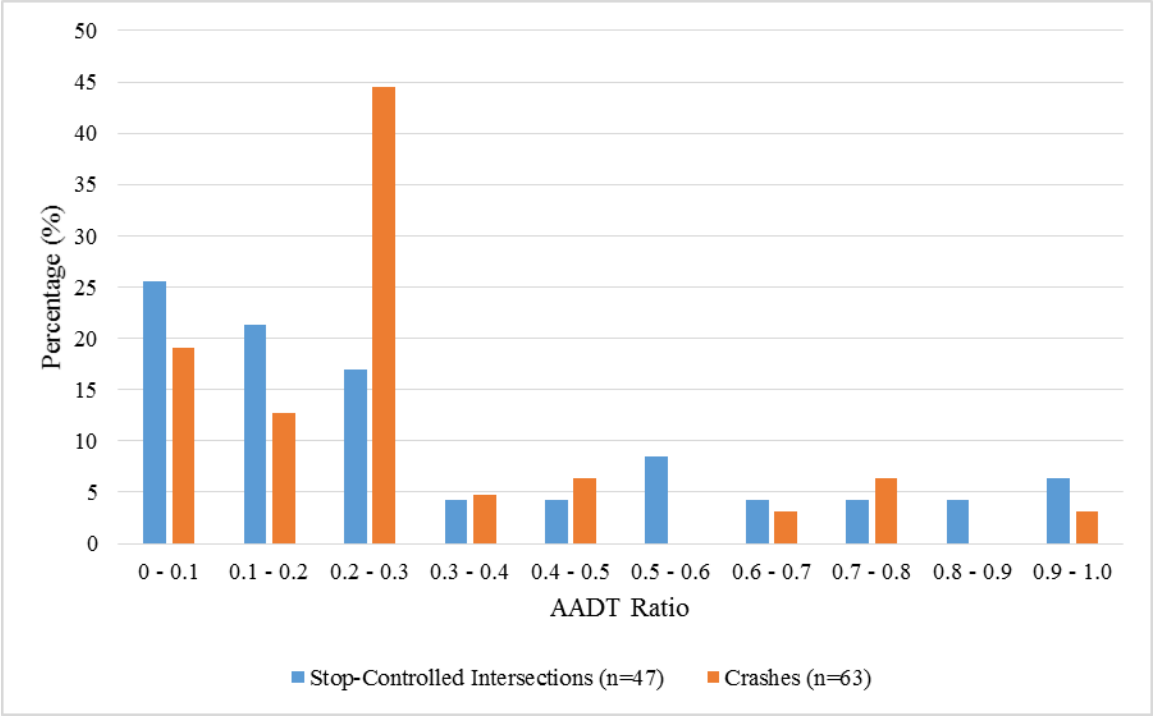

Figure 13. Dallas County stop-controlled intersection and intersection crash distribution

The changes listed above redefine the criteria for meeting the radius and volume based safety risk factors and also introduce some "weight" to these safety factors at locations that previously were not considered. This approach, similar to that followed for the engineering judgment case study, was applied to acknowledge the fact that some level of safety risk related to these factors exists at all location. In this case, the level of over-representation of crashes was also taken into account to define the amount of "weight" assigned to the safety risk factor at each location. More specifically, severe roadway departure crash data from Iowa DOT Districts 4 and 6 were used to redefine the criteria for radius and volume based horizontal curve and roadway segment safety risk factors. In addition, stop-controlled intersection crashes of all severities were used to reassign the "weights" applied to the stop-controlled intersection AADT ratio safety risk factor, and all the other safety risk factor "weights" were double. This sensitivity analysis approach might be considered representative of a methodology that uses crash data to more closely represent safety risk at particular locations.

The six rankings produced by this sensitivity analysis were compared to the initial rankings (previously described) using the two methodologies described in the next section of this chapter. The results of these comparisons are summarized later in this chapter.

Ranking Comparison Methodologies

Top 20 Shift Comparison

The rankings produced as part of the Minnesota CRSP approach sensitivity analysis were compared with two methods. The first method determined the percentage of locations (i.e., horizontal curves, stop-controlled intersections, and roadway segments) that changed in the "top 20" ranked with the application of the sensitivity analysis. The "top 20" group of locations is representative of those considered to be higher priority for potential safety improvements. Therefore, any shifts within this group could be viewed as a measure of the potential decision-making impacts if this tool were used. The second method used to evaluate the shift in the rankings was a statistical non-parametric comparison test. This test is described in detail below and its results noted later in this report.

Statistical Comparison

Sensitivity analyses are used to investigate potential changes in methodology results due to changes in assumed input parameters. A sensitivity analysis was used in this research project to determine whether a change in the importance or "weight" of the safety risk factors (an important part of the Minnesota CRSP approach) would significantly impact the rankings it produces for horizontal curves, stop-controlled intersection, and/or segment rankings. The changes in usRAP results, however, were evaluated in a non-statistical manner.

Many statistical methodologies and tests include an assumption that the data being evaluated are normally distributed. There are, however, also many situations where the data sample is small or the data simply does not have any normal distribution characteristics. The ranking data being compared in this research project falls into this category. Fortunately, statisticians have developed alternative, non-parametric or distribution-free, statistical procedures that can be applied (*23*).

Non-parametric tests are considered to be robust because they are not sensitive to the inaccuracy or error that might occur if data are assumed to follow a normal distribution. There are a number of non-parametric tests and several were evaluated and compared to determine their applicability to the ranking data results of this project. The Kendall rank correlation coefficient, however, was ultimately selected for use. It can be used to statistically compare the original and new rankings produced by the sensitivity analysis. In other words, it can be used to determine if the two rankings are statistically correlated/similar or not.

The Kendall rank correlation coefficient is also known as Kendall's tau coefficient (*24*). Kendall's tau coefficient is applicable to non-parametric data situations as a measure of the association between two measured quantities (*24*). The Kendall tau coefficient can be used to test for the statistical dependence of paired data sets. In other words, this test specifically measure the monotone relationship between variates or the paired ranked data set (*24*).

