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Evaluation of systemic safety methodologies on low-volume rural paved roadways

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Evaluation of systemic safety methodologies on low-volume rural paved roadways

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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ABSTRACT

Prioritizing locations in rural areas has been a major concern to various transportation agencies due to the wide-spread nature of crashes on rural roadways. A systemic (more proactive) approach is required to rank sites in this case since the traditional "hot spot" method only considers crash data. The thesis was based on a prioritization project funded by Mid-America Transportation Center (MATC). Several systemic safety methodologies were explored and summarized in the report. However, one technique was selected, i.e. Minnesota CRSP approach, on the basis of a decision-making matrix that included five factors. The selected technique was applied on secondary paved rural roadways in Buchanan and Dallas counties in Iowa. Data was collected along 197 miles in Buchanan County and 156 miles in Dallas County. Initial prioritized ranking lists were generated for the three transportation elements (horizontal curves, stop-controlled intersections and rural segments) that were identified in the Minnesota CRSP approach. The tool was then evaluated to determine if a change in the weight/coefficient of risk factors in each transportation element would have a statistical impact on the prioritized list. Three different sensitivity analysis approaches were designed and tested. Results showed no statistical significance in the shift of rankings for all cases. A "top 20" analyses was then conducted to evaluate the number of sites that shifted from the prioritization lists compared to the initial ranking. A maximum of 50 percent shift was recorded for rural horizontal curves in Dallas County when the third sensitivity analysis approach was applied.

CHAPTER 1

INTRODUCTION

Systemic safety is defined as an approach that uses system-wide crash data to identify a safety problem across an entire road network and recognize roadway characteristics or risk factors present at locations with severe crashes. Systemic safety methodologies/tools would then consider multiple low-cost countermeasures and prioritize locations for implementing safety improvements (*1*).

Safety on rural roadways in Iowa became a major concern in 2012 as a result of the alarming statistics. More than 70 percent of fatal crashes in Iowa occurred on secondary rural roadways, taking into consideration that secondary rural roadway in Iowa account for approximately 79 percent of the total roadways (*2*). Several initiatives, such as hot spot approach, i.e. ranking based on crash frequency, severity or a combination of both, were developed with the intention to reduce these events. However, a prioritization methodology different than the traditional reactive hot spot approach is required due to the widespread nature of crashes on rural roadways. The use of proactive systemic safety improvement methodologies and tools is more appropriate since they consider both crash data and roadway features in order to estimate the risk and to identify as well as prioritize locations that require safety improvements.

The thesis was based on a research project funded by Mid-America Transportation Center (MATC). Several systemic tools/methodologies are described in this project and the selection of the methodology or tool for further analysis within this project essentially depends on its availability and other factors. Results of this research could be used by state and local agencies in order to guide them for making better choices related to the application of the methodologies to prioritize and improve low-volume rural roadways.

Problem Addressed

Crash fatalities along secondary rural roadways in Iowa accounted for approximately 70 percent in 2012 (*2*). A vast majority of these roadways experience low volume traffic volumes and the fatal crashes occurring on them are extensive. Therefore, it is not be feasible to use reactive hot spot method with the rare occurrence of a crash within a short vicinity of the same location. However, it should be noted that the lack of crashes in a particular location is not an indicator of low risk. One of the most ultimate solutions would include the addition of a proactive and systemic methodology to the traditional reactive hot spot approach which would help in improving the decision-making process (prioritization) when low-volume rural roads are considered. At least one proactive systemic tool would be identified and evaluated in this research project. A statistical analysis is then completed to determine the significance of any ranking changes that may occur.

Project Objectives

The proactive systemic tools or methodologies incorporate various risk factors relevant to the characteristics of the roadway. Three main objectives were acknowledged for the thesis research project. The first objective was to summarize the research of several systemic safety tools/methodologies for rural paved roadways as it would assist both state and local agencies to efficiently identify and prioritize the locations that require improvement. Additionally, the tools/methodologies were investigated and compared. The second objective included the selection of one systemic safety tool which would be applied on a sample of roadway mileage in Iowa. Finally, results generated following the implementation of the selected systemic tool would be evaluated through a sensitivity analysis focused on changes in one or more primary inputs which is part of the third objective. A statistical assessment would be then conducted to measure the significance of the sensitivity analysis results.

Thesis Content

The contents of the thesis are divided into five chapters. The first chapter provides an overview of the project and addresses the problem statement. The identified objectives are also included in this chapter. The second chapter would be focusing on the literature review of several systemic safety tools/methodologies where the processes of these tools are summarized. The selection of the appropriate systemic methodology for further investigation is also discussed in Chapter 2. Moreover, the contents of the third chapter mostly describe the input data requirements of the selected tool and provides details of the data collection process. Initial ranking results of the systemic safety tool/methodology are documented in Chapter 4 along with the sensitivity analyses approaches. A statistical comparison is then completed to compare the initial ranking results of the systemic safety tools/methodologies and the rankings that results due to the sensitivity analyses. The final chapter (Chapter 5) provides recommendations for future research work and includes a conclusion of the tasks performed in this project.

CHAPTER 2

LITERATURE SUMMARY

Chapter 1 indicated that several systemic safety tools/methodologies have been introduced to better address the identification, prioritization, and improvement of locations along low-volume rural roadways. The traditional hot spot approach to these tasks, using crash rate, frequency, and/or costs were not considered adequate. The fatal and severe injury crashes that occur on low-volume rural roadways are often spread throughout the transportation network. However, research has shown that some of the characteristics of rural roadways (i.e. risk factors) that might impact their safety include traffic volume, horizontal curve radius, and roadside obstacles. This chapter summarizes the characteristics of five potential tools/methodologies that could be used for systemic safety management along low-volume rural roadways. It also includes a summary of some relevant rural roadway safety research and concludes with a comparison and selection of two tools/methodologies for additional investigation.

Systemic Safety Tools/Methodologies

Systemic safety approaches applied along low-volume rural roadways should generally identify and prioritize locations that appear to have a higher potential risk for fatal or severe crashes. The assessment of locations is based on risk factors related to the features of the roadway that might have an impact on safety. These approaches should also assist the user with the identification and implementation of low-cost safety improvements. This research focuses on the identification and prioritization tasks results. The following systemic tools/methodologies were identified and summarized as part of this research project:

- Minnesota County Roadway Safety Plan (CRSP) Approach
- Federal Highway Administration (FHWA) Systemic Safety Project Selection Toolkit
- United States Roadway Assessment Program (usRAP) Safer Road Investment Plans
- Development of a Systemic Road Safety Analysis Tool: Roadway Departure Crashes at Bridges in Salem County, New Jersey
- SafetyAnalyst

Minnesota County Roadway Safety Plan (CRSP) Approach (*3*)

The Minnesota Department of Transportation (MnDOT) funded the creation of County Roadway Safety Plans (CRSPs) for every county in the state. The main objective of these plans were to identify and prioritize roadway segments, horizontal curves, and intersections for widespread low cost safety improvements implementation to reduce the number of fatal crashes and injuries along the county roadway system. These three main roadway elements were selected for evaluation because they consisted of the greatest number of crashes. Therefore, these elements had the greatest opportunity. Their methodology was based on a star ranking system that prioritizes at risk locations. The process followed to prioritize the segments, horizontal curves, and intersections in one county (i.e., Otter Tail County) is summarized in the next three sections.

Rural Roadway Horizontal Curves Prioritization

Analysis of curve related crashes in ATP 4 district supported the concept that traditional “hot spot” reactive methods were not efficient to prioritize at risk locations in low-volume rural roadways. Consequently, a new approach was used to evaluate the risk at curves. Five roadway features were used in Otter Tail County to prioritize rural roadway horizontal curves. The risk factors were selected using statewide, districtwide, and/or countywide crash and characteristic data and from roadway safety research results. The five classified risk factors included the following:

- Curve Radius:

Results from a plot relating severe crashes on curves and curve radius in ATP 4 district showed that 68 percent of the severe crashes (fatal and major injury) occurred on curves with 500 to 1,200 foot radius. Therefore, rural roadway horizontal curves with a radius between 500 and 1,200 feet received a star rating as they were considered to be at risk. Bonneson et al. developed a relationship between curve crash rate and radius (*4*). The study showed that there was a sharp increase in crash rate for curves with radius less than 1000 feet. It was also indicated from the study that the increase of crash rate on sharper curves resulted in fatalities and more injuries.

- Traffic Volume:

Horizontal curves with an ADT between 200 and 600 vehicles per day (vpd) received a star since this range of volume accounted for 51 percent of severe crashes (fatal and major injury) on curves in ATP 4 district.

- Intersection in Curve:

Curves with an intersection received a star because the presence of an intersection at a certain location increased the level of risk. A study conducted in Alberta, Canada examined intersection crash data for the period 2003 to 2005 on rural undivided highways. Results showed that the presence of an intersection in a horizontal curve tends to increase the fatality rate due to reduced intersection sight distance (*5*).

- Visual Trap:

The authors of CRSP for Otter Tail County indicated that the presence of a visual trap increased the risk of being involved in a crash and these curves received a star. Visual traps usually exist when a minor obstacle or object continues on a tangent. The negative safety impacts of a visual trap also increased when a crest vertical curve occurs before the horizontal curve.

- Crash Experience:

A horizontal curve experiencing a severe crash (fatal and major injury) for the 5 year study period (2005 – 2009) received a star.

Horizontal curves in the county system with a star rating of three stars or more were given the highest priority in the safety countermeasure plan.

Rural Stop Controlled Intersections Prioritization

A similar approach was used to assess the safety risk at Stop controlled intersections in Otter Tail County. Through/STOP-controlled intersections in the ATP 4 district were examined and results showed that the average severe crash density was comparatively low (0.10 severe crashes per intersection per year). The low value supported the notion that a more proactive and systemic process was required to prioritize and evaluate the risk of an intersection. However, there were seven risk factors defined by statewide, districtwide, or countywide crash and characteristic data or safety research results. The seven risk factors identified were as follow:

- Geometry of Intersection (Skew Angle):

It was reported in the CRSP that skewed intersections have a higher risk to experience a crash. Therefore, an intersection received a star if it had a skewed approach greater than 15 degrees measured from 90 degrees. The Highway Safety Manual (HSM) indicated that exposure to a crash at an intersection could be reduced if the skew angle was reduced since there would a decrease in the crossing distance for pedestrians and vehicles (*6*). A relationship between skew angle and Crash Modification Factor (CMF) value demonstrated a potential increase in crash for stop controlled intersections in rural areas as the skew angle increased.

- Geometry of Roadway (Intersection On/Near Curve):

An intersection located on or near (within 150 feet) a horizontal curve received a star. Peter Savolainen and Andrew Tarko examined a sample of two-way stop controlled intersections along four-lane divided high-speed highway located on super-elevated curves in Indiana (*7*). Results from the negative binomial models showed that curvature had statistical significance on crash level. In other words, a curve tends to increase crash frequency for an intersection as these intersections experienced more right-angle and single-vehicle crashes.

- Commercial Development:

The presence of a commercial development (other than residence or a farm) in any quadrants of an intersection increased the level of risk. If an intersection had a commercial development in any of the quadrants, it was assigned a star.

- Distance to Previous Stop Sign:

It was discussed in the Minnesota CRSP that drivers frequently lose attention when driving for longer distances with no STOP sign and a star is given to an intersection if its minor approach leg did not have a STOP sign within 5 miles. This was based on previous research.

- ADT Ratio:

An intersection that had a minor roadway to major roadway ADT ratio between 0.4 and 0.8 received a star because this range of ADT ratio were at higher risk to severe crashes in Otter Tail County. Results of the intersection research project in Indiana (*7*) also indicated that as the AADT on both minor and major approaches of an intersection increased then the crash frequency substantially increased. However, the effect of the minor approach AADT was stronger than the major approach AADT.

- Railroad Crossing on Minor Approach:

An intersection received a star if it had a railroad crossing one of its minor leg approaches. The presence of a railroad track and potential train was considered a safety risk.

- Crash History:

A star was assigned to an intersection if it experienced any crash (all types of crashes) during the five year period analysis (2005 – 2009).

All the intersections of the county roadways with other paved roadways were considered in this analysis. When star rating were the same, crash costs were used as a tie-breaker. Intersections with a total rating of three stars or more were considered for safety improvement projects.

Rural Segment Prioritization

Otter Tail County in Minnesota has a total of 1,004 miles of rural two-lane paved roadways and 193 segments were defined by a consistency in speed limits, average daily traffic (ADT) and roadway cross section. These segments were prioritized and the levels of risk assigned to each segment were based on five risk factors:

- ADT Range:

It was determined from the county mileage and roadway departure crashes by ADT plot generated that 16 percent of the segments in Otter Tail County with an ADT between 600 and 1,200 vpd accounted for almost 35 percent of severe (fatal and major injury) roadway departure crashes. Thus, segments within the defined range received a star since they are susceptible to increase the level of risk. The effect of AADT on crash frequency was illustrated through a

Safety Performance Function (SPF) model for rural two-lane roadway segments in the HSM (*6*). The expected number of crashes per mile increased as the AADT increased.

- Access Density:

Roadway segments received a star if they had an access density greater than 10.8 access points per mile (the estimated average access density of the rural roadways within Otter Tail County). The effect of access points was one of the factors examined during a study performed to determine the empirical relationship between geometric characteristics of roadway segments along with environmental factors and crashes in northern part of Iran (*8*). Both non-parametric model, Hierarchical Tree-Based Regression (HTBR), and parametric model, Negative Binomial Regression (NBR), were used to establish the relationship. Results of the HTB and NB regression models indicated that the number of access points in rural roadway segments had a significant impact on crash frequency.

- Roadway Departure Crash Density:

A segment received a star if its roadway departure crash density was higher than 0.08 crashes per mile per year (the estimated average roadway departure crash density along rural segments in Otter Tail County).

- Critical Radius Curve Density:

Horizontal curves in Otter Tail County with critical range from 500 to 1,200 foot were considered at higher risk. These curves experienced 50 percent of severe road departure crashes in the county. Hence, any roadway segment with a horizontal curve density greater than 0.35 curves per mile received a star (the estimated average of critical curves for segments). The rural roadway segments study in Iran (*8*) also assessed the impact of the number of horizontal curves on crash frequency using the HTBR and NBR models. Analysis results from both approaches showed that the crash frequency increased with more horizontal curves in a particular section.

- Edge Risk Assessment:

Roadside safety levels were assessed and categorized along each segment in the following manner. A rating of one was received if a roadway segment had a usable shoulder and what was considered a reasonable clear zone. A rating of two was received if the road segment had little or no usable shoulder but a reasonable clear zone. A rating of two was also applied for roadways with a usable shoulder but fixed objects in the clear zone. Finally, a rating of three was given to a roadway segment if it had no usable shoulder and fixed objects in the clear zone. It was decided that only those segments with a rating of two or three would receive one star. Refer to Figure 1 to illustrate the different edge risk assessment ratings that were developed.

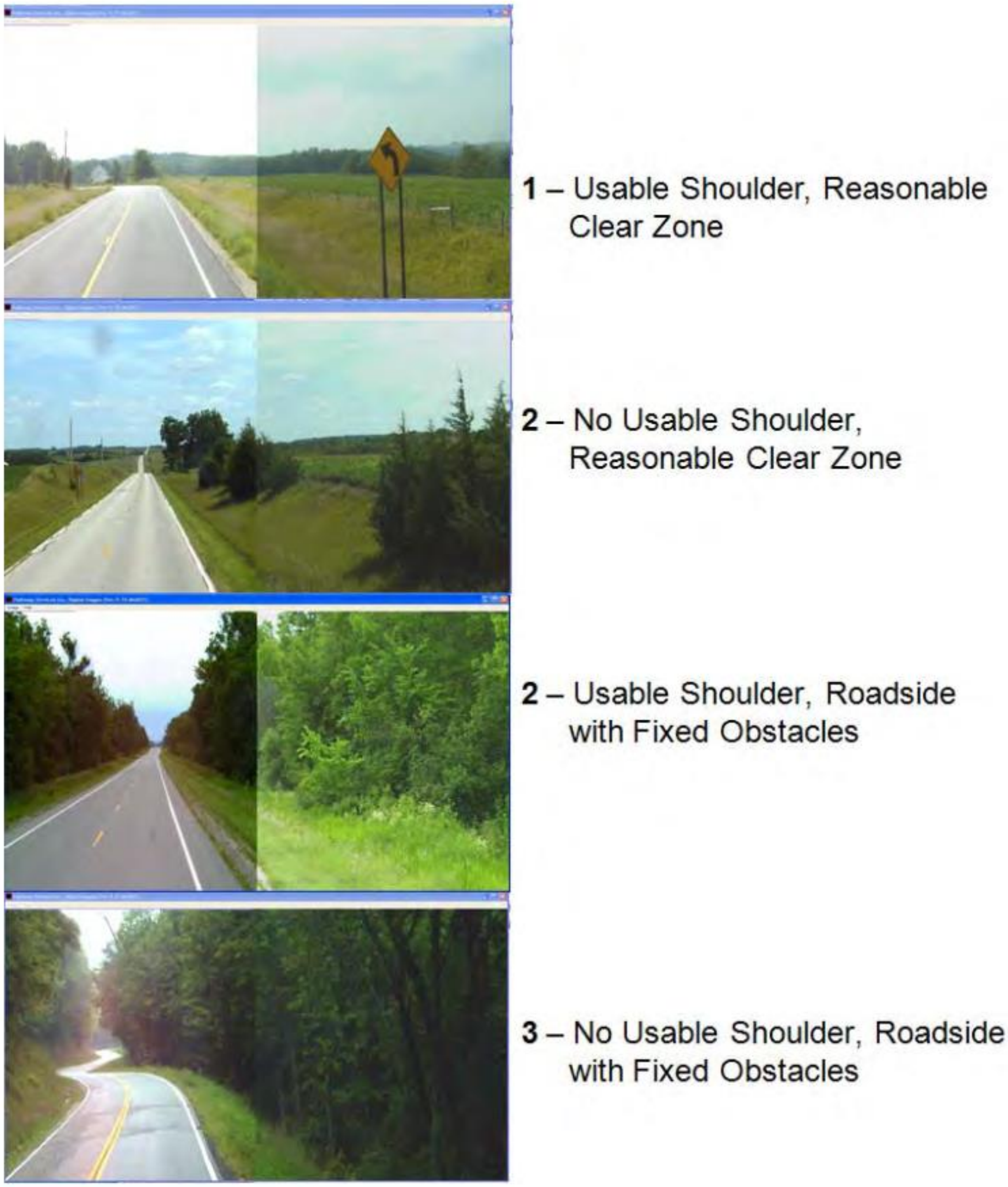

Figure 1: Sample of edge risk assessment ratings and description (Minnesota CRSP).

As noted, the determination of these five risk factors and their application criteria were defined through an evaluation of national, statewide, and/or regional data and research. Segments that received three stars or more were considered more “at risk” and, therefore, were given a higher priority in the safety plan. For segments that received the same star rating, the edge risk assessment then roadway crash departure values were used to determine their relative priority.

The county safety plan concluded with a prioritized list for the segment, curve, and intersection locations noted above. After the prioritization was completed, a series of low-cost infrastructure-based safety improvements were proposed for those locations determined to be higher priority. The safety improvements proposed for a location was based on the crashes to be addressed and the characteristics of the location.

The star rating used essentially weight each risk factor equally. This process is free and easy to use, and requires a reasonable amount of data to be collected (which could be reduced if needed by focusing on just one element, horizontal curves for example). Its basis of prioritization is a star rating but not weighted in any manner, and it has great potential for sensitivity analysis insight.

Federal Highway Administration (FHWA) Systemic Safety Project Selection Toolkit (*9*)

During the time period of this project the FHWA funded the development of a systemic safety project selection toolkit. Initially, it was assumed the toolkit would propose a new methodology or provide a new tool to complete systemic safety analysis of low volume rural roadways. However, the toolkit actually consists of a detailed description of the general processes or steps involved with the systemic safety improvement approach. It also includes several useful case studies and resources. The overall process described is essentially a generalization of the methodology used in Minnesota (i.e. Minnesota CRSP Approach described previously). The toolkit is a valuable resource because of the additional guidance it provides about the implementation of the systemic safety project selection process and the case studies provided. The systemic tool outlined a process consisting of three elements that could be implemented by agencies to guide them with better safety management practices. The three elements process involves the selection of systemic safety plan as the first step, then determine the level of funds available to implement systemic safety improvement projects, and finally evaluate the effectiveness of the systemic plans.

The systemic tool designed by the FHWA is flexible and easy to use as it assists agencies in identifying potential risk factors. The amount of data required for this tool are flexible and it is easy to comprehend the output results. However, the process described in the document is similar to the one used in Minnesota and it does not offer a specific approach to be used as part of this research project.

United States Road Assessment Program (usRAP) Systemic Safety Tool (*10*, *11*, *12*)

The usRAP process started in 2004 with the objective of evaluating the level of risk of severe crashes including fatalities and/or serious injuries influenced by road infrastructure. The basis of the overall approach used by usRAP was initiated by the International Road Assessment Programme (iRAP) which is considered to be a non-profit organization that is constantly working in partnership with both government and non-government organizations to implement safe roads with the aim to decrease fatal crash injuries. A set of four reliable star rating protocols were developed by iRAP using the expertise of many professionals and these could be applied internationally to evaluate and improve the safety of roads. These protocols are used in usRAP to assess the level of risk relevant to vehicle occupants, pedestrians, bicyclists and motorcyclists on different types of roadways (urban, semi-urban and rural roads). Generally, a Road Protection Score (RPS) is generated for each road segment by the usRAP tool which serves as score to assess relative risk of a crash and safety of infrastructure on a road section. 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. A star ranking from one to five stars is then produced based on this modeling. At first, approximately 40 road attributes need to be collected for each road segment at 328 foot (100 meters) intervals. The RPS for each road segment is then calculated for each of the four roadway user types by combining the relative risk factors of the 40 roadway attributes using a multiplicative model. The approach basically assigns the total number of crash in a proportional manner with the defined risk. A "Safer Road Investment Plan (SRIP)" is created after the RPS is determined for each segment. This plan is a prioritized list of safety improvements that might be applied along the roadway segments identified. It is a network level ranking of countermeasures by a benefit-cost ratio related to their expected impacts. Approximately 70 countermeasures are considered and reviewed for each of the 328 foot roadway segment. However, the countermeasures that are selected for detailed safety and economic analyses depend on the user expertise and engineering judgment.