The notion of concordance is a fundamental term used in the Kendall tau coefficient calculations (*24*). Let (x_i, y_i) and (x_j, y_j) be any pair of observations (sample) from a bivariate population where X and Y are joint random variables. Any pair is said to be concordant if both $x_i > x_j$ and $y_i > y_j$ or if both $x_i < x_j$ and $y_i < y_j$. They are said to be discordant if $x_i > x_j$ and $y_i < y_j$ or if $x_i < x_j$ and $y_i > y_j$. If $x_i = x_j$ or $y_i = y_j$, the pair is neither concordant nor discordant. In other words, the sample size should have $\binom{n}{2}$ distinct pairs, and each pair would either be concordant or discordant, excluding ties (*24*). Kendall's tau coefficient for a sample is defined as (*24*)

$$\tau = \frac{S}{\binom{n}{2}} = \frac{2S}{n(n-1)}$$

Where the variable S is the number of concordant pairs minus the number of discordant pairs. The coefficient is always between negative one and one since the denominator represents the total number pair combinations (*24*). If the coefficient is equivalent to one then there is a perfect positive correlation (i.e., the two rankings are the completely the same). A coefficient value of negative one, on the other hand, means that there is a perfect negative correlation (i.e., the two rankings are completely different). Additionally, if the coefficient is approximately zero then the data being compared are also independent.

The following adjusted formula for the Kendall tau coefficient, known as for Kendall's tau-b, is used when ties exist in the data and it was applied in this project (*24*):

$$\tau_b = \frac{S}{\left[\sqrt{\frac{n(n-1)}{2} - T}\right]\left[\sqrt{\frac{n(n-1)}{2}} - U\right]}$$

Where $T = \sum \frac{t(t-1)}{2}$ and t is the number of tied values in the X observations and $U = \sum \frac{u(u-1)}{2}$ and u is the number of tied values in the Y observations.

The Kendall tau-b coefficient for rank correlation can be used as a measure of dependence between two variables. The null hypothesis tested with this correlation coefficient assumes that the two data sets, variables X and Y are independent and the expected value of the tau-b coefficient is zero. The alternative hypothesis assumes that variables X and Y are dependent or related (*24*).

It should also be noted that for larger samples, when n > 10, it is common to assume the distribution to be normal and to use an approximation to the normal distribution with the mean equal to 0 ($\mu = 0$) and a standard deviation equivalent to the following:

$$\sigma = \sqrt{\frac{2(2n+5)}{9n(n-1)}}$$

The Kendall tau-b coefficient was used in this research to statistically compare the difference in the initial (described previously) and alternative rankings produced as a result of the sensitivity analysis approaches summarized previously. The alternative rankings and comparison results are described in the next section of this chapter.

Minnesota CRSP Approach – Statistical Analysis Results and Comparisons

Basic Application

The basic application sensitivity analysis, as noted previously, doubled the "weight" of the individual safety risk factors and re-ranked the horizontal curves, stop-controlled intersections, and roadway segments. These components were also re-ranked if the "weight" of the combination of safety risk factors impacting the most locations were doubled. This resulted in six to seven alternative rankings for the horizontal curves, stop-controlled intersections, and roadway segments in the database. The "top 20" initial ranking locations (i.e., all risk factors with an equal "weight"), alternative rankings, and the results of a "top 20 shift" and statistical comparisons are shown in Tables 11 to 14.

Several conclusions can be drawn from the comparison results in Tables 11 to 14. First, the percentage of "top 20" locations impacted by the shifts in safety risk factor "weights" ranged from zero to 45 percent (n = zero to nine locations). The overall average percentage of locations impacted, however, is about 13.6 percent. The average percentage of horizontal curves, stop-controlled intersections, and roadway segments shifting in the "top 20", however, was 12, 10, and 19 percent (n = approximately 2, 2, and 4 locations), respectively. These types of shifts, of course, could have an impact on the decision-making based on the results of this Minnesota CRSP application. However, on average, the number of higher priority locations shifting was still relatively small. It should also be noted that the combination "weight" change that impacted the most locations (e.g., the Max. Combo Shift in Tables 11 to 14) in the entire ranking list did not necessarily have the largest impact on the number of shifts in the "top 20" locations. Finally the results of all the statistical comparisons that were completed indicated that all the alternative rankings were statistically correlated to the initial ranking. This conclusion means that statistically, to a 95th percentile level of confidence, the rankings have not changed due to the shifts in safety risk factor "weight" considered.

Table 11. "Top 20" horizontal curve rankings and comparison results[1]

	Horizontal Curve Number													
	Initial Ranking[1]		**SRF 1 Shift[1]**		**SRF 2 Shift[1]**		**SRF 3 Shift[1]**		**SRF 4 Shift[1]**		**SRF 5 Shift[1]**		**Max. Combo Shift[1]**	
	County[2]		County[2]		County[2]		County[2]		County[2]		County[2]		County[2]	
Rank	**B**	**D**	**B**	**D**	**B**	**D**	**B**	**D**	**B**	**D**	**B**	**D**	**B**	**D**
1	70	44	14	79	70	44	70	44	57	54	70	44	70	79
2	14	79	4	54	14	79	14	79	56	42	4	42	14	29
3	4	54	65	29	65	29	4	54	70	44	50	6	65	51
4	65	29	1	51	1	51	65	29	14	79	38	79	1	44
5	1	51	70	44	50	6	1	51	4	29	61	54	50	54
6	50	42	12	62	38	16	50	42	65	51	82	29	38	6
7	38	6	26	37	61	40	38	6	1	6	14	51	61	16
8	61	16	58	28	57	54	61	16	50	16	65	17	57	40
9	57	40	2	43	82	28	57	40	38	40	1	49	82	62
10	82	62	24	69	39	43	82	62	61	62	36	32	39	37
11	39	37	50	47	40	4	39	37	82	37	57	16	40	28
12	40	28	38	4	76	75	40	69	39	28	39	40	76	43
13	56	43	61	75	4	13	56	47	40	43	40	62	4	69
14	76	69	57	71	2	42	76	71	76	69	56	37	11	47
15	12	47	82	13	24	45	12	17	12	47	76	28	71	4
16	26	4	39	42	11	76	26	45	26	4	12	43	67	75
17	58	75	40	6	71	22	58	76	58	75	26	69	52	71
18	2	71	56	16	67	21	11	22	2	71	58	47	19	13
19	24	13	76	40	52	3	71	21	24	13	2	4	64	42
20	11	17	46	19	19	52	67	3	11	17	24	75	32	45
Top 20 % Shift[1]	NA	NA	5%	5%	20%	30%	10%	25%	0%	0%	5%	10%	30%	5%
Kendall Tau-b	NA	NA	0.943	0.918	0.859	0.830	0.930	0.804	0.989	0.996	0.982	0.944	0.911	0.976
Sign.?[3]	NA	NA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

[1]SRF = Safety Risk Factor, SRF 1 = Radius, SRF 2 = Traffic Volume, SRF 3 = Intersection Presence, SRF 4 = Visual Trap Presence, and SRF 5 = Crash Experience. See text for explanation of shifts. Top 20 % Shift = percentage shift in "top 20" ranking locations.
[2]B = Buchanan County and D = Dallas County
[3]Are initial and alternative rankings significantly correlated (similar) to a 95th percentile confidence level if entire ranking list (not just the "top 20") are compared?

Table 12. Buchanan County "top 20" stop-controlled intersection rankings and comparison results[1]

Rank	Stop-Controlled Intersection Number							
	Initial Ranking[1]	SRF 1 Shift[1]	SRF 2 Shift[1]	SRF 3 Shift[1]	SRF 4 Shift[1]	SRF 5 Shift[1]	SRF 7 Shift[1]	Max. Combo Shift[1]
1	21	21	21	21	21	21	21	21
2	8	8	8	8	8	8	10	10
3	10	10	38	2	10	10	35	35
4	35	35	47	10	35	35	38	8
5	38	17	10	35	38	11	11	29
6	11	9	35	42	11	47	8	38
7	47	29	16	38	47	36	36	11
8	36	16	11	11	36	12	12	36
9	12	18	36	47	12	17	2	12
10	17	38	12	36	17	2	14	17
11	2	11	17	12	14	14	29	2
12	14	47	2	17	9	9	4	14
13	9	36	14	14	29	38	42	9
14	29	12	9	9	4	44	43	4
15	16	2	29	23	18	48	44	18
16	4	14	4	29	43	27	47	42
17	18	50	18	16	27	29	48	43
18	42	28	42	4	2	16	17	47
19	43	23	43	18	28	4	9	50
20	44	15	44	43	15	18	50	28
Top 20 % Shift[1]	NA	20%	0%	5%	15%	10%	10%	10%
Kendall Tau-b	NA	0.873	0.980	0.940	0.897	0.941	0.858	0.903
Sign.?[2]	NA	Yes	Yes	Yes	Yes	Yes	Yes	Yes

[1]SRF = Safety Risk Factor, SRF 1 = Skew, SRF 2 = Intersection On/Near Horizontal Curve, SRF 3 = Commercial Development, SRF 4 = Distance to Nearest Stop Sign, SRF 5 = AADT Ratio, and SRF 7 = Crash History. Note – No locations met the criteria for SRF 6 = Railroad Crossing on Minor Approach safety risk factor. See text for explanation of shifts. Top 20 % Shift = percentage shift in "top 20" ranking locations.
[2]Are initial and alternative rankings significantly correlated (similar) to a 95th percentile confidence level if entire ranking list (not just the "top 20") are compared?

Table 13. Dallas County "top 20" stop-controlled intersection rankings and comparison results[1]

Rank	Stop-Controlled Intersection Number								
	Initial Ranking[1]	SRF 1 Shift[1]	SRF 2 Shift[1]	SRF 3 Shift[1]	SRF 4 Shift[1]	SRF 5 Shift[1]	SRF 6 Shift[1]	SRF 7 Shift[1]	Max. Combo Shift[1]
1	39	39	39	45	39	39	39	39	39
2	45	45	29	39	14	45	45	45	14
3	14	14	10	14	29	14	14	14	29
4	29	29	19	29	10	28	29	29	10
5	10	10	45	42	18	29	42	10	45
6	18	18	28	25	45	10	10	18	28
7	19	19	14	10	28	18	18	19	18
8	28	25	30	18	30	19	19	42	19
9	42	30	16	19	31	6	28	25	30
10	25	31	26	28	19	11	25	31	31
11	30	16	18	8	42	38	30	16	16
12	31	26	42	30	1	46	31	26	26
13	16	38	25	31	25	42	16	6	6
14	26	28	31	16	22	25	26	11	11
15	6	46	12	26	16	30	33	28	42
16	11	42	7	33	17	31	6	1	1
17	38	22	41	40	26	16	11	8	25
18	46	17	6	35	24	26	38	30	12
19	1	7	11	6	6	43	46	40	38
20	8	6	38	11	11	27	1	12	46
Top 20 % Shift[1]	NA	15%	10%	15%	15%	10%	5%	10%	5%
Kendall Tau-b	NA	0.939	0.902	0.926	0.870	0.907	0.977	0.812	0.922
Sign.?	NA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

[1]SRF = Safety Risk Factor, SRF 1 = Skew, SRF 2 = Intersection On/Near Horizontal Curve, SRF 3 = Commercial Development, SRF 4 = Distance to Nearest Stop Sign, SRF 5 = AADT Ratio, and SRF 7 = Crash History. Note – No locations met the criteria for SRF 6 = Railroad Crossing on Minor Approach safety risk factor. See text for explanation of shifts. Top 20 % Shift = percentage shift in "top 20" ranking locations.
[2]Are initial and alternative rankings significantly correlated (similar) to a 95th percentile confidence level if entire ranking list (not just the "top 20") are compared?

Table 14. "Top 20" road segment rankings and comparison results[1]

	Roadway Segment Number													
	Initial Ranking[1]		SRF 1 Shift[1]		SRF 2 Shift[1]		SRF 3 Shift[1]		SRF 4 Shift[1]		SRF 5 Shift[1]		Max. Combo Shift[1]	
	County[2]		County[2]		County[2]		County[2]		County[2]		County[2]		County[2]	
Rank	**B**	**D**	**B**	**D**	**B**	**D**	**B**	**D**	**B**	**D**	**B**	**D**	**B**	**D**
1	44	54	44	54	44	54	44	30	44	54	44	54	44	54
2	18	30	18	17	18	30	18	20	18	30	18	20	18	20
3	54	20	54	47	54	20	54	17	54	47	54	23	54	17
4	55	17	55	23	55	17	55	54	55	55	55	55	55	23
5	17	47	17	30	3	47	17	28	17	26	31	7	17	30
6	13	23	13	20	31	23	13	33	13	20	17	30	13	33
7	3	55	3	19	41	55	3	43	3	53	13	41	3	43
8	31	7	14	42	20	7	31	31	12	42	3	33	58	31
9	41	28	57	34	45	28	41	26	31	5	21	43	30	51
10	20	41	58	5	46	41	20	51	41	17	41	31	51	19
11	45	33	56	50	17	34	45	53	20	23	20	51	49	50
12	46	43	39	37	13	37	46	19	45	16	45	17	31	47
13	14	31	5	40	58	45	14	47	46	14	46	50	41	40
14	57	26	38	58	30	14	57	23	14	1	14	47	20	58
15	58	51	30	45	51	6	56	40	57	7	57	16	45	55
16	56	53	51	55	49	44	39	58	58	28	58	6	46	7
17	39	19	6	7	23	35	5	55	56	27	56	44	14	28
18	5	42	49	28	21	36	38	7	39	41	39	1	57	41
19	38	34	33	41	14	21	6	29	5	33	5	35	56	26
20	30	5	31	33	57	4	33	48	38	43	38	36	39	53
Top 20 % Shift[1]	NA	NA	20%	25%	20%	45%	10%	20%	5%	20%	5%	35%	10%	15%
Kendall Tau-b	NA	NA	0.888	0.775	0.899	0.812	0.960	0.847	0.931	0.843	0.975	0.767	0.927	0.881
Sign.?[3]	NA	NA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