The development of the RPS and star ratings, along with the safety roads investments plan prioritization, are described in detail below. More emphasis is awarded to the four protocols and SRIPs as they are the base for the development of the star ratings that assists in offering cost-effective countermeasures to be implemented by local and funding agencies. Prior the inclusion of the proposed countermeasures in the plan, an economic evaluation is performed by comparing the cost of implementing the countermeasure to the benefit that would result from undertaking the action. It is essentially required for the countermeasure to satisfy the minimum threshold Benefit Cost Ratio (BCR) in order to be considered in the plan.

Star rating and SRIP are related and the development of star rating first includes the inspection of elements on the road infrastructure that have an influence on the possibility for a severe crash to occur. Conducting a detailed visual and accredited inspection on the elements of a road’s infrastructure is considered to be the foundation of usRAP star rating procedure. Currently, there are two inspection methods employed by iRAP and usRAP depending on the availability of technology. The two methods include drive-through and video-based inspection. However, for the most part, data for each 328 foot (100 meter) segment are collected through the use of StreetView mechanism of Google Earth. The RPS and star rating are then developed based on the inspection of the 40 different infrastructure elements known to have an immense impact on the probability for a crash to occur and on the severity of the crash. The elements collected are related to one or more of four categories of road users. These road users include car occupants, motorcyclists, bicyclists, and pedestrians. Each 328 foot (100 meter) road segement is awarded up to five stars depending on the safety level. As opposed to the star rating procedure created by the Minnesota Department of Transportation, iRAP and usRAP awards a 4 or 5 star rating to the safest roads. Safest roads are characterized by the road features that are suitable for the exisiting traffic speeds.

The road infrastructure elements on a safe road might incorporate 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 segment 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

Following the development of the star ratings, particular sites are assessed to determine the need of a safety countermeasure (if required). Almost 70 countermeasures are considered for each site and the software would then perform a benefit-cost analysis of every identified countermeasure. Benefits resulting from the implementation of a countermeasure are measured by estimating the new road score. The usRAP software usually takes into consideration all the countermeasures at the specific sites that require an improvement although the user could only target certain countermeasures of interest by setting a minimum threshold BCR.

The usRAP systemic tool essentially determines risk with the use of about 40 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 wrapped into the allocation of the known level of fatalities and injuries to each segment and the cost and crash reduction effectiveness of the countermeasures proposed. There is some potential for sensitivity analysis insight.

New Jersey Systemic Road Safety Analysis Tool (*13*)

A project was recently completed by researchers at Rutgers University Center for Advanced Infrastructure and Transportation Center (CAIT). The project developed a systemic road safety analysis tool and focused on roadway departure crashes at bridges in Salem County. The researchers indicated that the tool was based on a version of the roadway safety management process described in the HSM (*6*). There were five steps involved in the data collection process as well as the establishment of the systemic safety tool. These steps included the following:

Step 1: Network Screening for Crash Location

A five year crash history database was used and the extent of the safety improvement project was determined by performing a preliminary data analysis. Then, sites that require improvement were identified by screening the collected data. In addition, crash locations were prioritized using a grading system that was developed. These prioritized crash locations were based on a list of different crash attributes.

Step 2: Identification of High-Risk Road Features

The second step involved the identification of locations with high risk geometric features that might contribute to a roadway departure crash. This was done by conducting a field study to review crash locations and evaluate existing conditions of a specific road or network. Physical conditions such as crash rates, traffic volumes (if available) and other factors in the crash summary report, were taken into account during the site visit. Additional information related to roadway geometry, pavement conditions and signage were also recorded for a well-established field study to be completed. High risk geometric features were determined after conducting the field study since these characteristics might increase the potential for roadway departure crashes to occur. The geometric features of each site were compared to record any significant trends and the trends were distinctly displayed using another grading system. The sum of scores assigned to the different characteristics for each crash location was then computed and the top five features were highlighted.

Step 3: Countermeasure Selection

A list of recommended safety countermeasures was then provided to each of the high risk geometric features locations identified in Step 2 (diagnosis step). The countermeasures addressed safety improvements to reduce roadway departure crashes if implemented.

Step 4: Economic Appraisal

In this step, the effectiveness as well as the impact of the proposed safety countermeasures were examined using a benefit-cost analysis. The costs of implementing an appropriate countermeasure including construction and maintenance were weighed against the expected benefits in terms of crash reduction. Expected benefits from the implementation of a countermeasure on high risk bridge locations in Salem County were estimated by referring to the Safety Performance Functions (SPFs) and Crash Modification Factors (CMFs) techniques described in the HSM (*6*).

Step 5: Justification and Prioritization of Projects

The previous step described the economic appraisal process that was performed using a benefit-cost analysis to evaluate the efficiency of relevant countermeasures. However, the authors indicated that this process could also be used to group and prioritize projects. The tool was examined and the sensitivity analysis results provided three beneficial ideas. It is very important to collect most sensitive data pertained to each potential location. Additionally, sites with similar proposed countermeasures are expected to have the same benefit-cost ratio and, therefore, the countermeasures justified at one site might be also justified at similar sites. Finally, limitations in funding available for safety improvement projects has encouraged the use of benefit-cost ratio to prioritize projects. Projects with higher benefits were mainly considered.

The methodology presented by the Rutgers's research group is simply an application of the HSM approach using the SPFs and CMFs noted within that document. They adjusted an available excel sheet to fit their needs and would make it available once the project is published. The overall approach is similar to usRAP but uses the CMFs in the HSM to apply and calculate (when possible) the benefit-cost ratios for different countermeasures at each site. The approach of this systemic tool could be included in this research project because it uses CMFs that are available to the public when compared to usRAP. Some input values could be adjusted in this approach which is similar to usRAP, thus, the effectiveness of the countermeasure could be modified accordingly. The developed spreadsheet might be the most practical part of this project since crash reductions could be estimated and the benefit-cost ratio could be calculated easily and reliably. There is limited sensitivity analysis value with this tool, but it might be more comfortable to agencies because some CMFs are available. There were a number of assumptions made in the application of this process because of the gaps in the CMF research.

SafetyAnalyst (*14*)

SafetyAnalyst consists of a set of software tools that could be utilized by transportation agencies to manage their highway safety program. It could also be used to enhance the programming of safety improvements at specific locations. SafetyAnalyst includes the most advanced and modern safety management techniques for computerized systemic analysis. There are six different safety management tools incorporated in SafetyAnalyst:

- Network Screening Tool: identifies specific highway sites that have potential for safety improvement.
- Diagnosis Tool: investigates the characteristics of crash patterns at individual sites.
- Countermeasure Selection Tool: users could select the appropriate countermeasure to reduce the frequency and severity of crashes at specific locations.
- Economic Appraisal Tool: a countermeasure or various alternatives could be analyzed economically for one or several sites.
- Priority Ranking Tool: ranks the sites and proposed improvement projects.
- Countermeasure Evaluation Tool: performs an evaluation before and after implementing the countermeasures for safety improvement.

The process used by the SafetyAnalyst is quite detailed but generally follows an approach similar to some tools previously described (usRAP and New Jersey systemic safety tools). The amount of data needed for the software, however, is much more significant. The processes used to rank safety improvement sites are detailed in the following text. These processes include several of the tools listed above. The first module in SafetyAnalyst provided a list of six different approaches used to screen potential sites for safety improvement. These approaches included basic network screening based on Empirical Bayes (EB) principles, corridor screening, sudden and steady increase in mean crash frequency, and screening for high proportion of specific crash type. Information related to the characteristics of each site and safety performance are used to identify those high risk locations for further examination. This tool usually considers roadway segments, intersections and ramps for analysis. Crash patterns are then investigated to assist in identifying the relevant countermeasures. The second process requires crash data at each site (over-representation of collision types) and the tool would then provide crash summary statistics, collision diagrams and statistical analysis results. A combination of well-established engineering judgment and human factors are used in this process to diagnose safety issues at a particular site. Moreover, the third step involved the selection of countermeasure(s) for potential implementation from a list in SafetyAnalyst. It is possible to consider a combination of countermeasures using the software. Sites could also be eliminated if the countermeasure(s) have already been implemented. Finally, an economic analysis and location prioritization is completed. Although any economic criteria could be applied, only Net Benefits (NB) and BCR are included in the software. The final output of this process is a list of sites by NB or BCR and the proposed countermeasures at that location along with their expected effectiveness. In general, SafetyAnalyst is an expensive software and not easily available to local agencies.

The SafetyAnalyst is a detailed safety improvement management tool. It does have some significant data requirements, but the data could be collected if needed. However, it is not available for this project and is expensive. In addition, its value to this sensitivity analysis research is limited because the same type of countermeasures that could be adjusted if the usRAP and/or the Rutgers's tools (which is also based on the HSM) were considered. It would primarily focus on the inputs to the benefit-cost analysis but could also allow changing the safety effectiveness (which is not allowed in usRAP but is allowed in Rutgers systemic safety approach). The availability and cost does not allow this tool to be used.

Other Ranking Research

Un-signalized Rural Intersection Safety Index (*15*)

Montella and Mauriello have documented a procedure to rank un-signalized intersections during a safety inspection process. The method uses quantitative safety evaluations and it is considered to be efficient for the selection of cost-effective countermeasure treatments. It was proposed that this procedure might be useful for low-volume rural roadways where the final and major crashes occurring in this system are widespread in nature.

The approach proposed by Montella and Mauriello assigns intersections a Safety Index (SI) which is formulated by combining the exposure of road users to road hazard and the probability of being involved in a crash. The SI could be assessed with and without a crash database. In the case when an extensive and robust crash database is available then a combination of both the SI and Empirical Bayes (EB) frequency estimates could be used for ranking intersections. On the other hand, if crash data is not available or poorly represented then the SI could be used as the only alternative ranking criterion. The SI is then validated by comparing the results generated from the SI method with EB estimates. Montella and Mauriello evaluated their procedure on 22 three-leg intersections in Italy. They also calibrated a Safety Performance Function (SPF) and used the EB refinement technique to acquire more accurate estimates of the current safety performance for all the intersections of interest. Results showed a significant correlation between the SI and EB safety estimates.

Tool/Methodology Comparison

Comparison of Countermeasure Selection Methods (*16*)

A research team also considered and compared three different safety evaluation methodologies and their results. Two of these methods are discussed in detail earlier. The three methods compared were usRAP, the FHWA systemic safety project selection tool and the results of road safety audits. The methods were applied to a road network consisting of 219 roadway centerline miles in six counties in Kentucky and the results compared statistically. The research team concluded that the usRAP tool was the most robust and quantitative of the three methodologies. However, the application of the FHWA systemic safety project selection tool requires less input data and has more flexibility than usRAP. There is a disadvantage with the flexibility because the weighting of risk factors is not necessarily connected to the significance of their safety impact. It was found that road safety audits were also effective at identifying poor condition locations but could results in situations where some additional low cost safety improvements might not be proposed along roadway segments with no crash history.

The systemic tools previously described were compared for this research project. The objective of the comparison completed was to select one or two for further investigation. The following factors were taken into consideration during the comparison and selection:

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

These characteristics were identified for each of the tools and methodologies and matrix created and this information is contained in Table 1.

Table 1: Tool/Methodology Selection Matrix

	Factors of Consideration				
Systemic Tool	**General Availability**	**Input Data Required**	**Ease of Use**	**Basis of Prioritization**	**Sensitivity Analysis Insight**
Minnesota CRSP Tool	High	Low	Low	Star Rating	High
FHWA Systemic Safety Toolkit	High	Low	Medium	Star Rating	High
usRAP Systemic Safety Tool	High	Medium	Medium	Benefit-Cost	Medium
New Jersey Systemic Safety Tool	Medium	Medium	Low	Benefit-Cost	Medium
SafetyAnalyst	Low	High	Medium	Benefit-Cost	Medium

It was concluded that the Minnesota CRSP tool was the most appropriate for the purpose of this research project. This tool/methodology was selected based on its ease of availability and use, moderate amount of input data required, and its potential for sensitivity analysis insight. Although both the Minnesota CRSP tool and FHWA systemic safety project toolkit are very similar, the Minnesota CRSP tool was selected because this selection was completed before the FHWA toolkit was officially released.

The features of five systemic safety tools were summarized in this chapter along with some research pertinent to rural roadways. The potential methodologies were then compared using a matrix represented in Table 1. The comparison was based on five different factors and one systemic tool, Minnesota CRSP approach, was selected for futher investigation. Furthermore, Chapter 3 would be focusing on the application of the selected tool and the data input requirements.

CHAPTER 3

DATA COLLECTION AND SUMMARY

A few relevant systemic safety methodologies on paved low-volume rural roadways were summarized in the previous chapter and a matrix was developed to select the tool/methodology for assessment based on five characteristics. Following the selection of proactive systemic tool to be evaluated for the purpose of the project, the site selection and data collection processes are described explicitly in this chapter for the Minnesota CRSP approach. The data collection process is divided into two sections, with the first part focusing on the site selection and the data input for the Minnesota approach is discussed in the second part.

Site Selection

The engineers of two county jurisdictions in the state of Iowa, Buchanan and Dallas, were approached as potential sites for data collection and evaluation for this research project. The engineers of these counties agreed to collaborate with this research project and were also on its Technical Advisory Committee (TAC). The availability of required data in the electronic database to complete the assessment of the systemic tool was one of the important considerations for the selection of these two counties in this project. In addition, the availability of visualization aids such as Google StreetView Maps and ArcMap 10.1, to facilitate the data collection process was another factor considered.

Data Collection Process

The data collection process was completed along secondary paved rural roadways in the two Iowa counties, Buchanan and Dallas, using Google StreetView Maps and ArcMap 10.1 as visualization techniques. The map shown in Figure 2 shows the location of the two counties relative to the state. Roadway, roadside and crash data were collected along these roadways. However, the visualization capabilities were only available for a sample of the roadway mileage. Figures 3 and 4 demonstrate the paved secondary roadways in both Buchanan and Dallas for which data were collected. Overall, the roadway network consisted of 197 miles in Buchanan County and 156 miles in Dallas County.

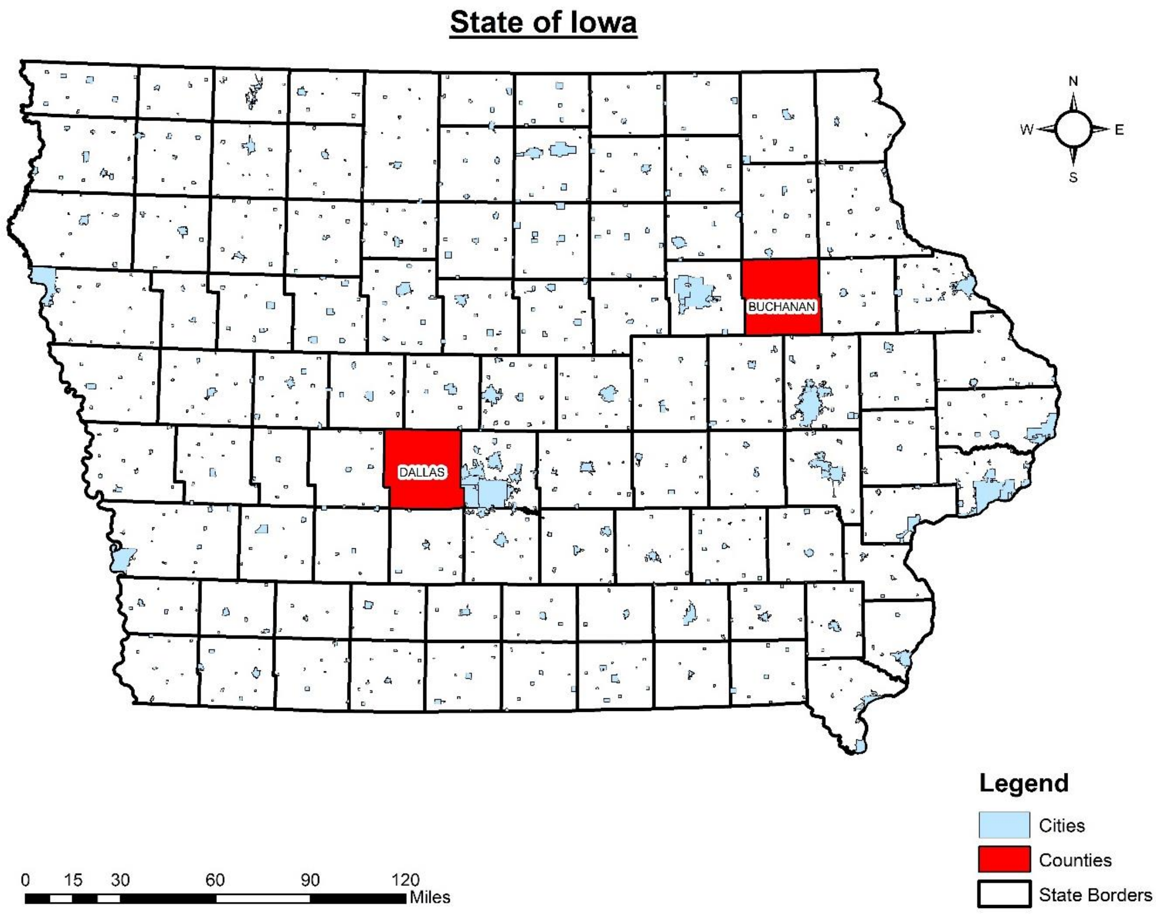

Figure 2: Buchanan and Dallas counties location in Iowa.

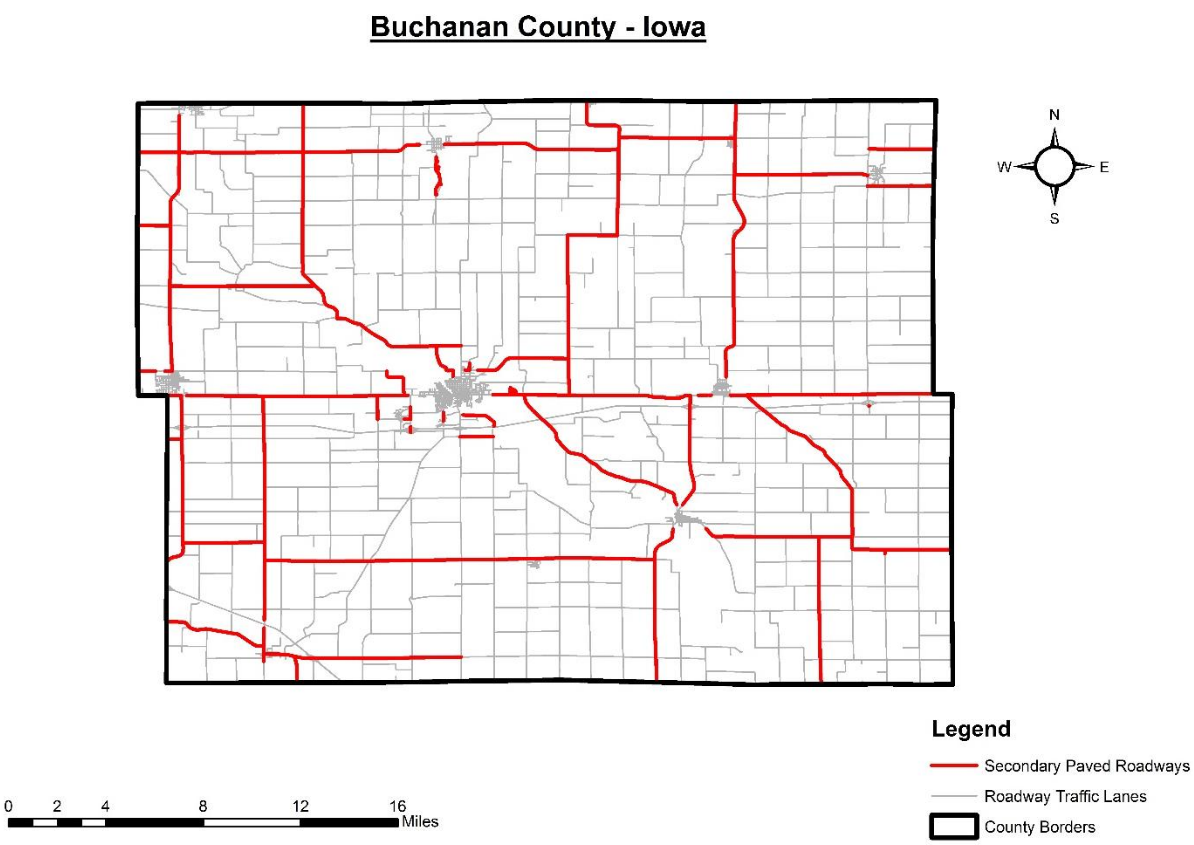

Figure 3: Paved secondary roadways with StreetView in Buchanan County.