[1]SRF = Safety Risk Factor, SRF 1 = AADT Range, SRF 2 = Access Density, SRF 3 = Roadway Departure Crash Density, SRF 4 = Critical Radius Curve Density, and SRF 5 = Edge Risk. See text for explanation of shifts. Top 20 % Shift = percentage shift in "top 20" ranking locations.
[2]B = Buchanan County and D = Dallas County
[3]Are initial and alternative rankings significantly correlated (similar) to a 95th percentile confidence level if entire ranking list (not just the "top 20") are compared?

Engineering Judgment Case Study

The engineering judgment case study sensitivity analysis was based on a different application and definition of the radius and volume based safety risk factors initially used for the Minnesota CRSP approach. The approach that was followed is described in detail earlier in this chapter. Its objective was to evaluate the potential impacts on ranking results from the Minnesota CRSP approach if a change in safety risk factor "weights" was completed that might be applied by a practitioner. A number of other potential changes could have been evaluated.

The initial and alternative "top 20" ranking results for the engineering judgment case study, along with the percentage of locations that changed in the "top 20" ranking list and the statistical comparison, are shown in Table 15. The percentage of locations that changed in the "top 20" ranged from five to 25 percent (n = one to five locations). The average percentage of horizontal curves, stop-controlled intersections, and roadway segments that changed due to this sensitivity analysis approach, however, was 17.5, 7.5, and 12.5 percent, respectively (n = three to four, one to two, and two to three locations). These shifts, therefore, may have some impact on the decision-making based on the results of this application. Finally, the results of the statistical comparison that were completed indicated that all the alternative rankings were statistically correlated to the initial ranking. This conclusion means that statistically, to a 95th percentile level of confidence, the rankings have not changed due to the shift in the safety risk factor "weights" adjusted for the engineering judgment case study.

Data Based Case Study

The data based case study sensitivity analysis approach changed several of the safety risk factor criteria used for the initial ranking. It used different defining criteria for the safety risk factors and also introduced the use of some additional county-based data to assist in the definition of at least one of these criteria. As noted previously, the primary objective was to apply a case study that might be considered representative of a systematic safety approach where the data were used to more specifically define the "weight" of the safety risk factors. The initial and alternative "top 20" ranking results, along with the percentage of locations that change in the "top 20" ranking list and the statistical comparison, are shown in Table 16. The percentage of locations that changed in the "top 20" ranged from 10 to 50 percent (n = two to 10 locations). The average percentage of horizontal curves, stop-controlled intersections, and roadway segments that changed due to this sensitivity analysis approach, however, was 35, 15, and 12.5 percent, respectively (n = seven, three, and two to three locations). These changes are likely to have an impact on the decision-making based on the results of this application. The size of the changes were also not completely unexpected, particularly for the horizontal curve rankings, where were the result of the largest changes in the Minnesota CRSP approach. The results of the statistical comparison, however, do show a statistical correlation between the alternative rankings and the initial ranking. In other words, at a 95th percentile level of confidence, the rankings have not changed in a statistically significant manner due to the shift in the safety risk factor "weights" adjusted for the data based case study.

Table 15. Engineering judgment case study: "top 20" horizontal curve, stop-controlled intersection, and roadway segment rankings and comparison results[1]

	Buchanan County						Dallas County					
	Horizontal Curve Number		Stop-Controlled Intersection Number		Roadway Segment Number		Horizontal Curve Number		Stop-Controlled Intersection Number		Roadway Segment Number	
Rank	Initial Ranking	Alternate Ranking	Initial Ranking	Alternate Ranking	Initial Ranking	Alternate Ranking	Initial Ranking	Alternate Ranking	Initial Ranking	Alternate Ranking	Initial Ranking	Alternate Ranking
1	70	70	21	21	44	44	44	44	39	39	54	30
2	14	4	8	8	18	18	79	42	45	29	30	54
3	4	50	10	10	54	54	54	6	14	10	20	26
4	65	38	35	35	55	55	29	79	29	19	17	20
5	1	61	38	38	17	17	51	54	10	45	47	53
6	50	82	11	29	13	13	42	29	18	14	23	42
7	38	14	47	16	3	3	6	51	19	16	55	17
8	61	65	36	11	31	12	16	17	28	26	7	47
9	57	1	12	47	41	31	40	49	42	18	28	55
10	82	36	17	36	20	41	62	32	25	25	41	28
11	39	57	2	12	45	20	37	16	30	30	33	33
12	40	39	14	17	46	45	28	40	31	31	43	43
13	56	40	9	2	14	46	43	62	16	28	31	31
14	76	56	29	14	57	14	69	37	26	42	26	51
15	12	76	16	9	58	57	47	69	6	12	51	19
16	26	12	4	50	56	56	4	47	11	7	53	5
17	58	26	18	4	39	39	75	71	38	6	19	23
18	2	58	42	18	5	5	71	45	46	11	42	40
19	24	11	43	42	38	38	13	76	1	38	34	58
20	11	71	44	43	30	6	17	22	8	46	5	16
Top 20 % Shift[1]	NA	10%	NA	5%	NA	10%	NA	25%	NA	10%	NA	15%
Kendall Tau-b	NA	0.913	NA	0.910	NA	0.882	NA	0.768	NA	0.835	NA	0.782
Sign.?[2]	NA	Yes	NA	Yes	NA	Yes	NA	Yes	NA	Yes	NA	Yes

[1]See text for explanation of shifts involved with the engineering judgment case study sensitivity analysis. Top 20 % Shift = percentage shift in "top 20" ranking locations.
[2]Are initial and alternative rankings significantly correlated (similar) to a 95th percentile confidence level if entire ranking list (not just the "top 20") are compared?