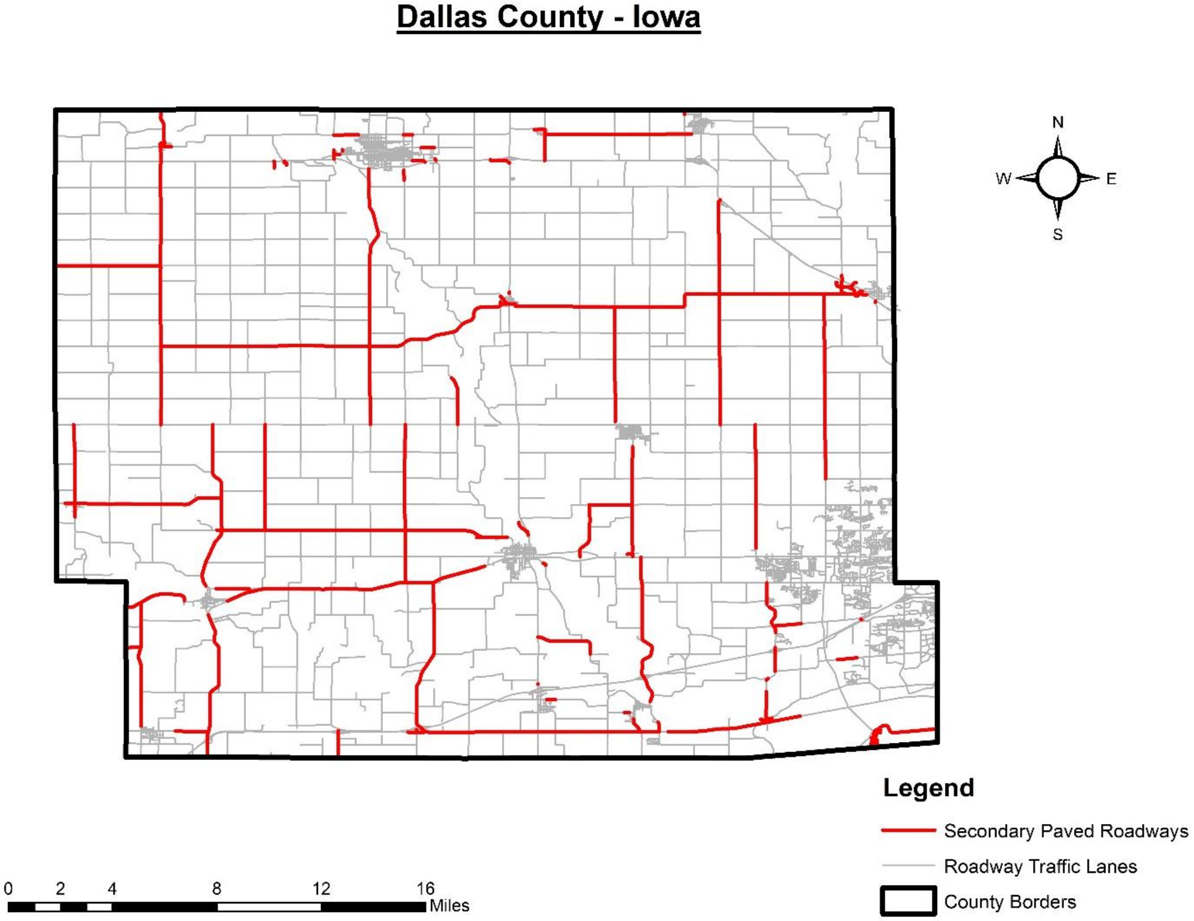

Figure 4: Paved secondary roadways with StreetView in Dallas County.

Data Collected

Minnesota CRSP tool was the selected systemic safety ranking method to be evaluated in this project and the detailed methodology of this tool was summarized in Chapter 2 of this document. A considerable amount of data need to be collected for the Minnesota CRSP approach and the data required could be categorized into roadway geometrics, volume and roadside characteristics. A list of the required input data for the Minnesota CRSP approach is included in Table 2. The Minnesota CRSP approach identified and evaluated risk factors for three major transportation system components including: rural horizontal curves, stop controlled intersections and rural highway segments.

Table 2: Minnesota CRSP Approach Data Input Requirements

Transportation System Component	Data Input Required
Rural Horizontal Curves	District level curve radius on secondary paved rural roads
	District level severe roadway departure crashes on curves
	District level AADT on curves
	County level recorded intersection in curve
	County level recorded visual traps
	County level severe crash data (fatal and major) from 2008 until 2012
Stop-Controlled Intersections	County level skew angle measurement
	County level recorded intersection on or near a curve
	County level recorded commercial development
	County level recorded stop sign within 5 miles
	County level computed ADT ratio
	County level recorded railroad crossing on minor approach of the intersection
	County level crash data (all crash types) from 2008 until 2012
Rural Segments	District level segment AADT
	District level severe roadway departure crashes on segments
	County level number of access points in each segment
	County level roadway departure crashed in each segment from 2008 until 2012
	County level number of curves in each segment
	County level roadside risk assessment

As noted in Table 2, some data were collected at the district level and other data were collected through various means for the specific horizontal curves, intersections and segments at the county level along the highlighted corridors in Figures 3 and 4.

District Level Input Data Descriptive Statistics

It is important to provide certain basic descriptive statistics on the base inventory data prior to data analysis and prioritization in order to become familiar with the road network and apply the appropriate analytical methodologies and strategies described in Chapter 4. The data collected on the district level to apply the CRSP approach are summarized in this section of the report. The first step of the CRSP approach involved the collection of certain data for the Iowa DOT districts within which the two counties reside. The focus was on Iowa DOT Districts 4 and 6 which contained Dallas County and Buchanan County respectively. District 4 covers the south western quadrant of Iowa and District 6 covers the eastern section of Iowa. Data collected for the two districts included traffic volume (AADT) on segments and horizontal curves, curve radius and severe roadway departure crashes. This would assist in the examination of crash patterns on paved secondary rural roadways and then extrapolate relevant information to the counties of interest. The data were acquired from the Iowa 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. Access to these databases was allowed through transportation researchers at the Iowa State University Institute for Transportation (InTrans).

Segment AADT

Traffic volume (AADT) for the entire transportation roadway system is collected on regular basis by the Iowa DOT. Usually, Iowa DOT covers one third of the transportation system in Iowa every three years. Segments defined by Iowa DOT are categorized by consistency in AADT, geometric features and speed. The length of roadway segments in both districts varied from a minimum of 9 feet to a maximum length of 1.5 miles. The minimum segment length identified in the road network is comparatively very small. This might have been a result of changes in the alignment and attributes of the roadway such as recording certain driveways in the network. A total of 5,736 secondary paved rural roadway segments were collected in District 4 and more than 7,900 segment links in District 6. Table 3 represents a summary in terms of descriptive statistics for the traffic flow characteristics collected in the two districts.

Table 3: District 4 and District 6 Segment Analysis and Descriptive Statistics

District Segment Analysis		
Iowa DOT District	District 4	District 6
Number of Samples (n)	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

The distribution of AADT is shown in Figure 5 and it should be noted that the analysis was initially done in increments of 100. However, at higher AADT values the increments altered to 1000 due to low counts of segments in certain clusters. Approximately 40 percent of segments in District 6 have an AADT less than 400 vpd which is lower compared to District 4 at 55 percent. Therefore, these results indicate that an adequate proportion of the secondary (local) paved roadways in both districts are low volume. Figure 5 also shows that District 6 has more high volume segments than District 4. This result is expected because District 6 has more suburban areas which means additional trips are estimated to generate into and out of the district compared to District 4 which has more rural areas.

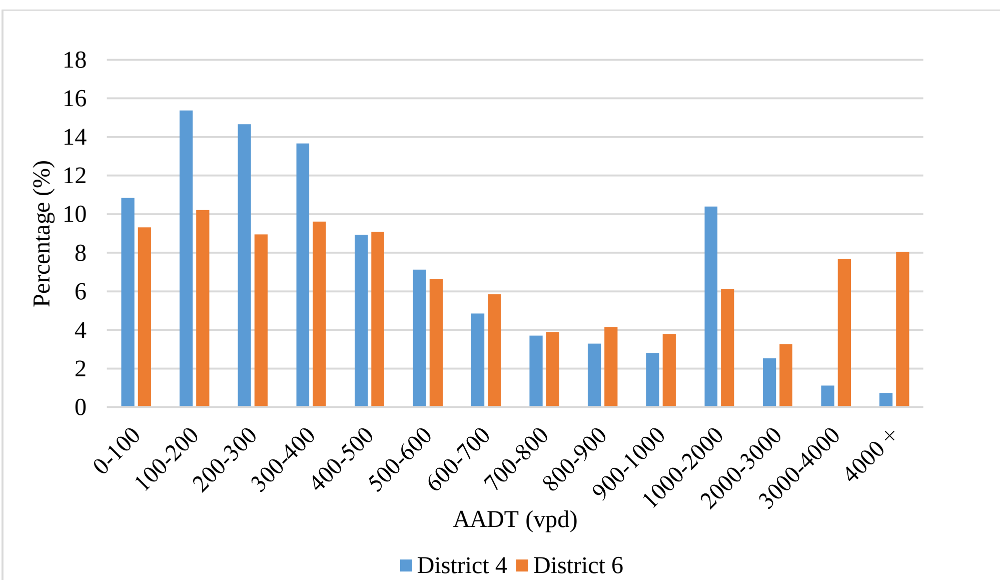

Figure 5: District 4 and District 6 segments AADT distribution.

Horizontal Curves

Impact of curvature on safety is also substantial since unsafe curves could lead to severe and fatal crashes with no proper delineation, advanced curve warning signs, rail guards and so forth. Horizontal curve radii and AADT on these curves data were also collected on the district level in the CRSP approach. The radii of the curves were estimated by the Iowa DOT using two approaches. The first technique used circular regression to estimate the radius of each curve and the second method was based on curve and chord length. These methods require at least five points on the curve to perform the computation and in some cases it was not possible to utilize both approaches to calculate the curve radius. Three horizontal curves in District 4 had a zero curve radius based on the Iowa DOT inventory database. However, following visual inspection on ArcMap, these curves were either small or flat to apply the two curve radius estimation methodologies. These curves were excluded from the analysis. The average of the estimated curve radius values is generally used by the Iowa DOT because larger differences between the two estimated radius values might represent lower confidence in the actual value itself.

A summary of the district curve analysis on secondary paved rural roadways is provided in Table 4. The table included descriptive statistics of the horizontal curve radius and their corresponding traffic flow characteristics for Districts 4 and 6.

Table 4: District 4 and District 6 Horizontal Curves Analysis and Descriptive Statistics

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

The average horizontal curve radii is 1,274 feet in District 4 and 1,058 feet in District 6. The AADT on these horizontal curves have an average of 5,600 vpd in District 4 and 9,200 vpd in District 6. Figures 6 and 7 also illustrate the distribution of curve radii and AADT within the districts.

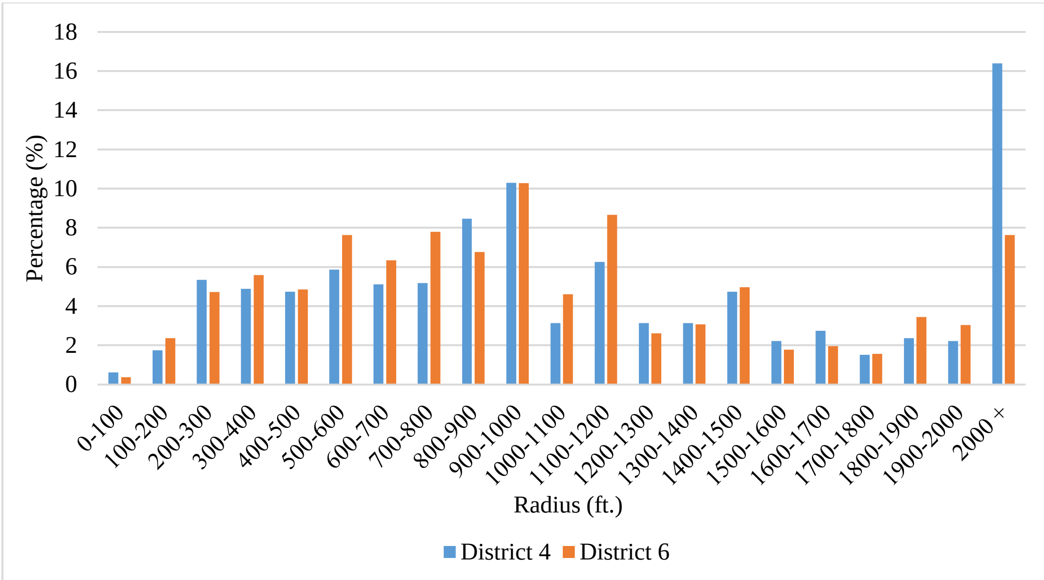

Figure 6: District 4 and District 6 horizontal curve radius distribution.

Approximately 52 percent of the horizontal curves in District 4 versus 57 percent in District 6 have a radius less than 1000 feet. According to a previous discussion in the literature review chapter, Bonneson et al. (*4*) indicated in their research that curves with a radius less than 1000 feet are expected to experience a sharp increase in crash rate. Hence, a considerably large amount of curves within the districts are at risk.

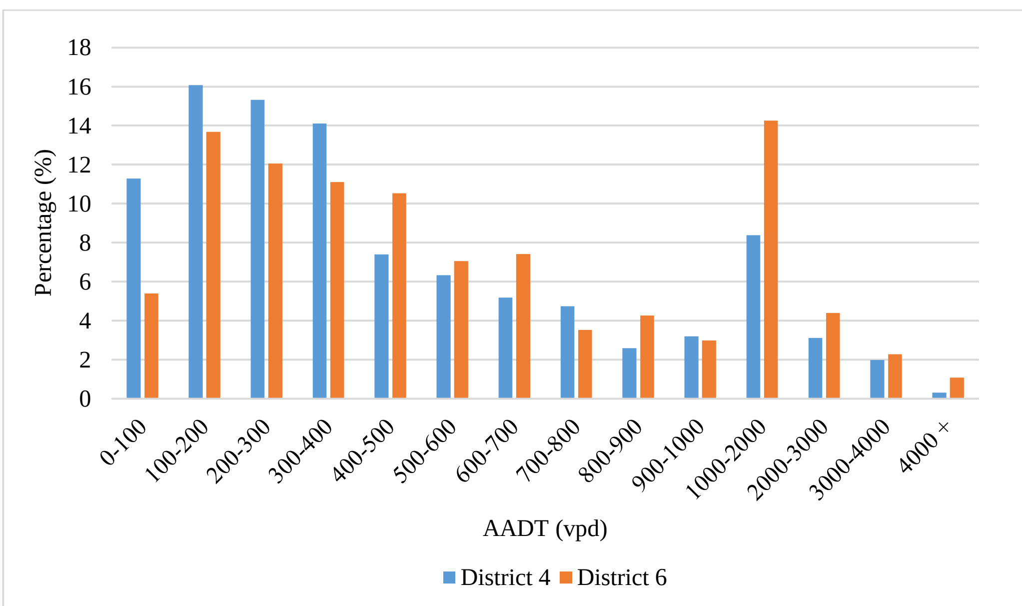

Figure 7: District 4 and District 6 horizontal curves AADT distribution.

The distribution in Figure 7 show that more than 40 percent of the horizontal curves in District 4 and 6 are considered to be low volume because the AADT on these curves is less than 400 vpd.

Crash Data Summary

The FHWA reported some alarming statistics regarding roadway departure safety from the Fatal Analysis Reporting System (FARS) web database. In 2011, almost 50 percent of the total fatalities in the US were caused by roadway departure crashes (*17*). Roadway departure crash data from 2008 to 2012 were collected and summarized for the overall districts (District 4 and 6) including segments and horizontal curves. These results are provided in Tables 5 and 6 respectively.

Table 5: Roadway Departure Crashes on Secondary Paved Roadway Segments in Districts 4 and 6

District	Total Crashes	Fatalities	Injuries				
			Major	Minor	Possible	Unknown	Total
District 4	689	28	65	151	214	15	445
District 6	1259	27	87	260	298	21	666

Table 6: Roadway Departure Crashes on Secondary Paved Roadway Curves in Districts 4 and 6

District	Total Crashes	Fatalities	Injuries				
			Major	Minor	Possible	Unknown	Total
District 4	267	14	34	65	69	8	176
District 6	463	10	43	93	128	8	272

It could be noted from the statistical figures in Tables 5 and 6 that there were 689 total roadway departure crashes in District 4 segments and 1259 in District 6 segments for the five years crash analysis resulting in 65 and 87 fatalities respectively (which is almost 13 percent of the total injuries in both districts). Additionally, the fatalities caused by roadway departure crashes along horizontal curves compromise 50 percent of the total crashes in District 4 and approximately 37 percent in District 6.

Minnesota CRSP Approach County Level Input Data

The CRSP systemic tool was the methodology selected for evaluation. As mentioned previously, the CRSP approach was applied to paved secondary roadways with Street View in Buchanan and Dallas counties. Details of the process and methodology used in the CRSP were summarized in Chapter 2. The technique mainly focused on three roadway elements including rural horizontal curves, stop-controlled intersections and rural segments. A star ranking system was used to prioritize at risk locations by assigning risk factors to each element. The data collected on the district and county level to apply the CRSP approach are summarized in the following section of the report. Moreover, contents of the next chapter (Chapter 4) would be describing the ranking and sensitivity analysis results of the prioritization process.

Rural Horizontal Curves

The assessment of rural horizontal curves in both counties was based on five risk factors and the required input data used for prioritization are discussed in this section. The five risk factors included the following:

- Curve Radius
- Traffic Volume
- Intersection in Curve
- Visual Trap
- Crash Experience

Buchanan County has 82 rural horizontal curves identified as part of the secondary paved rural road network while Dallas County has a total of 83 curves. Only seven of these curves in both counties experienced a severe crash (i.e. fatal and major injury) between 2008 and 2012 (five year study period). Thus, this affirms the notion that the traditional reactive method used for prioritization is not efficient due to the wide spread nature of crashes in rural areas. In other words, the number of crashes were very few to serve as a consistent indicator of risk.

An element received a star ranking if it satisfied the criteria of the risk factor. A more detailed analysis highlighting the data input required to generate the criterion of each risk factor in the elements are described as follow:

Curve Radius It was discussed in the previous section of this chapter that curve radius data were collected on district level. A range of curve radii in each district that had an over-representation in severe crashes (i.e. fatal and major injury) on secondary paved rural roadways was selected. Plots in Figures 8 and 9 illustrate the percentage of horizontal curves along with percentage of severe (fatal and major injury) roadway departure crashes on those horizontal curves of the radii shown for Iowa DOT District 4 and 6, respectively.

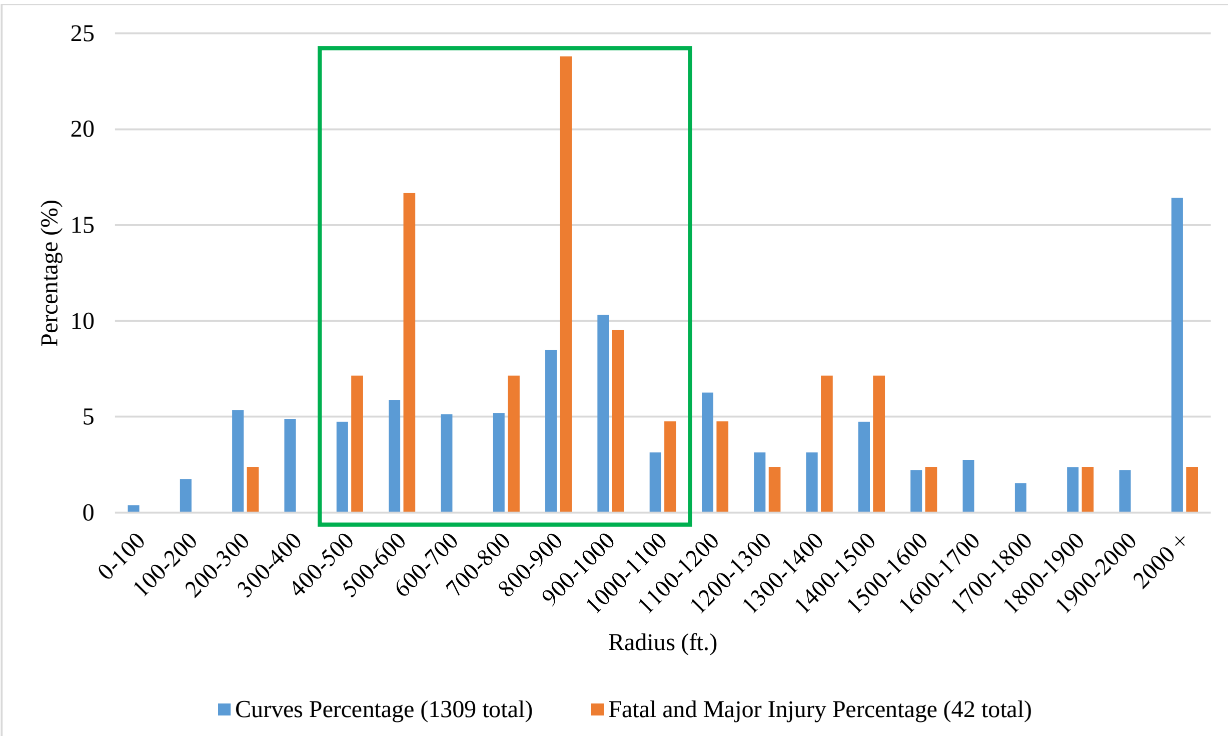

Figure 8: District 4 severe roadway departure crashes on curves and curve radius.

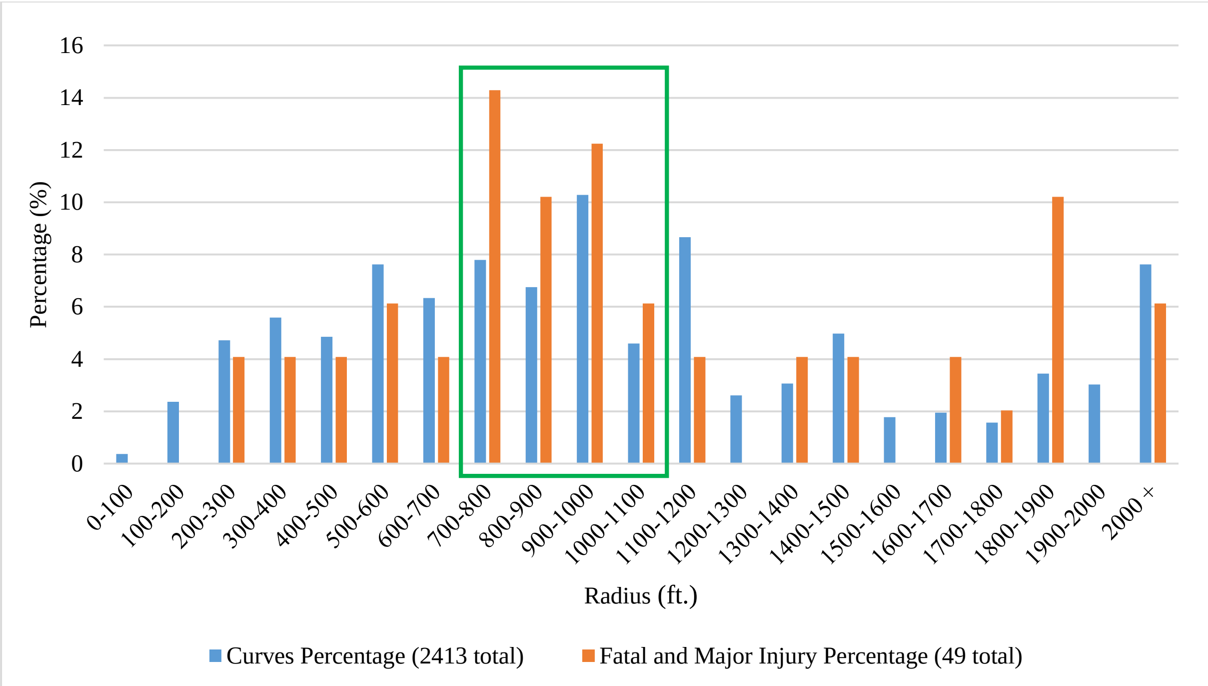

Figure 9: District 6 severe roadway departure crashes on curves and curve radius.

The project team made a subjective decision for the selection of the over-represented ranges. The over-represented range marked by the box in each plot shows that approximately 70 percent of the severe roadway departure crashes in District 4 occurred on horizontal curves with radius ranging between 400 and 1100 feet compared to 42 percent between 700 feet and 1100 feet in District 6. Rural curves in Buchanan and Dallas counties were assessed according to the criteria determined from district analysis. Therefore, a curve radius satisfying the criteria of the over-represented range received a star.

Traffic Volume AADT on curves was another characteristic collected at the district level. Figures 10 and 11 show the percentage of horizontal curves in each district (District 4 and 6 respectively) and percentage of severe (fatal and major injury) roadway departure crashes by AADT on these curves.

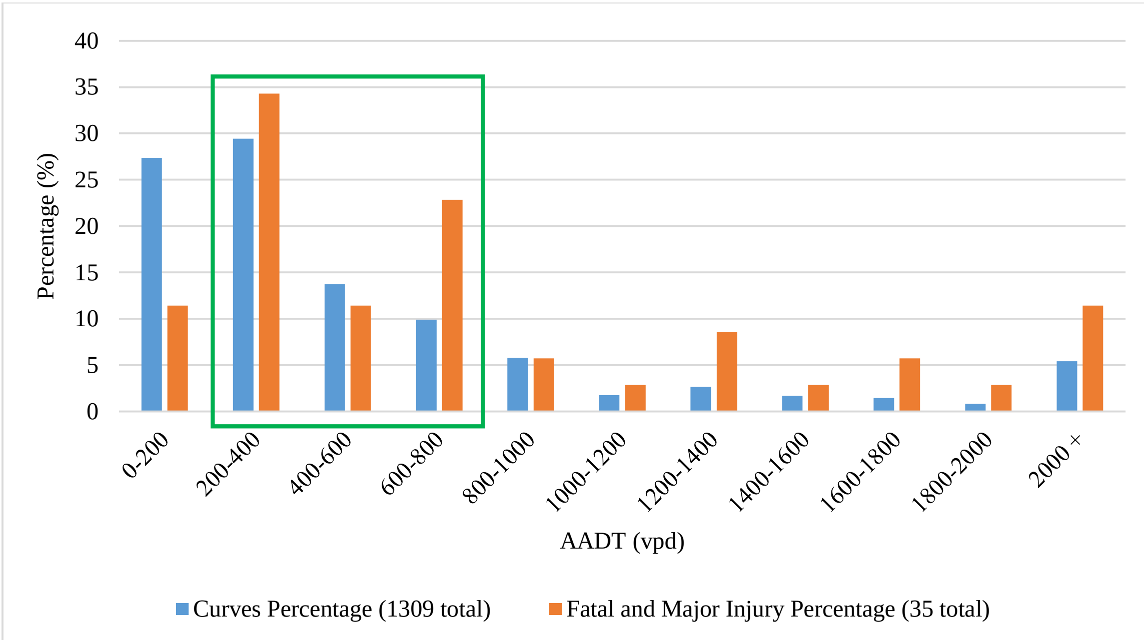

Figure 10: District 4 severe roadway departure crashes on curves and curve AADT.

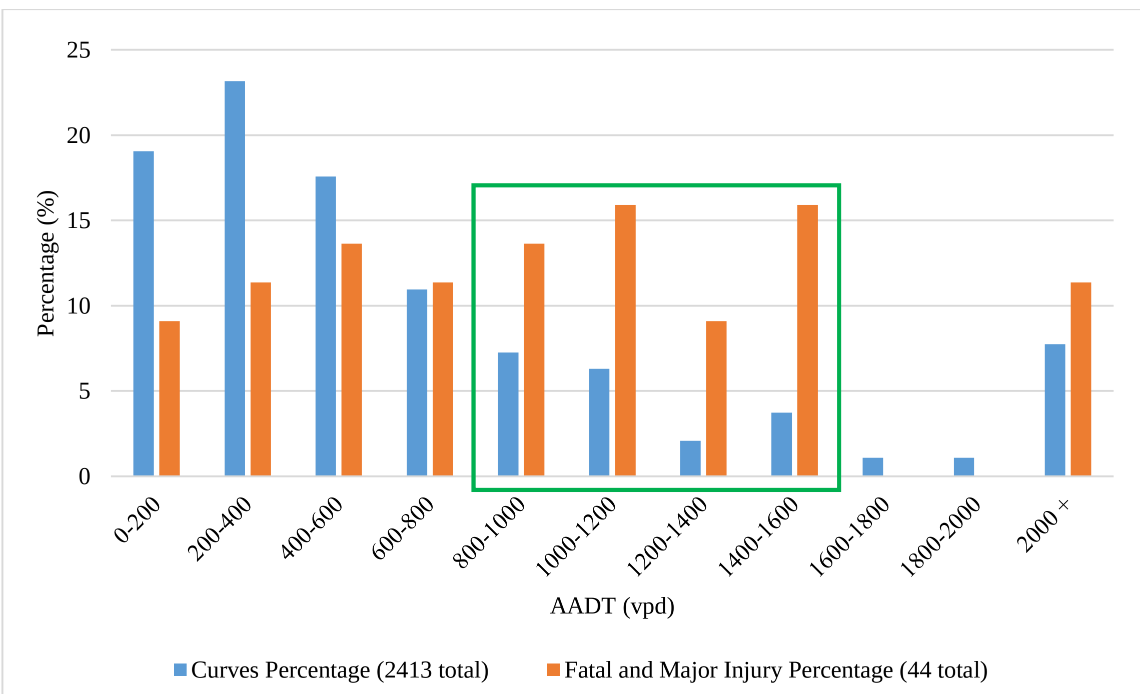

Figure 11: District 6 severe roadway departure crashes on curves and curve AADT.

Every roadway network has a range of traffic volume that is over-represented in relation to the frequency of curve-related crashes. In District 4, horizontal curves in the volume range of 200 and 800 vpd accounted for 68 percent of severe roadway departure crashes. However, the curves in the volume range of 800 and 1600 vpd in District 6 resulted in 55 percent of the severe roadway departure crashes. These results were then used as input criteria for the evaluation of rural curves in Buchanan and Dallas counties. A star was assigned to each curve that met the criteria.

Intersection in Curve Visualization technique, ArcMap, was used to determine if an intersection was present at a spatial proximity of 150 feet of the curve location. One paved intersection could be within a 150 feet radius of multiple horizontal curves. Hence, horizontal curves with an intersection received a star.

Visual Trap As noted in Chapter 2, the presence of a visual trap increases the risk of being involved in a crash and these curves were assigned a star. Visual traps were recorded from Google StreetView images.

Crash Experience Crash data from the Iowa DOT database was used to determine if a horizontal curve experienced a severe crash (i.e. fatal and major injury) during the five year analysis period (from 2008 until 2012). Curves that experienced a severe crash received a star.

Stop-Controlled Intersections

Another element of the transportation roadway system evaluated in the CRSP approach was stop-controlled intersection. At risk intersection locations in Buchanan and Dallas counties were prioritized using seven risk factors. The identified seven risk factors included the following:

- Skew angle
- Intersection On/Near Curve
- Commercial Development
- Distance to Previous Stop Sign
- AADT Ratio

- Railroad crossing on Minor Approach
- Crash History

Buchanan County has 52 through/stop-controlled intersections while Dallas County has 47 of them identified along secondary paved rural roadways. These intersections were then evaluated using the seven risk factors identified by the CRSP methodology. The input data required to define these risk factors included the following:

Skew Angle The skew angle of an intersection was measured using the measurement tools available in ArcMap. According to the Minnesota CRSP report (referring to Chapter 2), skewed intersections have a higher risk to experience a crash. Therefore, an intersection received a star if it had a skewed approach greater than 15 degrees measured from the base (90 degrees).

Intersection On/Near Curve It was determined if an intersection was located on or near (within 150 feet) a horizontal curve. This risk factor differs from the one identified for horizontal curves by the range of intersections around a curve. In other words, an intersection point might have one or more horizontal curves within 150 feet radius. A star was assigned for an intersection located on or near a curve.

Commercial Development The presence of a commercial development (other than residence or a farm) was recorded in any quadrant of an intersection. An intersection with a commercial development received a star since it increased the level of risk.

Distance to Previous Stop Sign As noted in Chapter 2, drivers frequently lose attention when driving for longer distances with no stop sign. Therefore, the presence of a stop sign within five miles on the paved approach of an intersection which is part of the roadway network and/or has Google StreetView images was determined. A star was given to an intersection when its minor leg approach did not have a stop sign within five miles.

AADT Ratio Traffic volume data were collected for the major and minor approaches of each intersection in the two counties. The ratio of the minor intersection-leg AADT to major intersection-leg AADT was then computed for every intersection. An intersection-leg with the minimum AADT was identified as the minor approach while the major approach had the maximum AADT. There were three different scenario calculations of the AADT ratio and they included the following:

- For 3-leg intersections: the average value of AADT on the main approach was computed since there is traffic flow on both legs of the intersection. The minimum AADT value from both the main approach and intersecting road was divided by the maximum value.
- For 4-leg intersections: the average value of AADT on both the main and intersecting legs of the intersection was determined and the AADT ratio was then computed.
- For local roadways intersecting with arterial roadways: the average value of AADT was first determined for the local roadways only. This is because the arterial road, for instance an interstate or US highway, intersecting with the local roadway was a one-way ramp generating flow into the traffic stream. The AADT ratio was then calculated.

Referring to the county system in the Minnesota CRSP approach, there was a range of ADT ratio more prone to severe crashes than others. It was recognized that intersections with an ADT ratio between 0.4 and 0.8 received a star (there was no justification for the selected over-represented range). On the other hand, the same criteria was applied in both Buchanan and Dallas counties due to the unavailability of ADT ratio information in the Iowa DOT electronic database and since there is a reasonable similarity in the data compared to the counties in the Minnesota ATP 4 District. It was not possible to create a plot of intersection frequency on district level in Iowa (Districts 4 and 6) for different ranges of AADT ratios.

Railroad Crossing on Minor Approach This risk factor used to systemically rank rural stop-controlled intersection was determined using ArcMap. An intersection received a star if a railroad crossing was located within 500 feet of the intersection since the level of risk to be involved in a crash would increase.

Crash History Any rural stop-controlled intersection in Buchanan and Dallas counties that experienced a crash (any type of crash) during the five year period analysis (i.e. from 2008 to 2012) was assigned a star.

Rural Segments

Rural two-lane paved segments were another component of the systemic evaluation and prioritization in the Minnesota CRSP approach. The level of risk Assigned to each segment was based on five risk factors:

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

Buchanan and Dallas counties had a total of 197 and 156 miles of secondary paved rural roadways with Google StreetView images, respectively. The overall mileage in the two counties was divided into 58 segments on the basis of several factors including continuity in the roadway section, and similarity in AADT, speed limit and geometric features. The minimum defined length of a segment in both counties was 0.50 miles and the maximum segment length was 10 miles. The identification of segments in each county helps in determining the corridors/segments that have higher level of risk to experience a severe roadway departure crash. The input data requirements for the five risk factors to complete the prioritization process included the following:

AADT Range As noted previously, traffic volume and severe (fatal and major injury) roadway departure crash data on segments were also collected at the district level (Districts 4 and 6). The plots in Figures 12 and 13 show the percentage of secondary rural paved roadways by AADT along with the percentage of severe roadway departure crashes for Iowa DOT Districts 4 and 6. Segments that had an over-representation in the severe roadway departure crashes were highlighted on the plots. It could be observed that approximately 20 percent of the rural segments in District 4 with an AADT between 600 and 1400 vpd experienced 31 percent of the severe roadway departure crashes. Similarly, 35 percent of the segments in District 6 with an AADT between 600 and 1600 vpd had an over-representation of severe roadway departure crashes by 55 percent. These results were then applied to the segments identified in Buchanan and Dallas counties.

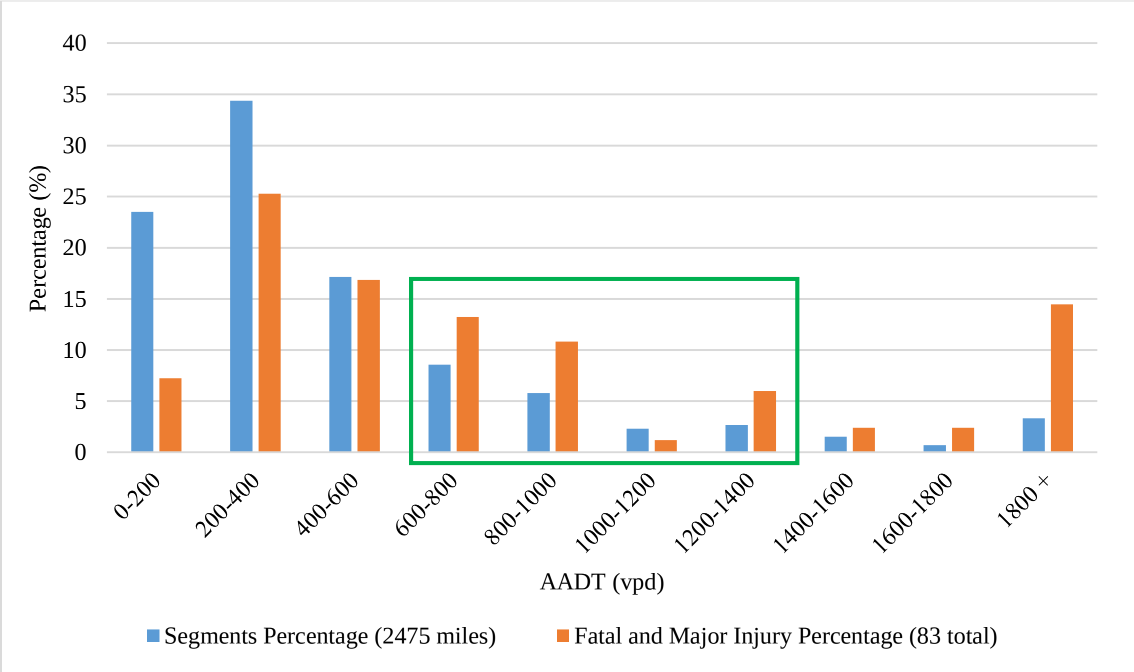

Figure 12: District 4 mileage and severe roadway departure crashes by AADT.

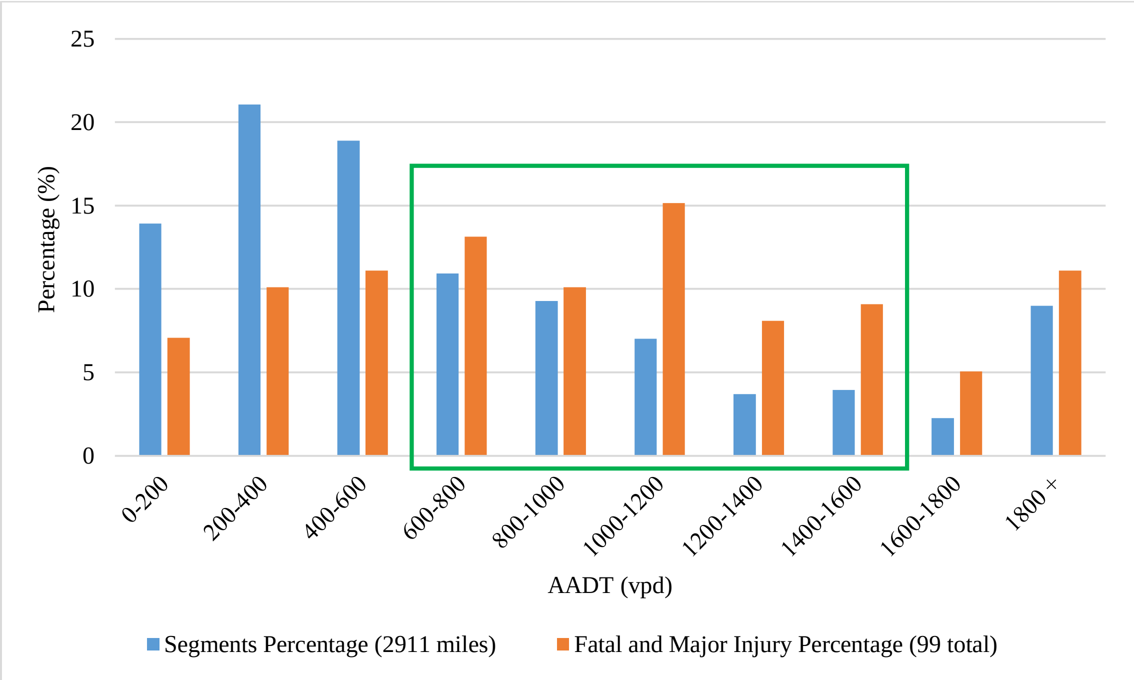

Figure 13: District 6 mileage and severe roadway departure crashes by AADT.

Access Density The impact of access points on the risk level of every segment in Buchanan and Dallas counties was evaluated through access density. Access density was calculated by dividing the total access points in a defined road segment by the total length of the segment (access point per mile). The average access density in Buchanan and Dallas counties were 9.23 and 12.87 respectively. Roadway segments with access density greater than the computed average values received a star.

Roadway Departure Crash Density Average roadway departure crashes per mile per year for the segments in each county were computed (considering crash data from 2008 until 2012). The defined segments on the secondary paved two-lane rural roadways in both counties (Buchanan and Dallas) had an average roadway departure crash density of 0.058 crashes per mile per year (including all roadway departure crash types). These results are fairly similar to the Otter Tail County in Minnesota with 0.08 roadway departure crashes per mile per year (see Chapter 2). Any segment experiencing a road departure density higher than the average value received a star.

Critical Radius Curve Density As previously discussed in Chapter 2, at risk curve locations identified also impact the risk level of segments. The total number of critical curves was calculated (previously mentioned in the horizontal curves section) per mile for each segment in the two counties. These values were compared to the district-level average critical radius curve density (0.144 critical curves per mile in District 4 versus 0.075 critical curves per mile in District 6). If the critical radius curve density of a segment +was greater than the average district value then it received a star.

Edge Risk Assessment The level of risk involved when vehicles leave the travel lane was assessed and categorized with the help of a rating system that was developed by the Minnesota DOT (refer to Chapter 2). Segments were assigned a star if they had an edge risk assessment rating of two or three.

Results shown in Table 7 provide the number of locations that met the input data criteria of risk factors for each of the three transportation elements (i.e. rural horizontal curves, rural stop-controlled intersections and rural segments) when the Minnesota CRSP approach was applied.

Table 7: Sites Count in Buchanan and Dallas Counties Satisfying Risk Factor Input Data Requirements

Transportation Element	Risk Factor	Buchanan County		Dallas County	
		Count	(%)	Count	(%)
Rural Horizontal Curves	Curve Radius	12	15	20	24
	Traffic Volume	43	52	37	45
	Intersection in Curve	37	45	47	57
	Visual Trap	2	2	2	2
	Crash Experience	7	9	7	8
Rural Stop-Controlled Intersections	Skew Angle	16	31	17	36
	Intersection On/Near Curve	5	10	11	23
	Commercial Development in Quadrants	4	8	7	15
	Distance to Previous 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 Range	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 Assessment	2	3	24	41

It could be indicated from the results in Table 7 that there is a similarity in the number of sites receiving a star rating for a wide variety of risk factors when comparing Buchanan and Dallas counties. On the other hand, there were a few risk factors in each transportation element (for instance, intersection on/near curve and distance to previous stop sign in stop-controlled intersections, and edge risk assessment in rural segments) with a drastic difference in the number of locations between the two counties.

The application of the Minnesota CRSP approach was merely based on a decision making matrix that assisted in the selection of the appropriate tool for evaluation. Furthermore, the evaluation was implemented on two counties, Buchanan and Dallas County, as part of the agreement to collaborate in this project and availability of data. This chapter mainly presented the input data required to apply the Minnesota CRSP approach. Further details and examination would be provided in the next chapter, focusing on the prioritization results (ranking list) of the selected systemic methodology and the sensitivity analysis conducted to study the effect of the shift in rating/ranking by adjusting factors.

CHAPTER 4

PRIORITIZATION RESULTS AND SENSITIVITY ANALYSIS

This chapter was specifically designed to demonstrate the prioritization results from the CRSP systemic safety methodology. As discussed in Chapter 2, the technique was selected based on five qualifying characteristics. The third chapter contents described the data collection process required to apply the CRSP approach. Additionally, a complete sensitivity analysis would be performed in order to statistically measure the effect of changing the weights of risk factors in the selected systemic safety approach. Significance in the results might have an extensive influence on the process of the methodology. In other words, there might be a need to be rational with the selection of appropriate risk factors and in the assignment of weights to these risk factors. However, if results from the sensitivity analysis were statistically insignificant, this does not necessarily mean that the prioritization techniques were inefficient. It could either correlate to the fact that the weights do not have an adverse effect on the prioritization technique or simply risk factors need to be selected more attentively based on the variability of the roadway system.