Table 16. Data based case study: "top 20" horizontal curve, stop-controlled intersection, and roadway segment rankings and comparison results[1]

	Buchanan County						Dallas County					
	Horizontal Curve Number		Stop-Controlled Intersection Number		Roadway Segment Number		Horizontal Curve Number		Stop-Controlled Intersection Number		Roadway Segment Number	
Rank	Initial Ranking	Alternate Ranking	Initial Ranking	Alternate Ranking	Initial Ranking	Alternate Ranking	Initial Ranking	Alternate Ranking	Initial Ranking	Alternate Ranking	Initial Ranking	Alternate Ranking
1	70	38	21	21	44	44	44	42	39	39	54	30
2	14	70	8	38	18	18	79	6	45	29	30	20
3	4	4	10	8	54	54	54	49	14	10	20	54
4	65	50	35	10	55	55	29	32	29	14	17	33
5	1	36	38	35	17	17	51	17	10	42	47	43
6	50	82	11	29	13	13	42	54	18	18	23	31
7	38	56	47	16	3	31	6	69	19	19	55	26
8	61	14	36	4	31	41	16	47	28	45	7	51
9	57	65	12	18	41	20	40	51	42	25	28	53
10	82	1	17	42	20	45	62	71	25	30	41	55
11	39	67	2	43	45	46	37	52	30	31	33	7
12	40	52	14	11	46	3	28	53	31	16	43	28
13	56	16	9	47	14	12	43	56	16	26	31	41
14	76	61	29	36	57	50	69	41	26	1	26	32
15	12	57	16	2	58	14	47	82	6	8	51	42
16	26	40	4	14	56	57	4	60	11	22	53	17
17	58	76	18	9	39	56	75	24	38	17	19	47
18	2	12	42	22	5	39	71	65	46	33	42	23
19	24	26	43	31	38	5	13	44	1	40	34	16
20	11	58	44	12	30	38	17	79	8	12	5	1
Top 20 % Shift	NA	20%	NA	10%	NA	10%	NA	50%	NA	20%	NA	15%
Kendall Tau-b	NA	0.736	NA	0.807	NA	0.874	NA	0.466	NA	0.744	NA	0.683
Sign.?[2]	NA	Yes	NA	Yes	NA	Yes	NA	Yes	NA	Yes	NA	Yes

[1]See text for explanation of shifts involved with the engineering judgment case study sensitivity analysis. Top 20 % Shift = percentage shift in "top 20" ranking locations.

[2]Are initial and alternative rankings significantly correlated (similar) to a 95th percentile confidence level if entire ranking list (not just the "top 20") are compared?

usRAP Approach Results and Comparison Discussion

The second systemic safety tool/methodology chosen for consideration as part of this research project was the usRAP approach. The process used by the usRAP approach to identify locations of safety concern was described in Chapter 2. The data collected for its application were summarized in Chapter 3. Overall, data were collected for more than 40 different roadway characteristics for each 328 foot segment within the paved secondary roadway databases considered. These data were input into the usRAP software package and the process applied for each county.

The output from the process that was of interest to this research project included the star rating and Safer Roads Investments Plan for each county. As noted in Chapter 2 the star ratings are based on the modeling and scoring completed through the usRAP process. They are measure of the presence of roadway elements that have been shown to impact or are related to the occurrence of serious crashes. The Safer Roads Investment Plans, on the other hand, are a list of potential countermeasures suggested by usRAP that also meet the acceptable benefit-cost ratio input by the user. Initially, an acceptable benefit-cost ratio of one was used for the application of usRAP to the Buchanan and Dallas County databases. The number of miles that received a star rating of one to five for automobile occupants (versus motorcyclists, bicyclists, or pedestrians) safety are summarized below:

- Buchanan County
  - Five Stars: 1.24 miles (2 km)
  - Four Stars: 64 miles (103 km)
  - Three Stars: 128.62 miles (207 km)
  - Two Stars: 2.49 miles (4 km)
  - One Star: 0.62 miles (1 km)
- Dallas County
  - Five Stars: 0.62 miles (1 km)
  - Four Stars: 22.99 miles (37 km)
  - Three Stars: 118.06 miles (190 km)
  - Two Stars: 12.43 miles (20 km)
  - One Star: 0.62 miles (1 km)

The star ratings above generally indicate that the vast majority of roadway mileage in Buchanan and Dallas county databases were assigned three or more stars by usRAP. In fact, in Buchanan County more than 98 percent of the roadway mileage considered received three or more stars and in Dallas County more than 91 percent of the roadway mileage met this requirement. The usRAP documentation describes roadway segments assigned four and five stars as those that have the most safety-related elements for the vehicle speed considered. Those assigned one or two stars don’t have as many of these elements. In general, both the star ratings and the Safer Roads Investment Plan results (described below) should be considered starting points for potential safety improvements. The *Guide to Using usRAP Star Ratings and Safety Roads Investment Plans* should be referenced when considering the application of either (*6*).

usRAP Results Comparison

One objective of this research project was to apply a sensitivity analysis to one or more systemic safety improvement tools or methodologies. The Minnesota CRSP sensitivity analysis was described previously. Upon closer examination of the usRAP software and process, however, it was determined that, for the purposes of a sensitivity analysis and the objectives of this research project, an adjustment of only two usRAP inputs was possible. The first input that was considered for alteration included the acceptable benefit-cost ratio for countermeasures (i.e., safety improvements) to be included in the usRAP Safer Roads Investment Plan results. The second input considered for alteration was to limit the type and/or amount of countermeasures that might be considered during the application of usRAP. It was concluded by the research team that only the acceptable benefit-cost ratio adjustment was appropriate for the objectives of this research project. In addition, the impact of this shift would be evaluated through a comparison of the type and number of countermeasures suggested by usRAP and the overall benefit-cost ratio of the output.

The sensitivity analysis application to usRAP was limited to the consideration of the impacts on its results due to an adjustment in its acceptable benefit-cost ratio. Therefore, the usRAP software was run for a benefit-cost ratio of one and two for both counties. Then, the "top 5" roadway safety countermeasures suggested by usRAP were compared to determine the potential impact of this shift in input value. The overall list of countermeasures suggested and the benefit-cost ratios were also considered. The results for both counties, with an acceptable benefit-cost ratio of one and two, are shown in Table 17.

The results are not surprising and show that as the acceptable benefit-cost ratio is increased the overall benefit cost also increases. However, the number of sites or mileage for which countermeasures are proposed decreases. In addition, the total number of countermeasures suggested also decreases if the entire list, rather than just the "top 5", are considered. Lastly, it was also interesting to note that the roundabout suggestion in the "top 5" countermeasures appears to have shifted out or changed to a left-turn lane improvement. It is believed that this is a result of the an institution of rules applied within usRAP that limits the countermeasures suggested to those that do not conflict with each other (e.g., a left-turn lane improvement can't be suggested at an intersection if a roundabout is also suggested).

Table 17. usRAP "top 5" roadway safety improvement suggestions

Countermeasure Type	Sites or Mileage*	Benefit-Cost Ratio	Countermeasure Type	Sites or Mileage*	Benefit-Cost Ratio
Buchanan County (Benefit-Cost Ratio = 1.0)			*Buchanan County (Benefit-Cost Ratio = 2.0)*		
Roundabout	2 sites	1.56	Shoulder Paving (< 3.3 feet)	3.11 miles	5.53
Shoulder Paving (< 3.3 feet)	8.08 miles	3.20	Shoulder Paving (> 3.3 feet)	1.24 miles	4.67
Shoulder Paving (> 3.3 feet)	1.24 miles	4.67	Left Turn Lane (unsign., 3 leg)	1 site	4.07
Road Surface Improvement	1.24 miles	3.18	Road Surface Improvement	1.24 miles	3.31
Sideslope Improvement - Left	0.62 miles	2.70	Sideslope Improvement - left	< 0.62 miles	3.09
Total		**2.34**	**Total**		**4.72**
Dallas County (Benefit-Cost Ratio = 1.0)			*Dallas County (Benefit-Cost Ratio = 2.0)*		
Shoulder Paving (< 3.3 feet)	14.29 miles	13.89	Shoulder Paving (< 3.3 feet)	6.84 miles	26.7
Roundabout	2 sites	1.21	Shoulder Paving (> 3.3 feet)	0.62 miles	3.30
Road Surface Improvement	3.11 miles	3.40	Sideslope Improvement – Left	1.24 miles	3.41
Sideslope Improvement – Left	1.24 miles	3.26	Road Surface Improvement	1.86 miles	4.58
Shoulder Paving (> 3.3 feet)	0.62 miles	2.82	Left Turn Lane (unsign. 3 leg)	1 site	2.67
Total		**6.47**	**Total**		**16.32**

*Mileage rounded off to the nearest 0.62 miles (1 km).

Potential Countermeasure Information

Summaries of the research and potential safety improvement impacts of several rural roadway countermeasures were also completed as part of this research. The summaries and information created were posted to www.ctre.iastate.edu/research-synthesis/. The countermeasures for which summaries were completed focused on roadway departures, intersections, and speed management.

Summary of Findings

This chapter summarized the results of the Minnesota CRSP and usRAP systemic safety tool/methodologies evaluated as part of this research project. The processes and procedures followed by these tools/methodologies are described in Chapter 2 and the data collected for their application were summarized in Chapter 3. In this chapter the initial rankings produced by the Minnesota CRSP were summarized and described. Then, three different sensitivity analysis approaches that focused on changing the "weight" of the safety risk factors considered by the Minnesota CRSP systemic safety tool were summarized. These three approaches included a basic application, an engineering judgment case study, and a data based case study. The two comparison methodologies used to evaluate the differences that might occur due to the application of the sensitivity analysis approaches were also described. One of these comparison methodologies considered the percentage of locations that changed in the "top 20" locations ranked and the other calculated the Kendall tau-b correlation coefficient. The results showed that anywhere between 0 percent and 50 percent of the "top 20" locations changed when the safety risk factor "weights" were altered. The typical average in the percentage of locations that changed, however, was generally between 10 and 20 percent. It was concluded that these shifts could have an impact on the decision-making related to the use of the Minnesota CRSP approach results. The statistical analysis, on the other hand, concluded that the alternative rankings were statistically correlated (i.e., similar) to the initial rankings in all cases. This difference in results is not surprising. The statistical analysis considered the entire list of locations in the rankings while the "top 20" comparison evaluated only those shifts in locations that might have the greatest influence on decision-making.

The results from the application of the usRAP process in Buchanan and Dallas County were also summarized in this chapter. The mileage assigned one to five stars by usRAP was noted and the impacts on the type and number of suggested countermeasures were compared for acceptable benefit-cost ratios of one and two. Not surprisingly, the overall benefit-cost ratio of the roadway safety countermeasures suggested increased and the mileage or number of sites at which these countermeasures could be acceptably implemented decreased. The chapter concluded with the identification of a new resource created as part of this project that summarizes some of the information available for various safety improvements along rural roadways.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This research project focused on the investigation of systemic safety tools/methodologies. The overall objective was to expand upon the state-of-the-knowledge and guidance available about the application of the systemic safety process. This objective was accomplished by summarizing the literature, applying two systemic safety tools/methodologies to a sample set of paved local rural roadways, completing a sensitivity analysis of the results from these tools/methodologies by adjusting one or more of their primary input variables, and quantitatively comparing the changes that might occur. In addition, a focus group meeting was held that created a list of potential systemic safety risk factors for unpaved roadways and a rural roadway safety improvement informational website was created. The completion of these tasks and their results are described in this report. The conclusions reached by the completion of these activities are summarized below:

- A number of tools/methodologies are available that can be applied in a proactive systemic safety manner. The systemic safety approach generally is proactive in nature and uses crash and roadway characteristic data in combination with research and engineering judgment to quantify the potential safety risk at particular locations. Some of the tools/methodologies that can be applied in systemic manner have existed for several years and others have been more recently introduced. The application of systemic safety tools/methodologies has become more common, but very little to no research has been done on the potential impacts on their results due to the various decisions made during their use. This research project was completed to begin to address this lack of evaluation and/or specific guidance.

- The literature view completed as part of this research project revealed that there were a number of methodologies/tools that could be or are being used for systemic safety purposes. The Minnesota CRSP approach, FHWA systemic safety project selection tool, usRAP, New Jersey systemic road safety analysis tool, and SafetyAnalyst are all described in Chapter 2. A summary matrix of their general availability (e.g., cost, etc.), required input data, ease of use, basis of prioritization, and potential for sensitivity analysis insight (as part of this research project) was developed. It was found that some of the tool/methodologies were relatively easy to apply and available for use, but the range of data requirements for their application was significant. “Star” ratings and/or benefit-cost ratios are used by the tools/methodologies for prioritization purposes and all of them were expected to provide some type of insight if evaluated through a sensitivity analysis. The summary matrix content was used to select the Minnesota CRSP and usRAP approaches for further investigation as part of this research project.

- The literature review also revealed that very little research has been completed on the application of the systemic safety approach along unpaved roadways. Literature documents were summarized that introduced the idea of a rural road safety index (RRSI) and the concept of variable and/or incremental safety improvements along unpaved rural roadways. A process to follow that resulted in the recommendation and prioritization of safety improvements

along unpaved rural roadways was also documented. It was found that the content of this literature generally described safety improvement methodologies that essentially followed many of the basic elements of systemic safety.