Minnesota CRSP Approach Prioritization Results

The CRSP tool known for identifying and prioritizing at risk locations was used to evaluate secondary paved rural roadways within Buchanan and Dallas counties in Iowa. The methodology was explicitly presented in the literature review and is mainly based on a star ranking system used to prioritize at risk locations including: rural horizontal curves, stop-controlled intersections and rural segments. Moreover, Chapter 3 provided the data input required to be collected so that the ranking evaluation would be completed. The results of the prioritization process are described below.

Rural Horizontal Curves

As noted in Chapter 3, a total of 82 rural horizontal curves in Buchanan County and 83 curves in Dallas County were prioritized. The prioritization process involved assigning risk to each curve based on the five risk factors and the curves with highest number of stars were considered to be highest priority. As opposed to the CRSP approach, a decision was made to use curve radius as tie breaker in cases where curves received the same number of stars. Curves with shorter radius have more risk. Additionally, if a tie still existed, then an average value of the sites' ranks was computed. Originally, there were no tie breakers identified for rural horizontal curves in the CRSP systemic safety approach and curves with a total of three stars or more were considered higher priority. However, the decision of using radius as tie breaker was considered most appropriate based on the variability of the data and for the selection of curves with highest risk. Funding federal projects is an obstacle in every nation due to its limitation. Therefore, it is essential to be careful with the allocation of funds and selection of sites to apply the countermeasures.

A complete prioritization list of horizontal rural curves in Buchanan and Dallas counties is provided in Appendix A. While a summary of the results in terms of the number of curves in both counties that received a particular star ranking ranging from zero through five are presented in Table 8.

Table 8: Total Star Ranking for Horizontal Curves in Buchanan and Dallas Counties

Rural Horizontal Curves	**Total Star Ranking**						**Average Ranking**	**Ranking Standard Deviation**
	Number of Horizontal Curves							
County Name	**0**	**1**	**2**	**3**	**4**	**5**		
Buchanan County	21	31	20	10	0	0	1.23	0.97
Dallas County	11	38	27	7	0	0	1.36	0.82

Table 8 shows that a total of ten curves in Buchanan County and only seven curves in Dallas County received a total star ranking of three (none received a total ranking higher than three). These curves would be considered higher priority when applying this methodology and a list of these locations are included in Table 9 for both counties. Therefore, it could be concluded that a majority of rural horizontal curves in the secondary paved roadway network for both counties are moderately safe with very few curves that require improvement projects.

Table 9: Higher Priority Horizontal Curves in Buchanan and Dallas Counties

Curve Number	Total Stars	Radius (ft.)	Priority Ranking
Buchanan County			
Curve 70	3	582	1
Curve 14	3	831	2
Curve 4	3	842	3
Curve 65	3	978	4
Curve 1	3	1047	5
Curve 50	3	1199	6
Curve 38	3	1868	7
Curve 61	3	1906	8
Curve 57	3	1907	9
Curve 82	3	3746	10
Dallas County			
Curve 44	3	367	1
Curve 79	3	420	2
Curve 54	3	697	3
Curve 29	3	779	4
Curve 51	3	826	5
Curve 42	3	1129	6
Curve 6	3	1307	7

Stop-Controlled Intersections

The evaluation of stop-controlled intersections along the secondary paved roadway network was based on an assessment of the intersection's exposure to seven factors. A total of 52 intersections in Buchanan County and 47 intersections in Dallas County were identified when the CRSP approach was applied. A star was assigned to an intersection for each factor if the conditions were satisfied and intersections with most stars, i.e. three stars or more, were considered to be higher priority. The CRSP approach used crash cost as a tie breaker in cases where intersections received the same number of stars. However, AADT ratio was used as a tie breaker during the prioritization of sites in Buchanan and Dallas counties. Sites with higher AADT ratio have more risk associated with them. The decision of using AADT ratio as a tie breaker was made because this parameter has more variability in the data collected and would eliminate as much ties as possible. Furthermore, an average value of the ranks would be computed if certain locations were tied in terms of star ranking and AADT ratio.

Detailed results and data used during the prioritization process are provided in Appendix B. Table 10 summarizes the results of the prioritized stop-controlled intersections and shows the number of sites in both counties that received a total star ranking ranging from zero through seven.

Table 10: Total Star Ranking for Stop-Controlled Intersection in Buchanan and Dallas Counties

Stop-Controlled Intersections	**Total Star Ranking**								**Average Ranking**	**Ranking Standard Deviation**
	Number of Horizontal Curves									
County Name	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		
Buchanan County	9	13	16	10	3	1	0	0	1.77	1.23
Dallas County	5	15	13	9	4	1	0	0	1.89	1.22

Locations with a total star ranking of three star or more have the highest priority and are considered for safety improvement projects. Reviewing the results in Table 10, approximately 27 percent (14 locations out of 52) of intersections in Buchanan versus 30 percent (14 locations out of 47) in Dallas were considered higher priority with only one location in both counties that had a maximum ranking of five stars. Moreover, it could be established from the average star ranking values that a vast majority of stop-controlled intersections in both counties are in good condition. Table 11 provides a list of high priority locations in Buchanan and Dallas counties.

Table 11: Higher Priority Stop-Controlled Intersections in Buchanan and Dallas Counties

Intersection Number	Total Stars	AADT Ratio	Priority Ranking
Buchanan County			
Intersection 21	5	0.739	1
Intersection 8	4	0.769	2
Intersection 10	4	0.461	3
Intersection 35	4	0.400	4
Intersection 38	3	0.803	5
Intersection 11	3	0.775	6
Intersection 47	3	0.745	7
Intersection 36	3	0.719	8
Intersection 12	3	0.588	9
Intersection 17	3	0.555	10
Intersection 2	3	0.468	11
Intersection 14	3	0.443	12
Intersection 9	3	0.426	13
Intersection 29	3	0.219	14
Dallas County			
Intersection 39	5	0.454	1
Intersection 45	4	0.650	2
Intersection 14	4	0.448	3
Intersection 29	4	0.375	4
Intersection 10	4	0.107	5
Intersection 18	3	0.970	6
Intersection 19	3	0.913	7
Intersection 28	3	0.554	8
Intersection 42	3	0.329	9
Intersection 25	3	0.157	10
Intersection 30	3	0.124	11
Intersection 31	3	0.111	12
Intersection 16	3	0.110	13
Intersection 26	3	0.069	14

Rural Segments

The identification of rural two-lane at risk segment locations is important in order to determine the appropriate safety improvement projects to be implemented and as a result help in improving conditions at specific locations. The prioritization list for Buchanan and Dallas counties was completed based on five different risk factors and 58 rural segments were identified in each of the two counties. The level of risk was evaluated for each segment and a star was assigned if the segment met the criteria of the risk factor. Segments that received three stars or more were considered higher priority. The CRSP approach initially used edge risk assessment and then roadway departure crash density as tie breakers in cases where segments received the same number of stars. However, it was decided to use AADT as a tie breaker instead since former parameters resembled low variability in the roadway network of interest. If segments were still tied then an average value of the ranks would be computed for these specific locations. Eliminating as much ties as possible is beneficial for selecting higher risk sites. A limitation in funds is a major obstacle in safety prioritization projects, therefore sites with higher priority should be selected attentively.

Appendix C provides the complete prioritization list and data set used during the process. Additionally, Table 12 summarizes the results of the prioritized segments showing the number of segments in Buchanan and Dallas counties that received a total star ranking ranging between zero and five.

Table 12: Total Star Ranking for Rural Segments in Buchanan and Dallas Counties

Rural Segments	**Total Star Ranking**						**Average Ranking**	**Ranking Standard Deviation**
	Number of Horizontal Curves							
County Name	**0**	**1**	**2**	**3**	**4**	**5**		
Buchanan County	15	16	19	4	4	0	1.41	1.16
Dallas County	5	19	27	6	1	0	1.64	0.85

A total of eight segments in Buchanan (14 percent) versus seven segments in Dallas (12 percent) are at higher risk as they received a total star ranking of three or more and these corridors are taken into account for future safety improvements. None of the segments received a total star ranking higher than four. On the contrary, it could be established from these results that both counties have a relatively good roadway system since all segments had an average value of less than two stars. Results provided in Table 13 consist of the high priority segments in Buchanan and Dallas counties that were identified through the prioritization process.

Table 13: Higher Priority Rural Segments in Buchanan and Dallas Counties

Segment Number	Total Stars	AADT (vpd)	Priority Ranking
Buchanan County			
Segment 44	4	1350	1
Segment 18	4	900	2
Segment 54	4	825	3
Segment 55	4	720	4
Segment 17	3	1410	5
Segment 13	3	1330	6
Segment 3	3	630	7
Segment 31	3	330	8
Dallas County			
Segment 54	4	660	1
Segment 30	3	3450	2
Segment 20	3	1515	3
Segment 17	3	840	4
Segment 47	3	765	5
Segment 23	3	710	6
Segment 55	3	370	7

Sensitivity Analysis and Statistical Evaluation

Any model is subject to change and error in terms of the parameter values and assumptions made. As a result, sensitivity analysis is used to investigate the potential changes and errors then evaluate the impact on the model. Sensitivity analysis has several possible uses including decision support, communication, comprehending and quantifying the system better, and model development purposes.

The importance of conducting a sensitivity analysis in this project is to measure whether a change in the weight/coefficient of risk factors in the CRSP approach would have a significant change in the ranking of sites. Dr. Gary Smith, a professor in Economics, discussed in his book "Statistical Reasoning" that various statistical methods such as the t-statistics, F-test and so forth, assume that the random variables in the data are normally distributed (*18*). Other statistical tests also assume normality. For example, the error term in the parameters of the regression model is considered to be normally distributed. The random variation in the analysis-of-variance tests is also assumed to conform a normal distribution. On the other hand, there are situations where the number of samples in the population is small or the data does not resemble any normal distribution characteristics. Smith then declared that statisticians have developed alternative methods for researchers who are hesitant to assume normality. Non-parametric or distribution-free statistical procedures were devised with the purpose to be applied for all data type regardless distribution. Therefore, non-parametric statistics works for both normal and non-normal distribution (*18*).

Non-parametric tests are considered to be very robust since they are not sensitive to the inaccuracy or error in the normality assumption. There are many widely used non-parametric tests. However, one of these methods is discussed intensively in this section of the report. Taking into account the nature of the data to be evaluated, the Kendall rank correlation coefficient would be more appropriate to assess whether the original and new ranking might be regarded as statistically dependent. The Kendall rank correlation coefficient which is also known as Kendall's tau coefficient was first proposed by Gustav Fechner in 1897 then Maurice Kendall redeveloped it in 1938. Kendall's tau coefficient is used in non-parametric statistics as a measure of association between two measured quantities and a tau test hypothetically tests for statistical dependence in the paired data set on the basis of the tau coefficient. Therefore, this test specifically measures the monotone relationship between variates or the paired ranked data set (*19*).

The notion of concordance is a fundamental term used in Kendall's tau. 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. The Kendall's tau for a sample is defined as follow (*19*):

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

Equation 1: Kendall Tau Coefficient

Where the variable S is the number of concordant pairs minus the number of discordant pairs. The coefficient must always be in the range of $-1 \leq \tau \leq 1$ since the denominator represents the total number pair combination (*3*). In cases if the coefficient is equivalent to 1 then there is a perfect positive correlation, i.e. the two rankings are the same. A coefficient value of -1 means that there is a perfect negative correlation, i.e. the two rankings are different. Additionally, if the coefficient was approximately zero then both X and Y are independent variables. However, the following adjusted formula is used when ties exist in the data, otherwise known as Kendall Tau-b (*19*):

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

Equation 2: Kendall Tau-b Coefficient

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

The Kendall coefficient of rank correlation has been widely used as a logical measure of dependence between two variables and is also frequently used in testing hypotheses. The null hypothesis assumes that variables X and Y are independent, thus the tau coefficient has an expected value of zero. While the alternative hypothesis would assume that variables X and Y are dependent. A one-tailed test is restricted to either concordance or discordance which is an unusual assumption. Commonly, a two-tailed test is used as it takes into consideration the probability of concordance or discordance, i.e. positive or negative correlation (*19*).

For larger samples, when $n > 10$, it is common to assume the distribution to be normal and use an approximation to the normal distribution with the mean equal to zero $(\mu = 0)$ and standard deviation equivalent to the following (*20*):

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

Equation 3: Standard Deviation for Larger Samples (n > 10)

A sensitivity analysis would be primarily performed on the initial rankings produced via the Minnesota CRSP approach and then the level of significance is measured by applying the Kendall Tau-b statistics.

Minnesota CRSP Approach Sensitivity Analysis

Initially, each risk factor used in the assessment and prioritization of horizontal curves, intersections and segments was weighted equally, i.e. each risk factor had a weight of one. For instance, if a specific location met the criteria of a risk factor then it would receive a star and the location's level of risk is determined by the accumulated number of stars. One of this project's objectives is to determine the impact on the prioritization list by altering the weight/coefficient of certain primary inputs (risk factors). Therefore, a comprehensive sensitivity analysis would be performed to evaluate whether a modification in the method of assigning weights to risk factors would have a significant influence on the ranking. Three different schemes were designed as part of the sensitivity analysis in order to assess risk factors by assigning relative weights using different techniques.

The three sensitivity analysis approaches consisted of the following:

- Sensitivity Analysis Approach 1: Basic Application
- Sensitivity Analysis Approach 2: Engineering Judgment and Point System
- Sensitivity Analysis Approach 3: Variable Data Input and Point System

The general technique applied to all the three sensitivity analysis schemes would involve changing the weight (coefficient) of risk factors from one to two. Risk factors that have a stronger affiliation with locations experiencing a crash are allotted higher weights. In this case the coefficient of risk factors are doubled and this technique is maintained in all the sensitivity analysis approaches for consistency.

A detailed explanation of each methodology is provided in the following section. The steps involved in the application of each scheme included the following:

Step 1: Obtain the initial documents containing the excel files used to create the prioritization list for horizontal rural curves, stop-controlled intersections and rural segments.

Step 2: Select the risk factors for analysis by applying the methodology of each sensitivity analysis scheme.

Step 3: Change the weight/coefficient of the selected risk factors according to the established criteria in each approach.

Step 4: Calculate the new total star ranking of each location and re-rank sites using the same tie-breaking rules mentioned in the previous sections of this chapter.

Step 5: Apply the Kendall Tau-b statistical test to measure the significance of shift in ranking. A positive correlation ($0 < \tau \leq 1$) means that there was no significant shift in ranking while a negative correlation ($-1 \leq \tau < 0$) means that the new ranking is different than the initial one, i.e. there was a significant shift in ranking of sites. However, if the tau coefficient was almost zero ($\tau \cong 0$) then the two variables are independent.

Step 6: Make a decision on the basis of Kendall Tau-b coefficient.

- If the two ranking systems were positively correlated then it could be concluded that the shift in ranking was insignificant.
- If the two ranking systems were negatively correlated then terminate the process since the shift in ranking was significant.

Step 7: Terminate the sensitivity analysis test and make conclusions accordingly by referring to the statistical evaluation results.

Sensitivity Analysis Approach 1: Basic Application The first scheme was designed to determine the minimum number of sites that need to be shifted resulting in a significant change by altering the weight/coefficient of risk factors. A matrix was developed for each transportation element, i.e. rural horizontal curves, stop-controlled intersections and rural segments, in Buchanan and Dallas counties including the number of locations affected by a combination of risk factors. These matrices show all the possible combination of risk factors with no repetition (double counting) along with the associated number of sites that received a star for these risk factor combinations. Consequently, the established matrices are presented in Appendix D. This approach first considers changing the weight/coefficient of the individual risk factor that has minimal effect on the sites shifted. The weight of the risk factor is changed from one to two and then Steps 4 through 6 are applied to compute the Kendall Tau-b coefficient. If the initial and new ranking lists are positively correlated then the process is continued by determining the next individual risk factor with minimum effect on the amount of sites shifted. Furthermore, if a change in the weight of the individual risk factors showed no statistical significance then the combinations of safety risk factors that would impact the most (but not all) transportation elements in the database were identified. The weight of these risk factors were doubled and new rankings were produced. The combinations considered for each transportation element in the two counties are presented in Table 14.

Table 14: Risk Factor Combinations Considered in Sensitivity Analysis Approach 1

Roadway Element	Risk Factor Combinations Considered	
	Buchanan County	Dallas County
Horizontal Curves	• Traffic Volume • Intersection in Curve	• Curve Radius • Traffic Volume • Intersection in Curve
Stop-Controlled Intersections	• Skew Angle • Commercial Development • Distance to Previous Stop Sign • Crash History	• Intersection On/Near Curve • Distance to Previous Stop Sign • AADT Ratio • Crash History
Segments	• AADT Range • Access Density • Critical Radius Curve Density	• AADT Range • Roadway Departure Crash Density • Edge Risk Assessment

The process would be terminated if the Kendall Tau-b coefficient was still positive and the least statistical test value (Kendall Tau-b coefficient) would be recorded.

Sensitivity Analysis Approach 2: Engineering Judgment and Point System In the second sensitivity analysis approach, a combination of techniques including professional engineering judgment and a point system would be used to modify the weight/coefficient of risk factors. One or more risk factors are selected for analysis on the basis of expert judgment which could be justified by referring to the vivid research documentation provided in the "Minnesota CRSP Approach" section of Chapter 2. The point system which is also incorporated in this approach includes three levels: low, moderate or normal and high risk levels. Each level has an associated weight/coefficient when applied to the risk factors of interest depending on the input data criterion established previously (see Chapter 3). Factors with a low risk level are assigned a weight/coefficient of zero. While factors with a moderate risk level are assigned a weight/coefficient of one and factors with a high risk level are assigned a weight/coefficient of two. The application of this approach along secondary paved roadways in Buchanan and Dallas counties is explained in Table 15 for each transportation roadway element prioritized in the CRSP methodology.

Table 15: Sensitivity Analysis Approach 2 Weight/Coefficient Assignment Process

Roadway Element	Selected Risk Factors	Weight/Coefficient Assignment Process
Rural Horizontal Curves	Curve Radius	• Assign a coefficient of two to the over-represented range of curve radii and traffic volume (considered highest risk level). • Assign a coefficient of one to the rest of the curve radii and AADT ranges (considered moderate risk level).
	Traffic Volume	
	Intersection in Curve	• Change the coefficient of these risk factors from one to two.
	Crash Experience	
Stop-Controlled Intersections	AADT Ratio	• Assign a coefficient of two to the over-represented range of AADT ratio (considered high risk level). • Assign a coefficient of one to the rest of AADT ratio ranges (considered moderate risk level).
	Skew Angle	• Change the coefficient of these risk factors from one to two.
	Intersection On/Near Curve	
	Crash History	
Rural Segments	AADT Range	• Assign a coefficient of two to the over-represented range of AADT (considered high risk level). • Assign a coefficient of one to the rest of AADT ranges (considered moderate risk level).
	Access Density	• Values above average receive a coefficient of two. • Values below average receive a coefficient of one. • Values equivalent to zero are assigned a coefficient of zero.
	Roadway Departure Density	
	Critical Radius Curve Density	

The defined input data criterion remains unchanged but the assignment of weights/coefficients has been modified in this approach. Originally, a weight of one was assigned to each risk factor if the input data criteria was met (or else it would receive zero stars). In this approach the selected factors that satisfied the input data criterion were considered high risk levels and assigned a coefficient of two. However, the under-represented data points were believed to have an influence on the risk level. Therefore, they were considered moderate risk level and assigned a coefficient of one. Steps 4 through 7 are then applied to complete the sensitivity analysis approach.

Sensitivity Analysis Approach 3: Variable Data and Point System The third approach uses the point system similar to the second approach with some minor changes in the assignment of weights/coefficients for certain risk factors. This approach uses a combination of the point system described earlier and also takes into account the variability in the input data of some risk factors. In the second sensitivity analysis approach, curve radius and traffic volume risk factors were assigned a coefficient of two for the defined over-represented range or else they received a coefficient of one. On the other hand, the weights/coefficients of these risk factors would be modelled in this approach based on a computed ratio. The same plots generated in the previous chapter are used and the ratio of percentage severe roadway departure crashes to percentage of locations within each range is calculated. A plot of the prioritized intersections in Buchanan and Dallas counties and crash by AADT ratio is produced (due to unavailability of AADT ratio data on district-level) and the ratio is computed in the same manner (see Figures 14 and 15). Information presented in Tables 16 (rural horizontal curves, 17 (stop-controlled intersections) and 18 (rural segments) describe the technique applied and the changes considered. The sensitivity analysis is then completed by applying the basic steps discussed earlier.

Table 16: Sensitivity Analysis Approach 3 Weight/Coefficient Assignment Process for Curves

Roadway Element	Risk Factors	Weight/Coefficient Assignment Process
Rural Horizontal Curves	Curve Radius	• Use district-level plots that were generated in Chapter 3. • Calculate the ratio of percentage severe roadway departure crashes to percentage of locations within each range. • If the ratio was greater than one then assign a coefficient of two (over-representation in crash). • If the ratio was less than one then assign a coefficient of one (under-representation in crash). • A ratio equivalent to zero corresponds to zero risk.
	Traffic Volume	
	Intersection in Curve	• If the location met the input data criteria then assign a coefficient of two. • Otherwise assign a coefficient of zero.
	Visual Trap	
	Crash Experience	

Table 17: Sensitivity Analysis Approach 3 Weight/Coefficient Assignment Process for Intersections

Roadway Element	Risk Factors	Weight/Coefficient Assignment Process
Stop-Controlled Intersection	AADT Ratio	• Plot on county-level the crashes on intersections by AADT ratio. • Calculate the ratio of percentage intersection crashes to percentage of locations within each category. • If the ratio was greater than one then assign a coefficient of two (over-representation in crash). • If the ratio was less than one then assign a coefficient of one (under-representation in crash). • A ratio equivalent to zero corresponds to zero risk.
	Skew Angle	• If the location met the input data criteria then assign a coefficient of two. • Otherwise assign a coefficient of zero.
	Intersection On/Near Curve	
	Commercial Development	
	Distance to Previous Stop Sign	
	Railroad Crossing on Minor Approach	
	Crash History	

Table 18: Sensitivity Analysis Approach 3 Weight/Coefficient Assignment Process for Segments

Roadway Element	Risk Factors	Weight/Coefficient Assignment Process
Rural Segments	AADT Range	• Use district-level plots that were generated in Chapter 3. • Calculate the ratio of percentage severe roadway departure crashes to percentage of locations within each range. • If the ratio was greater than one then assign a coefficient of two (over-representation in crash). • If the ratio was less than one then assign a coefficient of one (under-representation in crash). • A ratio equivalent to zero corresponds to zero risk.
	Access Density	• Values above average receive a coefficient of two. • Values below average receive a coefficient of one. • Values equivalent to zero are assigned a coefficient of zero.
	Roadway Departure Density	
	Critical Radius Curve Density	
	Edge Risk Assessment	• If the location met the input data criteria then assign a coefficient of two. • Otherwise assign a coefficient of zero.