- The Minnesota CRSP and usRAP systemic safety approaches were applied to 197 and 156 miles of paved secondary (i.e., county) roadway in Buchanan and Dallas Counties. The data collected to apply the Minnesota CRSP approach focused on horizontal curves, stop-controlled intersections, and roadway segments. The approach required data to be collected for two Iowa DOT Districts and individual horizontal curves, stop-controlled intersections, and roadway segments within each county. Overall, data were collected to evaluate five safety risk factors at 82 and 83 horizontal curves within Buchanan and Dallas County, respectively. In addition, data were collected to evaluate seven safety risk factors at 52 and 47 stop-controlled intersections within Buchanan and Dallas County, respectively, and to evaluate five safety risk factors at 58 roadway segments in both counties. In addition, data that described approximately 40 to 50 different roadway characteristics were collected for every 328 foot segment in the two county databases to apply the usRAP approach. These data are listed and/or summarized in Chapter 3.

- This research project held a focus group meeting at which the attendees discussed their ideas for safety risk factors (e.g., roadway characteristics) along unpaved roadways. The focus group was held on August 23, 2013. Overall, 24 potential safety risk factors for unpaved roadways were identified and they are listed in Chapter 3. The factors suggested are related to the environment, roadway design or infrastructure, driver behavior and education, and roadway maintenance. It was obvious that many of the potential safety risk factors suggested for unpaved roadways also applied to paved roadways. However, it is also hypothesized that the significance of their impact on safety might be different along unpaved roadways than they are along paved roadways. In addition, there were also several safety risk factors in the focus group results that would not be relevant along paved roadways (e.g., dust and surface characteristics).

- A sensitivity analysis was performed on the results produced by the application of the Minnesota CRSP and usRAP approaches to the data collected for Buchanan and Dallas Counties. The coefficients, or "weight, of the safety risk factors applied in the Minnesota CRSP approach and the acceptable benefit-cost ratio used in the usRAP approach were adjusted and results compared. The potential changes in the rankings produced by the Minnesota CRSP approach were summarized by quantifying the percentage of locations that changed in the "top 20" of its ranking results, and through the calculation and statistical interpretation of the non-parametric Kendall tau-b correlation coefficient. For usRAP, the differences, if any, in the type and number of countermeasures suggested by its results, along with any changes in benefit-cost ratios, were summarized.

- Three approaches were used to adjust the "weight" of the safety risk factors when the sensitivity analysis was completed on the Minnesota CRSP approach. The first approach was a basic sensitivity analysis application. This approach individually shifted the "weight" of each safety risk factor, and a combination of safety risk factors, from one to two. The

application this sensitivity analysis approach involved the creation of 39 alternative rankings in addition to the six initial rankings created for Buchanan and Dallas Counties. The second sensitivity analysis approach was an engineering judgment case study. This approach was intended to be an example of what a practitioner might do if he/she were to change the "weights" of some safety risk factors. Overall, this sensitivity analysis required the creation of another six alternative rankings in addition to the six initial rankings already developed. The third sensitivity analysis was a data based case study. This approach was intended to be representative of the changes in safety risk factor "weights" that might be applied if additional data were available to more specifically define their criteria. This sensitivity analysis also required the creation of another six alternative rankings in addition to the six initial rankings already produced. Overall, a total of 57 rankings were completed.

- The initial and alternative rankings produced for the Minnesota CRSP approach sensitivity analysis were compared by determining the number of locations that changed in the "top 20" rankings and the Kendall tau-b correlation coefficient. Overall, the percentage of locations that changed in the "top 20" ranged from zero to 50 percent when the initial and alternative rankings were compared. The typical average percentage change, however, was generally between 10 and 20 percent (i.e., two to four locations). These shifts are likely to have an impact on the decision-making related to the results of this tool/methodology. The comparison completed with the Kendall Tau-b correlation coefficient, on the other hand, showed that the initial and alternative rankings were statistically correlated (i.e., similar) in all cases. This statistical comparison considered the entire ranking list and not just the "top 20" locations ranked. These results may be due to the design of the sensitivity analysis approaches used.

- The sensitivity analysis performed on the usRAP approach results was a simple comparison of the type and number of countermeasures suggested for Buchanan and Dallas Counties when its acceptable benefit-cost ratio was shifted from one to two. Not surprisingly, the overall benefit-cost of the countermeasures suggested increased when the acceptable benefit-cost ratio was increased. However, the number of sites or mileage proposed for the application of a countermeasure decreased. In addition, there were some changes in the type and number of countermeasures suggested. These results were not unexpected, but are valuable to the interpretation of usRAP output.

- Finally, a number of informational summaries were completed that focused on the state-of-the-knowledge related to the safety-related impacts of a various rural roadway improvements. The summaries focused on safety improvements related to roadway departures, intersections, and speed management. The information developed as part of this research project is available at www.ctre.iastate.edu/research-synthesis/.

Recommendations

The following recommendations were developed through the completion of the tasks previously described and the results they produced. They focus on the application of the results of this research and how they might be improved.

- This research project used three different approaches to the sensitivity analysis approaches to evaluate the impact of changes to the typical safety risk factor "weight" often used in the Minnesota CRSP approach. It is recommended that a similar analysis be completed for data collected from counties with a higher variability in roadway characteristics. It is also recommended that a greater variety of safety risk factor "weights" (e.g., 0.5 and 2.0) be applied and additional sensitivity analyses completed. In addition, other more specific safety risk factors might be selected and applied to the two counties considered in this research (instead of just applying those used in the Minnesota CRSP reference).

- The selection of safety risk factors in the application of the Minnesota CRSP approach is a critical decision. It is recommended that the safety risk factors used for particular components of a transportation system (e.g., horizontal curves) meet at least two objectives. First, they should assist in the identification of locations with characteristics that are commonly known to impact rural roadway safety. Second they should differentiate locations that have individual or combinations of safety risk factor characteristics that are relatively unique and believed to have a significant impact on safety.

- It is also recommended that the variability in the roadway characteristics connected to potential safety risk factors be considered during their selection. It is believed that this information may be of value to their application within the Minnesota CRSP approach. If a characteristic or combination of characteristics that define one or more safety risk factors have a low amount of variability in the transportation system being considered (i.e., it or they occur at the vast majority of the locations) the ranking impact of a safety risk factor may be muted. In other words both of the objectives noted above will not be met. In these situations the "tiebreaker" used to complete the ranking of the locations becomes more important and it is believed any small changes in the "weight" of a safety risk factor will likely have little locational differentiation ability.

- It is recommended that a research project be completed that uses the regional and/or data available to more specifically define the "weight" of safety risk factors selected for individual locations. The two typical approaches to defining the "weight" of safety risk factors is to either treat them equally (e.g., the location meets the requirement or it does not) or to model the potential safety impact of the characteristic through the application of known research relationships (often requiring additional data). It is proposed that a research project be designed that uses data that might typically be collected for the Minnesota CRSP approach in a manner that more specifically identifies and quantifies safety risk at individual locations, but still does not require complete coefficient model development.

- It is recommended that ranking changes that result from alterations in safety risk factor "weights" be evaluated when applied. The impact these changes on decision-making is an obvious measure of impact. It is suggested that in some situations the effort needed to make these changes may not have a large impact on user decision-making and, therefore, when a new safety plan is developed the change in "weights" may not be necessary. This research project found a relatively small level of impact on the "top 20" locations ranked for the safety risk factor "weights" considered. These results, however, should be used with caution

because they are based on data that describes two relatively similar transportation systems, a particular the method of application, and various sensitivity analysis designs. It is recommended above that this research be completed for more transportation system with a wider variety of characteristics.

- It is recommended that a research project be designed that focuses on the selection and application of safety risk factors for the application of systemic safety analyses along gravel and/or rock roadways. In general more research is also needed in the selection of safety risk factors, the development of ranking “tiebreakers”, and the proper evaluation of programs applying systemic safety approaches.

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APPENDIX A. USRAP INPUT DATA VARIABLES

Information on the following usRAP input data variables were collected for every 328 foot segment within the roadway database for this research project. The options for answers and additional details can be found in the reference document *usRAP Coding Manual for Star Ratings and Safety Roads Investment Plans* (*8*).

1. Carriageway/roadway: divided and undivided highways and direction of travel
2. Distance: distance in kilometers from the start of the road segment
3. Length: length of the roadway section is generally in kilometers and should always be 100 meters or 328 feet.
4. Latitude and Longitude: Co-ordinates in decimal degrees for the start point of each 328 foot roadway section
5. Landmark: identifies key landmarks
6. Traffic Flow: the traffic flow is recorded for each section of the road (i.e., AADT)
7. Motorcycle Percentage: the percentage of motorcycles in the traffic flow
8. Observed Bicycle Flow: the observed number of bicycles is noted
9. Pedestrian Flow – Crossing Road: the number of pedestrians observed crossing the road is recorded
10. Pedestrian Flow – Along Road: the number of pedestrians observed walking along the road is recorded
11. Area Type: the area type attribute represents the level of roadside development (e.g., urban, semi-urban, etc.)
12. Number of Lanes for Use by Through Traffic: the total number of lanes in one direction of travel is recoded
13. One-Way/Two-Way Flow: the traffic flow operation is noted
14. Speed: the actual posted numerical speed limit in miles per hour (mph) should be coded
15. Lane Width for Lanes Serving through Traffic: the distance from the outside edge of the travelled way or the center of the edgeline marking to the center of the adjacent lane or centerline marking
16. Paved Shoulder Width: the paved section of the roadway outside the edgeline which is safe and drivable. Usually measured from the center of the shoulder marking to the outside edge of the paved roadway or from the outside edge of the travelled way to the outside edge of the paved roadway
17. Unpaved Shoulder Width: space available for the pedestrians to walk along the side of the road
18. Shoulder Rumble Strips: the existence of rumble of strips should be recorded
19. Curvature: the horizontal alignment (e.g., very sharp, sharp, etc.) of the roadway that may be based on advisory posted speed limits if available
20. Quality of Curve: this attribute is a measure of the judgment of drivers to determine the sharpness of the curve and select the speed to traverse the curve
21. Overtaking Demand: This is developed in the pre-processing stage rather than coded. It represents the frequency of the possibility vehicles would undertake passing tactics by using the lane with opposing direction of travel
22. Delineation: the quality of the traffic control devices that guide drivers

23. Vertical Alignment Variation: this is a measure of the change in the roadway gradient along its length
24. Road Condition: the roadway surface condition with respect to skid resistance is noted
25. Sidewalk Provision – Right: the presence of a sidewalk on the right side of the road
26. Sidewalk Provision – Left: the presence of built sidewalk on the left side of the road
27. Land Use – Right and Left Use: a measure of the possibility of generating pedestrian activity along the roadside
28. Side Friction: the extent of interaction between the activities along the roadside and traffic on the roadway
29. Pedestrian Crossing Facilities: the availability of pedestrian crossing facilities
30. Quality of Crossing: a measure of the visibility of the crossing to drivers and the presence of warning signs
31. Bicycle Facilities: the availability of facilities for bicyclists
32. Roadside Severity – Segregated Bicycle Path: a measure of the severity of the roadside present on segregated bicycle facilities
33. Motorcycle Facilities: the availability of facilities for motorcyclists or other motorized two-wheel vehicles
34. Roadside Severity – Segregated Motorcycle Path: a measure of the severity of the roadside present on segregated motorcycle facilities
35. Speed Limit – Segregated Motorcycle Path: the posted speed limit for segregated motorcycle paths
36. Median Type – Segregated Motorcycle Path: the presence of roadway infrastructure the separates the opposing traffic flows for a segregated motorcycle path
37. Minor Access – Point Density: the number of driveways within each 327 foot (100 meter) roadway segment for both urban and semi-urban areas
38. Roadside Severity – Right: the distance to the nearest object on the right roadside likely to be struck by an errant vehicle which could result in serious or fatal injury to car occupants
39. Roadside Severity – Left: the distance to the nearest object on the left of the roadside likely to be struck by an errant vehicle which could result in serious or fatal injury to car occupants
40. Intersection Type: the intersection type (e.g., signalized four-leg, unsignalized three-leg, etc.)
41. Intersection Quality: a measures of the quality of intersection design features (e.g., advance warning, signing and markings) as well as the sight distance to the intersection for approaching vehicles
42. Intersecting Road Volume: approach traffic volume (a rating based on volume if known)
43. Median Type – documents the infrastructure separating opposing traffic flow
44. Major Upgrade Cost Impact: this is a measure that takes into consideration the influence of the surrounding land use, environment and topography on the cost of major developmental upgrade projects
45. Comments: this is an open optional field meant to record important comments related to roadway safety and any obstacles faced during the coding process
46. Roadwork (Work Zones): the presence of any major roadway construction or work zones