Although the same point system is used in this approach but there are some differences between the second and third sensitivity analysis approaches. All risk factors are taken into consideration in the third approach instead of selected ones as seen in the second approach. Additionally, the defined input data criterion was not applied for certain roadway element risk factors, such as curve radius and traffic volume. Alternatively, the assignment of weights/coefficients to these risk factors was based on a computed ratio.

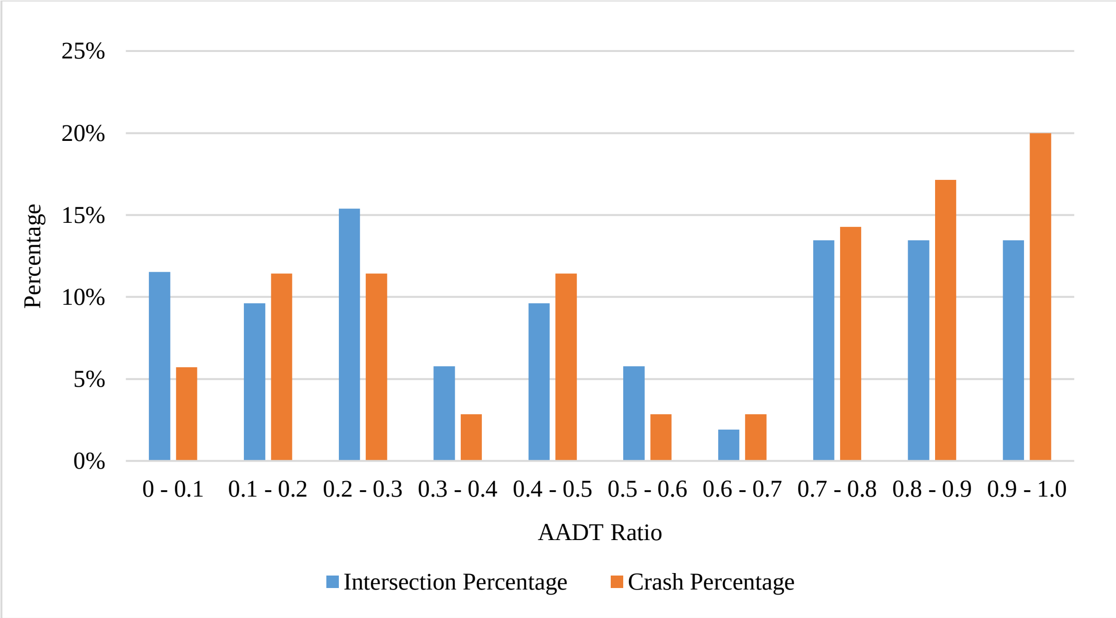

Figure 14: Buchanan County crashes on intersections and AADT ratio.

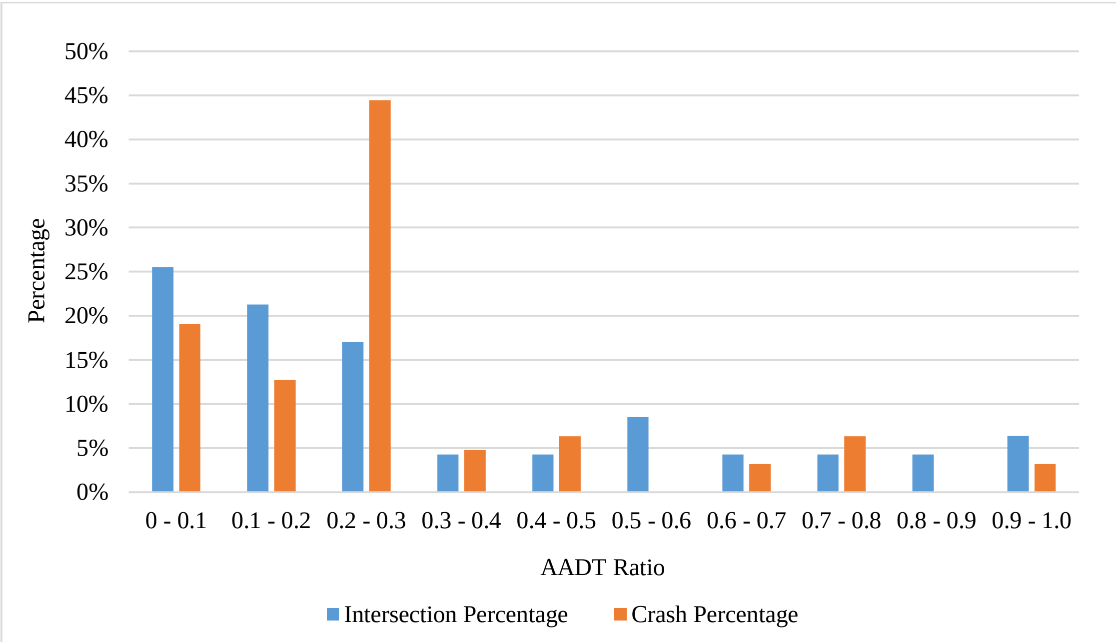

Figure 15: Dallas County crashes on intersections and AADT ratio.

Minnesota CRSP Approach Statistical Results

The software, IBM SPSS Statistics 22, was used to statistically compare the initial and new ranking prioritization lists after the application of the three sensitivity analysis approaches. The Kendall Tau-b coefficient was computed in every case and conclusions were established based on the results. The calculations involved in this statistical method were previously described in the section. A total of 16 ranking comparisons were completed for rural horizontal curve locations in Buchanan and Dallas counties. In addition, 19 and 16 ranking comparisons were done for stop-controlled intersection and segment locations in these two counties. Appendix E provides a complete list of ranking comparisons of the three prioritized transportation elements. A summary of the statistical analysis results are in Table 19. The table shows the Kendall Tau-b coefficient values of the two-tailed test generated from the SPSS software for the sensitivity analysis approaches in Buchanan and Dallas counties.

Table 19: Statistical Results of Sensitivity Analysis Approaches in Buchanan and Dallas Counties

Transportation Element	**Sensitivity Analysis Approach**	**Buchanan County**	**Dallas County**
		Kendall Tau-b	**Kendall Tau-b**
Rural Horizontal Curves	Approach 1	0.859	0.804
	Approach 2	0.913	0.768
	Approach 3	0.736	0.466
Stop-Controlled Intersections	Approach 1	0.858	0.812
	Approach 2	0.910	0.835
	Approach 3	0.807	0.744
Rural Segments	Approach 1	0.888	0.767
	Approach 2	0.882	0.782
	Approach 3	0.874	0.683

Overall, the results presented in Table 19 were significant at 0.01 level. The sensitivity analysis results indicate that modifying the weight/coefficient of risk factors does not have a significant effect on the ranking system. This is mainly due to the fact that the Kendall Tau-b coefficient was greater than zero for all comparisons completed (sensitivity analysis approaches) in both Buchanan and Dallas counties. The positive correlation between the new and initial ranking of locations denotes that the two ranking systems were similar. The test shows that the shift in the ranking of sites was not statistically significant. Nevertheless, the third approach yielded the least tau coefficient values as a consequence of the methodology applied. Weights of certain risk factors were substantially affected by the models created which also depended on the crash data. Therefore, the affiliation of locations with crash experience influenced the assignment of relative weights to these risk factors.

There are various influencing factors affecting the non-significance of the shift in ranking of locations. When the CRSP approach was applied on the secondary roadway system in Buchanan and Dallas counties, there were many locations that had the same number and type of risk factors. In other words, a wide variety of prioritized locations had similar safety risk results. A change in the coefficient of risk factors that define the ranking of locations is not expected to impact or change this situation. The results also indicate that the selection of appropriate risk factors for the roadway network of interest is important. This is because variability in the data reduces the amount of ties in the prioritized list and statistical correlation analysis might not occur as well.

Top "20" Shift Analyses

When the CRSP approach was first applied on the data collected, the higher priority sites with a total star ranking of three or more were considered for safety improvement projects. More attention is allocated to sites with higher risk level due to limitations in the funding available for improvement projects. Hence, further analysis is performed by evaluating the locations within the top 20 of the prioritization list to find the frequency of sites that shifted from the list in comparison to the base (initial) ranking.

The results provided in Table 20 summarizes the percentage of sites that shifted within the top 20, i.e. locations that shifted in or out of the list, of the rural horizontal curves, intersections and rural segments prioritization list in Buchanan and Dallas for all three sensitivity analysis approaches.

Table 20: Percentage of Sites Shifted In and Out of "Top 20" Prioritization List

Transportation Element	Sensitivity Analysis Approach	Buchanan County Percentage Shifted (%)	Dallas County Percentage Shifted (%)
Rural Horizontal Curves	Approach 1	20	25
	Approach 2	10	25
	Approach 3	20	50
Stop-Controlled Intersections	Approach 1	10	10
	Approach 2	5	10
	Approach 3	10	20
Rural Segments	Approach 1	20	35
	Approach 2	10	15
	Approach 3	10	15

The analysis shows the total locations shifted into and outside the "top 20" prioritization list. The greatest shift recorded was for rural horizontal curves in Dallas County with 50 percent (20 sites) of locations that shifted within the prioritization list when the comparison was made. This might be caused by the methodology applied in the third sensitivity analysis approach which depended on the variability of input data and the point system. Additionally, the percentage shift in ranking was greater in Dallas compared to Buchanan. However, the conflicting statistical analysis results showed a positive association between the new and initial ranking of sites. The shift in ranking was insignificant although the percentage of locations that shifted within and outside of the list was reasonable.

The most important elements of the project were discussed in this particular portion of the report. Outputs from the selected systemic prioritization tool, Minnesota CRSP approach, were summarized and a list of locations with highest level of risk were also identified. Performing a comprehensive sensitivity analysis facilitated in determining the effect on the prioritization list by altering the weights of risk factors. It was decided to apply Kendall Tau-b statistics as a measure of significance in the shift of ranking. However, the statistical analysis results showed that the shift in ranking was insignificant for sites in both Buchanan and Dallas due to the positive correlation between the initial and new ranking systems. The insignificance prevailed for all locations even with the effort to model coefficients in the second sensitivity analysis approach. This might be due to the selection of risk factors with low variability since risk factors affect the ranking of sites. A detailed conclusion and recommendations for future research insight are included in the next chapter.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

This study evaluated systemic safety tools on paved low-volume rural roadways. Three tasks were completed as part of this thesis research project. The tasks included a literature review, data collection process, prioritized list of locations and sensitivity analysis results. The previous three chapters in this thesis report described these tasks and the conclusions of each activity are summarized as follow:

- The use of reactive "hot spot" methods to evaluate safety of transportation elements in rural roadways is not efficient due to the widespread nature of crashes. Therefore, proactive systemic safety tools are appropriate to use when considering low volume paved rural roadways.
- Some research related to systemic safety improvements on paved rural roadways were summarized in the literature review. The Minnesota CRSP approach was selected from a variety of five methods. The selection was based on several characteristics such as availability of input data, cost and ease of implementation.
- The selected technique was applied on two county roadways in Iowa, Buchanan and Dallas counties. Data were collected on secondary paved low-volume roadways with Google StreetView images. Input data requirements and data collected were summarized in Chapter 3 of the report.
- A total of 197 miles in Buchanan County and 156 miles in Dallas County of secondary paved rural roadways with StreetView images were reviewed. Overall, data were collected for 82 and 83 horizontal curves, 52 and 47 stop-controlled intersections, and 59 rural segments in both Buchanan and Dallas counties respectively.
- The application of the CRSP approach generated a prioritized list of locations and these results were provided in Chapter 4. The results showed that the roadway system in both counties were generally in good condition due to the lower average total star ranking.
- An extensive sensitivity analysis was performed by changing the weights/coefficients of risk factors in the Minnesota CRSP approach. The impact on the prioritization list was then evaluated using, Kendall Tau-b coefficient, a non-parametric statistical method. Various schemes were established for the CRSP approach as part of the comprehensive

sensitivity analysis plan. Specifically, three approaches were designed and results indicated that altering the weights of risk factors did not have a significant effect on the ranking system due to the positive correlation. Although the rank of locations were shifted in the prioritization, the shift in ranking was statistically insignificant.

- It was then decided to perform a simple descriptive statistics due to the inconclusive results of the Kendall correlation coefficient test. The percentage of sites that shifted within the top 20 of the prioritization list was computed for each transportation element in all three sensitivity analysis approaches. More than 85 percent of the locations shifted by less than 25 percent in both Buchanan and Dallas counties. Maximum shift of 50 percent was recorded for rural horizontal curves in Dallas County when the third sensitivity approach was applied.

It was concluded that reasons for insignificance in results might be as a result of the uniform distribution in data for both Buchanan and Dallas. In other words, there was no variability in the data and this was not recognized by the CRSP approach since an over-represented range was subjectively selected for traffic volume and curve radius risk factors.

Limitations and Recommendations

It is recommended to have a complete inventory of the roadway systems and choose the appropriate risk factors as well as the associated weights. Variability in the data is an important subject for selecting risk factors because results depend on the input. Also the decision to apply tie-breaking rules is impacted by the variability in data (less variability corresponds to more ties). Risk factors based on human factors or previous research based safety issues, such as visual trap and railroad crossing on minor approach, had inadequate variability. There is limited research about selection of appropriate risk factors and associated weights/coefficients. Finally, it should be noted that this research project was intended to study the methodology of systemic safety tools as this would assist to make better decisions on the selection of risk factors and weights for future projects. Weighting does matter in the descriptive statistics as shown in the "top 20" analyses but not statistically. Another limitation could include the fact that the CRSP approach was only applied on two counties in Iowa. Therefore, it is recommended to investigate more county roadways for future research insight. A majority of the systemic research and ranking procedures that were previously performed have restricted the weight assignment between one and two. New methods could be developed and studied where the weights/coefficients of risk factors could be modeled. Finally, safety on unpaved (gravel) rural roadways could be taken into considerations since the level of risk on these roads is high.

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APPENDIX A: HORIZONTAL CURVES INITIAL RANKING LIST

Table 21: Initial Prioritized List (Ranking) of Horizontal Curves in Buchanan County

Horizontal Curves Star Ranking – Buchanan County								
Curve Number	**Curve Radius**	**Traffic Volume**	**Intersection in Curve**	**Visual Trap**	**Crash Experience**	**Total Stars**	**Average Radius (ft.)**	**Ranking**
Curve 70	0	1	1	0	1	3	582	1
Curve 14	1	1	1	0	0	3	831	2
Curve 4	1	0	1	0	1	3	842	3
Curve 65	1	1	1	0	0	3	978	4
Curve 1	1	1	1	0	0	3	1047	5
Curve 50	0	1	1	0	1	3	1199	6
Curve 38	0	1	1	0	1	3	1868	7
Curve 61	0	1	1	0	1	3	1906	8
Curve 57	0	1	1	1	0	3	1907	9
Curve 82	0	1	1	0	1	3	3746	10
Curve 39	0	1	1	0	0	2	197	11
Curve 40	0	1	1	0	0	2	269	12
Curve 56	0	0	1	1	0	2	581	13
Curve 76	0	1	1	0	0	2	617	14
Curve 12	1	0	1	0	0	2	712	15
Curve 26	1	0	1	0	0	2	754	16
Curve 58	1	0	1	0	0	2	768	17
Curve 2	1	1	0	0	0	2	980	18
Curve 24	1	1	0	0	0	2	1030	19
Curve 11	0	1	1	0	0	2	1129	20
Curve 71	0	1	1	0	0	2	1182	21
Curve 67	0	1	1	0	0	2	1367	22
Curve 52	0	1	1	0	0	2	1368	23
Curve 19	0	1	1	0	0	2	1422	24
Curve 64	0	1	1	0	0	2	1491	25
Curve 36	0	0	1	0	1	2	1706	26
Curve 32	0	1	1	0	0	2	1922	27
Curve 72	0	1	1	0	0	2	2836	28
Curve 35	0	1	1	0	0	2	2852	29
Curve 75	0	1	1	0	0	2	2868	30

Table 21 Continued: Initial Prioritized List (Ranking) of Horizontal Curves in Buchanan County

Curve 27	0	0	1	0	0	1	385	31
Curve 63	0	0	1	0	0	1	389	32
Curve 6	0	1	0	0	0	1	629	33
Curve 23	0	1	0	0	0	1	634	34
Curve 46	1	0	0	0	0	1	809	35
Curve 51	1	0	0	0	0	1	1049	36
Curve 30	1	0	0	0	0	1	1087	37
Curve 80	0	1	0	0	0	1	1100	38
Curve 7	0	1	0	0	0	1	1106	39
Curve 29	0	1	0	0	0	1	1116	40
Curve 10	0	1	0	0	0	1	1139	41
Curve 54	0	0	1	0	0	1	1142	42
Curve 34	0	1	0	0	0	1	1162	43
Curve 53	0	0	1	0	0	1	1190	44
Curve 15	0	1	0	0	0	1	1255	45
Curve 48	0	0	1	0	0	1	1408	46
Curve 59	0	1	0	0	0	1	1422	47
Curve 37	0	1	0	0	0	1	1430	48
Curve 68	0	0	1	0	0	1	1502	49
Curve 31	0	1	0	0	0	1	1622	50
Curve 9	0	0	1	0	0	1	1628	51
Curve 69	0	1	0	0	0	1	1666	52
Curve 16	0	0	1	0	0	1	1699	53
Curve 8	0	1	0	0	0	1	1745	54
Curve 5	0	1	0	0	0	1	1859	55
Curve 3	0	1	0	0	0	1	1883	56
Curve 28	0	0	1	0	0	1	1922	57
Curve 60	0	1	0	0	0	1	2122	58
Curve 13	0	1	0	0	0	1	2237	59
Curve 81	0	1	0	0	0	1	2785	60
Curve 33	0	1	0	0	0	1	3700	61
Curve 47	0	0	0	0	0	0	284	62
Curve 45	0	0	0	0	0	0	296	63
Curve 79	0	0	0	0	0	0	402	64
Curve 66	0	0	0	0	0	0	412	65
Curve 73	0	0	0	0	0	0	570	66

Table 21 Continued: Initial Prioritized List (Ranking) of Horizontal Curves in Buchanan County

Curve 49	0	0	0	0	0	0	1116	67
Curve 22	0	0	0	0	0	0	1128	68
Curve 77	0	0	0	0	0	0	1131	69
Curve 44	0	0	0	0	0	0	1133	70
Curve 62	0	0	0	0	0	0	1142	71
Curve 17	0	0	0	0	0	0	1148	72
Curve 41	0	0	0	0	0	0	1150	73
Curve 43	0	0	0	0	0	0	1260	74
Curve 20	0	0	0	0	0	0	1458	75
Curve 21	0	0	0	0	0	0	1586	76
Curve 42	0	0	0	0	0	0	1632	77
Curve 18	0	0	0	0	0	0	1688	78
Curve 74	0	0	0	0	0	0	1736	79
Curve 25	0	0	0	0	0	0	1856	80
Curve 78	0	0	0	0	0	0	2000	81
Curve 55	0	0	0	0	0	0	2706	82

Table 22: Initial Prioritized List (Ranking) of Horizontal Curves in Dallas County

Horizontal Curves Star Ranking – Dallas County								
Curve Number	Curve Radius	Traffic Volume	Intersection in Curve	Visual Trap	Crash Experience	Total Stars	Average Radius (ft.)	Ranking
Curve 44	0	1	1	0	1	3	367	1
Curve 79	1	1	1	0	0	3	420	2
Curve 54	1	0	1	1	0	3	697	3
Curve 29	1	1	1	0	0	3	779	4
Curve 51	1	1	1	0	0	3	826	5
Curve 42	0	0	1	1	1	3	1129	6
Curve 6	0	1	1	0	1	3	1307	7
Curve 16	0	1	1	0	0	2	186	8
Curve 40	0	1	1	0	0	2	382	9
Curve 62	1	0	1	0	0	2	425	10
Curve 37	1	0	1	0	0	2	682	11
Curve 28	1	1	0	0	0	2	710	12
Curve 43	1	1	0	0	0	2	726	13
Curve 69	1	0	1	0	0	2	762	14
Curve 47	1	0	1	0	0	2	768	15
Curve 4	1	1	0	0	0	2	773	16
Curve 75	1	1	0	0	0	2	809	17
Curve 71	1	0	1	0	0	2	891	18
Curve 13	1	1	0	0	0	2	1030	19
Curve 17	0	0	1	0	1	2	1126	20
Curve 45	0	1	1	0	0	2	1148	21
Curve 76	0	1	1	0	0	2	1262	22
Curve 22	0	1	1	0	0	2	1265	23
Curve 21	0	1	1	0	0	2	1271	24
Curve 3	0	1	1	0	0	2	1294	25
Curve 49	0	0	1	0	1	2	1324	26
Curve 52	0	1	1	0	0	2	1352	27
Curve 53	0	1	1	0	0	2	1385	28
Curve 56	0	1	1	0	0	2	1407	29
Curve 41	0	1	1	0	0	2	1436	30
Curve 32	0	0	1	0	1	2	1452	31
Curve 73	0	1	1	0	0	2	1784	32
Curve 24	0	1	1	0	0	2	1875	33
Curve 26	0	1	1	0	0	2	1904	34

Table 22 Continued: Initial Prioritized List (Ranking) of Horizontal Curves in Dallas County

Curve 65	0	0	1	0	0	1	213	35
Curve 19	1	0	0	0	0	1	635	36
Curve 68	1	0	0	0	0	1	729	37
Curve 15	1	0	0	0	0	1	764	38
Curve 59	1	0	0	0	0	1	779	39
Curve 58	1	0	0	0	0	1	800	40
Curve 14	1	0	0	0	0	1	965	41
Curve 39	0	0	1	0	0	1	1127	42
Curve 18	0	0	1	0	0	1	1145	43
Curve 70	0	0	1	0	0	1	1152	44
Curve 12	0	1	0	0	0	1	1156	45
Curve 64	0	0	1	0	0	1	1200	46
Curve 83	0	1	0	0	0	1	1249	47
Curve 9	0	1	0	0	0	1	1321	48
Curve 46	0	1	0	0	0	1	1364	49
Curve 82	0	0	1	0	0	1	1436	50
Curve 55	0	1	0	0	0	1	1449	51
Curve 31	0	1	0	0	0	1	1495	52
Curve 61	0	0	1	0	0	1	1617	53
Curve 5	0	1	0	0	0	1	1757	54
Curve 72	0	1	0	0	0	1	1778	55
Curve 80	0	1	0	0	0	1	1850	56
Curve 23	0	1	0	0	0	1	1860	57
Curve 60	0	0	1	0	0	1	1862	58
Curve 25	0	1	0	0	0	1	1894	59
Curve 77	0	0	1	0	0	1	1904	60
Curve 38	0	0	1	0	0	1	2155	61
Curve 48	0	1	0	0	0	1	2384	62
Curve 74	0	0	1	0	0	1	2587	63
Curve 66	0	0	1	0	0	1	2692	64
Curve 67	0	0	1	0	0	1	2698	65
Curve 35	0	0	1	0	0	1	2771	66
Curve 81	0	1	0	0	0	1	2785	67
Curve 34	0	0	1	0	0	1	2808	68
Curve 30	0	0	1	0	0	1	2836	69
Curve 11	0	0	1	0	0	1	3242	70

Table 22 Continued: Initial Prioritized List (Ranking) of Horizontal Curves in Dallas County

Curve 36	0	0	1	0	0	1	3571	71
Curve 57	0	0	0	0	1	1	4868	72
Curve 33	0	0	0	0	0	0	1193	73
Curve 7	0	0	0	0	0	0	1343	74
Curve 1	0	0	0	0	0	0	1693	75
Curve 27	0	0	0	0	0	0	1794	76
Curve 10	0	0	0	0	0	0	1826	77
Curve 8	0	0	0	0	0	0	1857	78
Curve 63	0	0	0	0	0	0	2483	79
Curve 2	0	0	0	0	0	0	2538	80
Curve 20	0	0	0	0	0	0	2793	81
Curve 78	0	0	0	0	0	0	2979	82
Curve 50	0	0	0	0	0	0	3238	83

APPENDIX B: STOP-CONTROLLED INTERSECTIONS INITIAL RANKING LIST

Table 23: Initial Prioritized List (Ranking) of Stop-Controlled Intersections in Buchanan County

Stop-Controlled Intersections Star Ranking – Buchanan County										
Intersection Number	**Skew**	**On/Near Curve**	**Commercial Development**	**Previous Stop Sign Distance**	**AADT Ratio**	**Railroad Crossing on Minor Approach**	**Crash History**	**Total Stars**	**AADT Ratio**	**Ranking**
Intersection 21	1	1	0	1	1	0	1	5	0.739	1
Intersection 8	1	1	0	1	1	0	0	4	0.769	2
Intersection 10	1	0	0	1	1	0	1	4	0.461	3
Intersection 35	1	0	0	1	1	0	1	4	0.400	4
Intersection 38	0	1	0	1	0	0	1	3	0.803	5
Intersection 11	0	0	0	1	1	0	1	3	0.775	6
Intersection 47	0	1	0	1	1	0	0	3	0.745	7
Intersection 36	0	0	0	1	1	0	1	3	0.719	8
Intersection 12	0	0	0	1	1	0	1	3	0.588	9
Intersection 17	1	0	0	1	1	0	0	3	0.555	10
Intersection 2	0	0	1	0	1	0	1	3	0.468	11
Intersection 14	0	0	0	1	1	0	1	3	0.443	12
Intersection 9	1	0	0	1	1	0	0	3	0.426	13
Intersection 29	1	0	0	1	0	0	1	3	0.219	14
Intersection 16	1	1	0	0	0	0	0	2	1.000	15
Intersection 4	0	0	0	1	0	0	1	2	0.982	16
Intersection 18	1	0	0	1	0	0	0	2	0.896	17
Intersection 42	0	0	1	0	0	0	1	2	0.841	18
Intersection 43	0	0	0	1	0	0	1	2	0.833	19
Intersection 44	0	0	0	0	1	0	1	2	0.779	20
Intersection 48	0	0	0	0	1	0	1	2	0.666	21
Intersection 27	0	0	0	1	1	0	0	2	0.594	22
Intersection 50	1	0	0	0	0	0	1	2	0.328	23
Intersection 28	1	0	0	1	0	0	0	2	0.327	24
Intersection 23	1	0	1	0	0	0	0	2	0.319	25
Intersection 15	1	0	0	1	0	0	0	2	0.216	26
Intersection 19	1	0	0	1	0	0	0	2	0.209	27
Intersection 22	0	0	0	1	0	0	1	2	0.160	28
Intersection 31	0	0	0	1	0	0	1	2	0.125	29
Intersection 13	1	0	0	1	0	0	0	2	0.099	30

Table 23 Continued: Initial Prioritized List (Ranking) of Stop-Controlled Intersections in Buchanan County

Intersection 39	0	0	0	0	0	0	1	1	0.959	31
Intersection 37	0	0	0	1	0	0	0	1	0.933	32
Intersection 46	0	0	0	1	0	0	0	1	0.917	33
Intersection 30	0	0	0	0	0	0	1	1	0.886	34
Intersection 1	0	0	0	1	0	0	0	1	0.818	35
Intersection 25	0	0	0	0	1	0	0	1	0.735	36
Intersection 3	0	0	0	0	0	0	1	1	0.262	37
Intersection 20	0	0	0	0	0	0	1	1	0.181	38
Intersection 26	0	0	0	0	0	0	1	1	0.176	39
Intersection 52	0	0	0	0	0	0	1	1	0.063	40
Intersection 41	0	0	1	0	0	0	0	1	0.055	41
Intersection 7	0	0	0	0	0	0	1	1	0.015	42
Intersection 51	1	0	0	0	0	0	0	1	0.002	43
Intersection 5	0	0	0	0	0	0	0	0	0.917	44
Intersection 34	0	0	0	0	0	0	0	0	0.911	45
Intersection 45	0	0	0	0	0	0	0	0	0.864	46
Intersection 32	0	0	0	0	0	0	0	0	0.285	47
Intersection 49	0	0	0	0	0	0	0	0	0.278	48
Intersection 33	0	0	0	0	0	0	0	0	0.243	49
Intersection 6	0	0	0	0	0	0	0	0	0.222	50
Intersection 24	0	0	0	0	0	0	0	0	0.138	51
Intersection 40	0	0	0	0	0	0	0	0	0.055	52

Table 24: Initial Prioritized List (Ranking) of Stop-Controlled Intersections in Dallas County

Stop-Controlled Intersections Star Ranking – Dallas County										
Intersection Number	**Skew**	**On/Near Curve**	**Commercial Development**	**Previous Stop Sign Distance**	**AADT Ratio**	**Railroad Crossing on Minor Approach**	**Crash History**	**Total Stars**	**AADT Ratio**	**Ranking**
Intersection 39	1	1	0	1	1	0	1	5	0.454	1
Intersection 45	1	0	1	0	1	0	1	4	0.650	2
Intersection 14	1	0	0	1	1	0	1	4	0.448	3
Intersection 29	1	1	0	1	0	0	1	4	0.375	4
Intersection 10	1	1	0	1	0	0	1	4	0.107	5
Intersection 18	1	0	0	1	0	0	1	3	0.970	6
Intersection 19	1	1	0	0	0	0	1	3	0.913	7
Intersection 28	0	1	0	1	1	0	0	3	0.554	8
Intersection 42	0	0	1	0	0	1	1	3	0.329	9
Intersection 25	1	0	1	0	0	0	1	3	0.157	10
Intersection 30	1	1	0	1	0	0	0	3	0.124	11
Intersection 31	1	0	0	1	0	0	1	3	0.111	12
Intersection 16	1	1	0	0	0	0	1	3	0.110	13
Intersection 26	1	1	0	0	0	0	1	3	0.069	14
Intersection 6	0	0	0	0	1	0	1	2	0.748	15
Intersection 11	0	0	0	0	1	0	1	2	0.719	16
Intersection 38	1	0	0	0	1	0	0	2	0.590	17
Intersection 46	1	0	0	0	1	0	0	2	0.500	18
Intersection 1	0	0	0	1	0	0	1	2	0.201	19
Intersection 8	0	0	1	0	0	0	1	2	0.179	20
Intersection 22	1	0	0	1	0	0	0	2	0.129	21
Intersection 17	1	0	0	1	0	0	0	2	0.072	22
Intersection 33	0	0	1	0	0	1	0	2	0.062	23.5
Intersection 40	0	0	1	0	0	0	1	2	0.062	23.5
Intersection 12	0	1	0	0	0	0	1	2	0.055	25
Intersection 35	0	0	1	0	0	0	1	2	0.050	26
Intersection 7	1	1	0	0	0	0	0	2	0.014	27
Intersection 24	0	0	0	1	0	0	0	1	0.928	28
Intersection 41	0	1	0	0	0	0	0	1	0.851	29
Intersection 43	0	0	0	0	1	0	0	1	0.696	30
Intersection 27	0	0	0	0	1	0	0	1	0.523	31
Intersection 4	0	0	0	0	0	0	1	1	0.291	32.5
Intersection 20	0	0	0	0	0	0	1	1	0.291	32.5
Intersection 2	0	0	0	0	0	0	1	1	0.282	34

Table 24 Continued: Initial Prioritized List (Ranking) of Stop-Controlled Intersections in Dallas County

Intersection 44	0	0	0	0	0	0	1	1	0.271	35
Intersection 3	0	0	0	0	0	0	1	1	0.256	36
Intersection 13	0	0	0	0	0	0	1	1	0.240	37
Intersection 15	0	0	0	1	0	0	0	1	0.197	38
Intersection 9	0	0	0	1	0	0	0	1	0.165	39
Intersection 34	0	0	0	0	0	0	1	1	0.089	40
Intersection 23	0	0	0	0	0	0	1	1	0.007	41
Intersection 47	0	0	0	0	0	0	1	1	0.006	42
Intersection 5	0	0	0	0	0	0	0	0	0.887	43
Intersection 37	0	0	0	0	0	0	0	0	0.210	44
Intersection 32	0	0	0	0	0	0	0	0	0.193	45
Intersection 21	0	0	0	0	0	0	0	0	0.044	46
Intersection 36	0	0	0	0	0	0	0	0	0.006	47

APPENDIX C: SEGMENTS INITIAL RANKING LIST

Table 25: Initial Prioritized List (Ranking) of Segments in Buchanan County

Rural Segments Star Ranking – Buchanan County								
Segment Number	**AADT Range**	**Access Density**	**Roadway Departure Density**	**Critical Radius Curve Density**	**Edge Risk Assessment**	**Total Stars**	**AADT**	**Ranking**
Segment 44	1	1	1	1	0	4	1350	1
Segment 18	1	1	1	1	0	4	900	2
Segment 54	1	1	1	1	0	4	825	3
Segment 55	1	1	1	1	0	4	720	4
Segment 17	1	0	1	1	0	3	1410	5
Segment 13	1	0	1	1	0	3	1330	6
Segment 3	1	1	1	0	0	3	630	7
Segment 31	0	1	1	0	1	3	330	8
Segment 41	0	1	1	0	0	2	3620	9
Segment 20	0	1	1	0	0	2	3330	10
Segment 45	0	1	1	0	0	2	1830	11
Segment 46	0	1	1	0	0	2	1600	12
Segment 14	1	0	1	0	0	2	1420	13
Segment 57	1	0	1	0	0	2	1410	14
Segment 58	1	1	0	0	0	2	960	15
Segment 56	1	0	1	0	0	2	920	16
Segment 39	1	0	1	0	0	2	850	17
Segment 5	1	0	1	0	0	2	800	18
Segment 38	1	0	1	0	0	2	740	19
Segment 30	1	1	0	0	0	2	730	20
Segment 51	1	1	0	0	0	2	720	21
Segment 6	1	0	1	0	0	2	700	22.5
Segment 49	1	1	0	0	0	2	700	22.5
Segment 33	1	0	1	0	0	2	640	24
Segment 23	0	1	1	0	0	2	430	25
Segment 12	0	0	1	1	0	2	400	26
Segment 21	0	1	0	0	1	2	30	27
Segment 50	0	0	1	0	0	1	1665	28
Segment 19	1	0	0	0	0	1	1590	29
Segment 16	1	0	0	0	0	1	1540	30

Table 25 Continued: Initial Prioritized List (Ranking) of Segments in Buchanan County

Segment 53	1	0	0	0	0	1	1390	31
Segment 52	1	0	0	0	0	1	1160	32
Segment 40	1	0	0	0	0	1	1080	33
Segment 7	1	0	0	0	0	1	1000	34
Segment 34	1	0	0	0	0	1	980	35
Segment 1	1	0	0	0	0	1	620	36
Segment 48	0	0	1	0	0	1	560	37
Segment 32	0	1	0	0	0	1	470	38
Segment 42	0	1	0	0	0	1	400	39
Segment 8	0	0	0	1	0	1	390	40
Segment 29	0	0	0	1	0	1	350	41
Segment 37	0	0	0	1	0	1	330	42
Segment 47	0	1	0	0	0	1	100	43
Segment 4	0	0	0	0	0	0	530	44
Segment 28	0	0	0	0	0	0	520	45
Segment 36	0	0	0	0	0	0	500	46
Segment 10	0	0	0	0	0	0	480	47.5
Segment 26	0	0	0	0	0	0	480	47.5
Segment 15	0	0	0	0	0	0	460	49.5
Segment 27	0	0	0	0	0	0	460	49.5
Segment 22	0	0	0	0	0	0	390	51
Segment 24	0	0	0	0	0	0	340	52.5
Segment 25	0	0	0	0	0	0	340	52.5
Segment 35	0	0	0	0	0	0	310	54.5
Segment 43	0	0	0	0	0	0	310	54.5
Segment 11	0	0	0	0	0	0	285	56
Segment 2	0	0	0	0	0	0	220	57
Segment 9	0	0	0	0	0	0	200	58

Table 26: Initial Prioritized List (Ranking) of Segments in Dallas County

Rural Segments Star Ranking – Dallas County								
Segment Number	AADT Range	Access Density	Roadway Departure Density	Critical Radius Curve Density	Edge Risk Assessment	Total Stars	AADT	Ranking
Segment 54	1	1	0	1	1	4	660	1
Segment 30	0	1	1	1	0	3	3450	2
Segment 20	0	1	1	0	1	3	1515	3
Segment 17	1	1	1	0	0	3	840	4
Segment 47	1	1	0	1	0	3	765	5
Segment 23	1	1	0	0	1	3	710	6
Segment 55	0	1	0	1	1	3	370	7
Segment 7	0	1	0	0	1	2	4040	8
Segment 28	0	1	1	0	0	2	3510	9
Segment 41	0	1	0	0	1	2	2450	10
Segment 33	0	0	1	0	1	2	2160	11
Segment 43	0	0	1	0	1	2	1940	12
Segment 31	0	0	1	0	1	2	1820	13
Segment 26	0	0	1	1	0	2	1690	14
Segment 51	0	0	1	0	1	2	1510	15
Segment 53	0	0	1	1	0	2	1400	16
Segment 19	1	0	1	0	0	2	1355	17
Segment 42	1	0	0	1	0	2	1240	18
Segment 34	1	1	0	0	0	2	1230	19
Segment 5	1	0	0	1	0	2	850	20
Segment 50	1	0	0	0	1	2	830	21
Segment 37	1	1	0	0	0	2	740	22
Segment 40	1	0	1	0	0	2	660	23
Segment 58	1	0	1	0	0	2	650	24
Segment 45	1	1	0	0	0	2	630	25
Segment 16	0	0	0	1	1	2	510	26
Segment 14	0	1	0	1	0	2	490	27
Segment 6	0	1	0	0	1	2	420	28
Segment 44	0	1	0	0	1	2	250	29
Segment 1	0	0	0	1	1	2	210	30
Segment 35	0	1	0	0	1	2	180	31
Segment 36	0	1	0	0	1	2	135	32
Segment 21	0	1	0	0	1	2	65	33
Segment 4	0	1	0	0	1	2	60	34

Table 26 Continued: Initial Prioritized List (Ranking) of Segments in Dallas County

Segment 29	0	0	1	0	0	1	3100	35
Segment 48	0	0	1	0	0	1	3000	36
Segment 27	0	0	0	1	0	1	2810	37
Segment 52	0	0	0	0	1	1	1990	38
Segment 32	0	0	0	0	1	1	1540	39
Segment 8	0	0	1	0	0	1	1420	40
Segment 22	1	0	0	0	0	1	1250	41
Segment 39	1	0	0	0	0	1	1190	42
Segment 9	1	0	0	0	0	1	1160	43
Segment 18	1	0	0	0	0	1	860	44
Segment 12	1	0	0	0	0	1	690	45
Segment 15	1	0	0	0	0	1	670	46
Segment 38	0	1	0	0	0	1	590	47
Segment 11	0	0	0	0	1	1	520	48
Segment 56	0	0	1	0	0	1	470	49
Segment 10	0	0	0	0	1	1	370	50
Segment 24	0	1	0	0	0	1	360	51.5
Segment 57	0	0	0	0	1	1	360	51.5
Segment 49	0	0	0	1	0	1	250	53
Segment 25	0	0	0	0	0	0	1465	54
Segment 46	0	0	0	0	0	0	530	55
Segment 13	0	0	0	0	0	0	480	56
Segment 3	0	0	0	0	0	0	450	57
Segment 2	0	0	0	0	0	0	360	58

APPENDIX D: RISK FACTORS PERMUTATION MATRICES

Table 27: Risk Factors Number Assignment for Horizontal Curves

Risk Factor	Risk Factor Assignment Number
Curve Radius	1
Traffic Volume	2
Intersection in Curve	3
Visual Trap	4
Crash Experience	5

Table 28: Different Risk Factor Permutations and Number of Horizontal Curves Affected in Buchanan and Dallas Counties

Risk Factor Combination	Buchanan Location Count	Dallas Location Count
1	3	6
2	19	13
3	9	18
4	0	0
5	0	1
1, 2	2	5
1, 3	3	5
1, 4	0	0
1, 5	0	0
2, 3	13	14
2, 4	0	0
2, 5	0	0
3, 4	1	0
3, 5	1	3
4, 5	0	0
1 ,2 and 3	3	3
1, 2 and 4	0	0
1, 2 and 5	0	0
1, 3 and 4	0	1
1, 3 and 5	1	0
1, 4 and 5	0	0
2, 3 and 4	1	0
2, 3 and 5	5	2
2, 4 and 5	0	0
3, 4 and 5	0	1
1, 2, 3 and 4	0	0
1, 2, 3 and 5	0	0
1, 2, 4 and 5	0	0
1, 3, 4 and 5	0	0
2, 3, 4 and 5	0	0
1, 2, 3, 4 and 5	0	0

Table 29: Risk Factors Number Assignment for Stop-Controlled Intersections

Risk Factor	Risk Factor Assignment Number
Skew	1
On/Near Curve	2
Commercial Development	3
Distance to Previous Stop Sign	4
AADT Ratio	5
Railroad Crossing on Minor Approach	6
Crash History	7

Table 30: Different Risk Factor Permutations and Number of Stop-Controlled Intersections Affected in Buchanan and Dallas Counties

Risk Factor Combination	Buchanan	Dallas
	Location Count	Location Count
1	1	0
2	0	1
3	1	0
4	3	3
5	1	2
6	0	0
7	7	9
1, 2	1	1
1, 3	1	0
1, 4	5	2
1, 5	0	2
1, 6	0	0
1, 7	1	0
2, 3	0	0
2, 4	0	0
2, 5	0	0
2, 6	0	0
2, 7	0	1
3, 4	0	0
3, 5	0	0
3, 6	0	1
3, 7	1	3
4, 5	1	0
4, 6	0	0
4, 7	4	1
5, 6	0	0
5, 7	2	2
6, 7	0	0
1, 2 and 3	0	0
1, 2 and 4	0	1
1, 2 and 5	0	0
1, 2 and 6	0	0
1, 2 and 7	0	3
1, 3 and 4	0	0
1, 3 and 5	0	0
1, 3 and 6	0	0
1, 3 and 7	0	1

Table 30 Continued: Different Risk Factor Permutations and Number of Stop-Controlled Intersections Affected in Buchanan and Dallas Counties

1, 4 and 5	2	0
1, 4 and 6	0	0
1, 4 and 7	1	2
1, 5 and 6	0	0
1, 5 and 7	0	0
1, 6 and 7	0	0
2, 3 and 4	0	0
2, 3 and 5	0	0
2, 3 and 6	0	0
2, 3 and 7	0	0
2, 4 and 5	1	1
2, 4 and 6	0	0
2, 4 and 7	1	0
2, 5 and 6	0	0
2, 5 and 7	0	0
2, 6 and 7	0	0
3, 4 and 5	0	0
3, 4 and 6	0	0
3, 4 and 7	0	0
3, 5 and 6	0	0
3, 5 and 7	1	0
3, 6 and 7	0	0
4, 5 and 6	0	0
4, 5 and 7	4	0
4, 6 and 7	0	0
5, 6 and 7	0	0
1, 2, 3 and 4	0	0
1, 2, 3 and 5	0	0
1, 2, 3 and 6	0	0
1, 2, 3 and 7	0	0
1, 2, 4 and 5	1	0
1, 2, 4, and 6	0	0
1, 2, 4 and 7	0	2
1, 2, 5 and 6	0	0
1, 2, 5 and 7	0	0
1, 2, 6 and 7	0	0
1, 3, 4 and 5	0	0
1, 3, 4 and 6	0	0
1, 3, 4 and 7	0	0
1, 3, 5 and 6	0	0
1, 3, 5 and 7	0	0
1, 3, 6 and 7	0	0
1, 4, 5 and 6	0	0
1, 4, 5 and 7	2	1
1, 4, 6 and 7	0	0
1, 5, 6 and 7	0	0
2, 3, 4 and 5	0	0
2, 3, 4 and 6	0	0
2, 3, 4 and 7	0	0
2, 3, 5 and 6	0	0
2, 3, 5 and 7	0	0

Table 30 Continued: Different Risk Factor Permutations and Number of Stop-Controlled Intersections Affected in Buchanan and Dallas Counties

2, 3, 6 and 7	0	0
2, 4, 5 and 6	0	0
2, 4, 5 and 7	0	0
2, 4, 6 and 7	0	0
2, 5, 6 and 7	0	0
3, 4, 5 and 6	0	0
3, 4, 5 and 7	0	0
3, 4, 6 and 7	0	0
3, 5, 6 and 7	0	0
4, 5, 6 and 7	0	0
1, 2, 3, 4 and 5	0	0
1, 2, 3, 4 and 6	0	0
1, 2, 3, 4 and 7	0	0
1, 2, 3, 5 and 6	0	0
1, 2, 3, 5 and 7	0	0
1, 2, 3, 6 and 7	0	0
1, 2, 4, 5 and 6	0	0
1, 2, 4, 5 and 7	1	1
1, 2, 4, 6 and 7	0	0
1, 2, 5, 6 and 7	0	0
1, 3, 4, 5 and 6	0	0
1, 3, 4, 5 and 7	0	0
1, 3, 4, 6 and 7	0	0
1, 3, 5, 6 and 7	0	0
1, 4, 5, 6 and 7	0	0
2, 3, 4, 5 and 6	0	0
2, 3, 4, 5 and 7	0	0
2, 3, 4, 6 and 7	0	0
2, 3, 5, 6 and 7	0	0
2, 4, 5, 6 and 7	0	0
3, 4, 5, 6 and 7	0	0
1, 2, 3, 4, 5 and 6	0	0
1, 2, 3, 4, 5 and 7	0	0
1, 2, 3, 4, 6 and 7	0	0
1, 2, 3, 5, 6 and 7	0	0
1, 2, 4, 5, 6 and 7	0	0
1, 3, 4, 5, 6 and 7	0	0
2, 3, 4, 5, 6 and 7	0	0
1, 2, 3, 4, 5, 6 and 7	0	0

Table 31: Risk Factors Number Assignment for Segments

Risk Factor	Risk Factor Assignment Number
AADT Range	1
Access Density	2
Roadway Departure Density	3
Critical Radius Curve Density	4
Edge Risk Assessment	5

Table 32: Different Risk Factor Permutations and Number of Segments Affected in Buchanan and Dallas Counties

Risk Factor Combination	Buchanan	Dallas
	Location Count	Location Count
1	8	6
2	3	2
3	2	4
4	3	2
5	0	5
1, 2	4	3
1, 3	8	3
1, 4	0	2
1, 5	0	1
2, 3	5	1
2, 4	0	1
2, 5	1	8
3, 4	1	2
3, 5	0	4
4, 5	0	2
1 ,2 and 3	1	1
1, 2 and 4	0	1
1, 2 and 5	0	1
1, 3 and 4	2	0
1, 3 and 5	0	0
1, 4 and 5	0	0
2, 3 and 4	0	1
2, 3 and 5	1	1
2, 4 and 5	0	1
3, 4 and 5	0	0
1, 2, 3 and 4	4	0
1, 2, 3 and 5	0	0
1, 2, 4 and 5	0	1
1, 3, 4 and 5	0	0
2, 3, 4 and 5	0	0
1, 2, 3, 4 and 5	0	0

APPENDIX E: RANKING COMPARISON

Table 33: Sensitivity Analysis Approaches Ranking Comparison of Horizontal Curves in Buchanan County

Curve Number	Initial Ranking	Approach 1						Approach 2	Approach 3
		New Ranking 1	New Ranking 2	New Ranking 3	New Ranking 4	New Ranking 5	New Ranking 6	New Ranking	New Ranking
Curve 1	5	7	9	4	5	4	4	9	10
Curve 2	18	18	19	9	31	14	28	31	34
Curve 3	56	56	56	56	57	45	53	57	43
Curve 4	3	5	2	2	3	13	13	2	3
Curve 5	55	55	55	55	56	44	52	56	42
Curve 6	33	33	33	36	40	27	33	40	47
Curve 7	39	39	39	39	46	33	36	46	52
Curve 8	54	54	54	54	55	43	51	55	41
Curve 9	51	51	51	51	37	59	48	37	26
Curve 10	41	41	41	41	48	35	38	48	54
Curve 11	20	20	21	23	18	16	14	19	21
Curve 12	15	15	16	6	15	29	25	16	18
Curve 13	59	59	59	59	59	47	56	59	64
Curve 14	2	4	7	1	2	2	2	7	8
Curve 15	45	45	45	45	50	37	42	50	77
Curve 16	53	53	53	53	38	60	50	38	13
Curve 17	72	72	72	72	72	72	72	72	75
Curve 18	78	78	78	78	78	78	78	78	59
Curve 19	24	24	25	27	22	20	18	23	24
Curve 20	75	75	75	75	75	75	75	75	78
Curve 21	76	76	76	76	76	76	76	76	82
Curve 22	68	68	68	68	68	68	68	68	71
Curve 23	34	34	34	37	41	28	34	41	48
Curve 24	19	19	20	10	32	15	29	32	35
Curve 25	80	80	80	80	80	80	80	80	61
Curve 26	16	16	17	7	16	30	26	17	19
Curve 27	31	31	31	34	29	50	31	29	31
Curve 28	57	57	57	57	39	61	54	39	62
Curve 29	40	40	40	40	47	34	37	47	53
Curve 30	37	37	37	22	44	54	61	44	50

Table 33 Continued: Sensitivity Analysis Approaches Ranking Comparison of Horizontal Curves in Buchanan County

Curve 31	50	50	50	50	53	40	47	53	38
Curve 32	27	27	27	30	25	22	20	25	44
Curve 33	61	61	61	61	61	49	58	61	66
Curve 34	43	43	43	43	49	36	40	49	55
Curve 35	29	29	29	32	27	24	22	27	28
Curve 36	26	26	10	29	24	42	30	10	5
Curve 37	48	48	48	48	52	39	45	52	57
Curve 38	7	9	4	12	7	6	6	4	1
Curve 39	11	12	12	16	11	10	10	12	30
Curve 40	12	13	13	17	12	11	11	13	16
Curve 41	73	73	73	73	73	73	73	73	76
Curve 42	77	77	77	77	77	77	77	77	39
Curve 43	74	74	74	74	74	74	74	74	81
Curve 44	70	70	70	70	70	70	70	70	73
Curve 45	63	63	63	63	63	63	63	63	46
Curve 46	35	35	35	20	42	52	59	42	33
Curve 47	62	62	62	62	62	62	62	62	45
Curve 48	46	46	46	46	35	57	43	35	37
Curve 49	67	67	67	67	67	67	67	67	70
Curve 50	6	8	3	11	6	5	5	3	4
Curve 51	36	36	36	21	43	53	60	43	49
Curve 52	23	23	24	26	21	19	17	22	12
Curve 53	44	44	44	44	34	56	41	34	23
Curve 54	42	42	42	42	33	55	39	33	36
Curve 55	82	82	82	82	82	82	82	82	80
Curve 56	13	2	14	18	13	26	24	14	7
Curve 57	9	1	11	14	9	8	8	11	15
Curve 58	17	17	18	8	17	31	27	18	20
Curve 59	47	47	47	47	51	38	44	51	56
Curve 60	58	58	58	58	58	46	55	58	63
Curve 61	8	10	5	13	8	7	7	5	14
Curve 62	71	71	71	71	71	71	71	71	74
Curve 63	32	32	32	35	30	51	32	30	32
Curve 64	25	25	26	28	23	21	19	24	25
Curve 65	4	6	8	3	4	3	3	8	9
Curve 66	65	65	65	65	65	65	65	65	68
Curve 67	22	22	23	25	20	18	16	21	11

Table 33 Continued: Sensitivity Analysis Approaches Ranking Comparison of Horizontal Curves in Buchanan County

Curve 68	49	49	49	49	36	58	46	36	58
Curve 69	52	52	52	52	54	41	49	54	40
Curve 70	1	3	1	5	1	1	1	1	2
Curve 71	21	21	22	24	19	17	15	20	22
Curve 72	28	28	28	31	26	23	21	26	27
Curve 73	66	66	66	66	66	66	66	66	69
Curve 74	79	79	79	79	79	79	79	79	60
Curve 75	30	30	30	33	28	25	23	28	29
Curve 76	14	14	15	19	14	12	12	15	17
Curve 77	69	69	69	69	69	69	69	69	72
Curve 78	81	81	81	81	81	81	81	81	79
Curve 79	64	64	64	64	64	64	64	64	67
Curve 80	38	38	38	38	45	32	35	45	51
Curve 81	60	60	60	60	60	48	57	60	65
Curve 82	10	11	6	15	10	9	9	6	6

Table 34: Sensitivity Analysis Approaches Ranking Comparison of Horizontal Curves in Dallas County

Curve Number	Initial Ranking	Approach 1						Approach 2	Approach 3
		New Ranking 1	New Ranking 2	New Ranking 3	New Ranking 4	New Ranking 5	New Ranking 6	New Ranking	New Ranking
Curve 1	75	75	75	75	75	75	75	75	80
Curve 2	80	80	80	80	80	80	80	80	73
Curve 3	25	25	27	31	19	20	24	22	29
Curve 4	16	16	19	12	11	33	15	33	47
Curve 5	54	54	55	54	41	65	54	66	81
Curve 6	7	7	3	17	5	7	6	3	2
Curve 7	74	74	74	74	74	74	74	74	55
Curve 8	78	78	78	78	78	78	78	78	63
Curve 9	48	48	49	48	35	61	48	62	54
Curve 10	77	77	77	77	77	77	77	77	61
Curve 11	70	70	71	70	70	51	70	51	37
Curve 12	45	45	46	45	33	59	45	60	69
Curve 13	19	19	22	15	13	35	18	35	51
Curve 14	41	41	42	25	54	58	41	59	68
Curve 15	38	38	39	22	51	55	38	56	46
Curve 16	8	8	11	18	6	8	7	11	40
Curve 17	20	20	8	26	32	15	32	8	5
Curve 18	43	43	44	43	56	37	43	37	24
Curve 19	36	36	37	20	49	53	36	54	78
Curve 20	81	81	81	81	81	81	81	81	75
Curve 21	24	24	26	30	18	19	23	21	28
Curve 22	23	23	25	29	17	18	22	20	53
Curve 23	57	57	58	57	44	68	57	69	64
Curve 24	33	33	33	39	25	28	30	28	17
Curve 25	59	59	60	59	45	69	59	70	65
Curve 26	34	34	34	40	26	29	31	29	66.5
Curve 27	76	76	76	76	76	76	76	76	83
Curve 28	12	12	15	8	9	31	11	31	43
Curve 29	4	5	6	3	3	4	2	6	22
Curve 30	69	69	70	69	69	50	69	50	36
Curve 31	52	52	53	52	40	64	52	65	58
Curve 32	31	31	10	37	39	26	34	10	4
Curve 33	73	73	73	73	73	73	73	73	70
Curve 34	68	68	69	68	68	49	68	49	35

Table 34 Continued: Sensitivity Analysis Approaches Ranking Comparison of Horizontal Curves in Dallas County

Curve 35	66	66	67	66	67	48	66	48	34
Curve 36	71	71	72	71	71	52	71	52	38
Curve 37	11	11	14	7	28	11	10	14	42
Curve 38	61	61	62	61	63	44	61	44	30
Curve 39	42	42	43	42	55	36	42	36	23
Curve 40	9	9	12	19	7	9	8	12	41
Curve 41	30	30	31	36	23	25	28	26	14.5
Curve 42	6	2	2	16	14	6	19	2	1
Curve 43	13	13	16	9	10	32	12	32	44
Curve 44	1	3	1	5	1	1	4	1	19
Curve 45	21	21	23	27	15	16	20	18	25
Curve 46	49	49	50	49	37	62	49	63	56
Curve 47	15	15	18	11	30	13	14	16	8
Curve 48	62	62	63	62	46	70	62	71	71
Curve 49	26	26	9	32	36	21	33	9	3
Curve 50	83	83	83	83	83	83	83	83	77
Curve 51	5	6	7	4	4	5	3	7	9
Curve 52	27	27	28	33	20	22	25	23	11
Curve 53	28	28	29	34	21	23	26	24	12
Curve 54	3	1	5	2	8	3	5	5	6
Curve 55	51	51	52	51	38	63	51	64	57
Curve 56	29	29	30	35	22	24	27	25	13
Curve 57	72	72	35	72	72	72	72	53	39
Curve 58	40	40	41	24	53	57	40	58	49
Curve 59	39	39	40	23	52	56	39	57	48
Curve 60	58	58	59	58	61	42	58	42	16
Curve 61	53	53	54	53	60	41	53	41	59
Curve 62	10	10	13	6	27	10	9	13	21
Curve 63	79	79	79	79	79	79	79	79	72
Curve 64	46	46	47	46	58	39	46	39	26
Curve 65	35	35	36	41	48	30	35	30	18
Curve 66	64	64	65	64	65	46	64	46	32
Curve 67	65	65	66	65	66	47	65	47	33
Curve 68	37	37	38	21	50	54	37	55	45
Curve 69	14	14	17	10	29	12	13	15	7
Curve 70	44	44	45	44	57	38	44	38	52
Curve 71	18	18	21	14	31	14	17	17	10

Table 34 Continued: Sensitivity Analysis Approaches Ranking Comparison of Horizontal Curves in Dallas County

Curve 72	55	55	56	55	42	66	55	67	82
Curve 73	32	32	32	38	24	27	29	27	60
Curve 74	63	63	64	63	64	45	63	45	31
Curve 75	17	17	20	13	12	34	16	34	50
Curve 76	22	22	24	28	16	17	21	19	27
Curve 77	60	60	61	60	62	43	60	43	66.5
Curve 78	82	82	82	82	82	82	82	82	76
Curve 79	2	4	4	1	2	2	1	4	20
Curve 80	56	56	57	56	43	67	56	68	62
Curve 81	67	67	68	67	47	71	67	72	74
Curve 82	50	50	51	50	59	40	50	40	14.5
Curve 83	47	47	48	47	34	60	47	61	79

Table 35: Sensitivity Analysis Approaches Ranking Comparison of Stop-Controlled Intersections in Buchanan County

Intersection Number	Initial Ranking	Approach 1 – New Ranking							Approach 2	Approach 3
		New 1	New 2	New 3	New 4	New 5	New 6	New 7	New Ranking	New Ranking
Intersection 1	35	36	35	36	36	40	29	35	41	32
Intersection 2	11	3	12	15	10	9	18	11	13	15
Intersection 3	37	38	37	38	37	30	37	36	33	38
Intersection 4	16	18	16	23	19	12	14	14	17	8
Intersection 5	44	44	44	44	44	44	44	44	44	43
Intersection 6	50	50	50	50	50	50	50	50	50	51
Intersection 7	42	42	42	43	42	37	42	41	37	41
Intersection 8	2	2	2	2	2	6	2	4	2	3
Intersection 9	13	14	14	6	12	19	12	13	15	17
Intersection 10	3	4	5	3	3	2	3	2	3	4
Intersection 11	6	8	8	11	5	5	6	7	8	12
Intersection 12	9	11	10	14	8	8	9	9	11	20
Intersection 13	30	30	30	22	31	35	24	26	29	27
Intersection 14	12	13	13	16	11	10	11	12	14	16
Intersection 15	26	26	26	20	27	31	20	22	25	25
Intersection 16	15	17	7	8	18	23	25	27	7	7
Intersection 17	10	12	11	5	9	18	10	10	12	21
Intersection 18	17	19	17	9	20	25	15	15	18	9
Intersection 19	27	27	27	21	28	32	21	23	26	26
Intersection 20	38	39	38	39	38	33	38	37	34	35
Intersection 21	1	1	1	1	1	1	1	1	1	1
Intersection 22	28	28	28	29	29	21	22	24	27	18
Intersection 23	25	15	25	19	26	29	33	21	24	24
Intersection 24	51	51	51	51	51	51	51	51	51	47
Intersection 25	36	37	36	37	23	41	36	43	42	46
Intersection 26	39	40	39	40	39	34	39	38	35	36
Intersection 27	22	23	22	28	16	27	17	30	32	37
Intersection 28	24	25	24	18	25	28	19	20	23	23
Intersection 29	14	16	15	7	17	11	13	5	6	6
Intersection 30	34	35	34	35	35	26	35	34	31	31
Intersection 31	29	29	29	30	30	22	23	25	28	19
Intersection 32	47	47	47	47	47	47	47	47	47	48
Intersection 33	49	49	49	49	49	49	49	49	49	50
Intersection 34	45	45	45	45	45	45	45	45	45	44
Intersection 35	4	5	6	4	4	3	4	3	4	5

Table 35 Continued: Sensitivity Analysis Approaches Ranking Comparison of Stop-Controlled Intersections in Buchanan County

Intersection 36	8	10	9	13	7	7	8	8	10	14
Intersection 37	32	33	32	33	33	38	26	32	39	29
Intersection 38	5	7	3	10	13	4	5	6	5	2
Intersection 39	31	32	31	32	32	24	34	31	30	28
Intersection 40	52	52	52	52	52	52	52	52	52	52
Intersection 41	41	31	41	42	41	42	41	40	43	40
Intersection 42	18	6	18	24	21	13	28	16	19	10
Intersection 43	19	20	19	25	22	14	16	17	20	11
Intersection 44	20	21	20	26	14	15	30	28	21	33
Intersection 45	46	46	46	46	46	46	46	46	46	45
Intersection 46	33	34	33	34	34	39	27	33	40	30
Intersection 47	7	9	4	12	6	16	7	18	9	13
Intersection 48	21	22	21	27	15	17	31	29	22	34
Intersection 49	48	48	48	48	48	48	48	48	48	49
Intersection 50	23	24	23	17	24	20	32	19	16	22
Intersection 51	43	43	43	31	43	43	43	42	38	42
Intersection 52	40	41	40	41	40	36	40	39	36	39

Table 36: Sensitivity Analysis Approaches Ranking Comparison of Stop-Controlled Intersections in Dallas County

Intersection Number	Initial Ranking	Approach 1 – New								Approach 2	Approach 3
		New 1	New 2	New 3	New 4	New 5	New 6	New 7	New 8	New Ranking	New Ranking
Intersection 1	19	20	23	21	22	12	22	16	16	21	14
Intersection 2	34	34	34	34	34	36	34	26	33	30	28
Intersection 3	36	36	36	36	36	38	36	28	35	32	30
Intersection 4	32.5	32.5	32.5	32.5	32.5	34.5	32.5	24.5	31.5	28.5	26.5
Intersection 5	43	43	43	43	43	43	43	43	43	43	46
Intersection 6	15	16	19	9	18	19	20	13	13	17	23
Intersection 7	27	27	27	29	16	30	19	34	26	16	22
Intersection 8	20	21	11	22	23	24	23	17	21	22	15
Intersection 9	39	39	39	39	39	25	39	42	38	42	34
Intersection 10	5	6	7	6	3	4	5	5	4	3	3
Intersection 11	16	17	20	10	19	20	21	14	14	18	24
Intersection 12	25	25	26	27	15	28	26	20	18	15	20
Intersection 13	37	37	37	37	37	39	37	29	36	33	31
Intersection 14	3	3	3	3	7	2	3	3	2	6	4
Intersection 15	38	38	38	38	38	23	38	41	37	41	33
Intersection 16	13	13	14	17	9	15	11	11	11	7	12
Intersection 17	22	23	25	24	25	16	18	32	23	24	17
Intersection 18	6	7	8	7	11	5	6	6	7	9	6
Intersection 19	7	8	9	8	4	10	7	7	8	4	7
Intersection 20	32.5	32.5	32.5	32.5	32.5	34.5	32.5	24.5	31.5	28.5	26.5
Intersection 21	46	46	46	46	46	46	46	46	46	46	44
Intersection 22	21	22	24	23	24	14	17	30	22	23	16
Intersection 23	41	41	41	41	41	41	41	35	41	36	36
Intersection 24	28	28	28	30	29	18	28	37	27	38	32
Intersection 25	10	10	6	14	13	13	8	9	17	10	9
Intersection 26	14	14	15	18	10	17	12	12	12	8	13
Intersection 27	31	31	31	20	31	33	31	40	30	40	47
Intersection 28	8	9	10	4	6	7	14	15	6	13	25
Intersection 29	4	4	4	5	2	3	4	4	3	2	2
Intersection 30	11	11	12	15	8	8	9	18	9	11	10
Intersection 31	12	12	13	16	14	9	10	10	10	12	11
Intersection 32	45	45	45	45	45	45	45	45	45	45	43
Intersection 33	23.5	15	16.5	25.5	26.5	26.5	24.5	33	40	35	18.5
Intersection 34	40	40	40	40	40	40	40	31	39	34	35
Intersection 35	26	26	18	28	28	29	27	21	25	26	21

Table 36 Continued: Sensitivity Analysis Approaches Ranking Comparison of Stop-Controlled Intersections in Dallas County

Intersection 36	47	47	47	47	47	47	47	47	47	47	45
Intersection 37	44	44	44	44	44	44	44	44	44	44	41
Intersection 38	17	18	21	11	20	21	13	22	19	19	39
Intersection 39	1	1	2	1	1	1	1	1	1	1	1
Intersection 40	23.5	24	16.5	25.5	26.5	26.5	24.5	19	24	25	18.5
Intersection 41	29	29	29	31	17	31	29	38	28	27	38
Intersection 42	9	5	5	13	12	11	16	8	15	14	5
Intersection 43	30	30	30	19	30	32	30	39	29	39	42
Intersection 44	35	35	35	35	35	37	35	27	34	31	29
Intersection 45	2	2	1	2	5	6	2	2	5	5	8
Intersection 46	18	19	22	12	21	22	15	23	20	20	40
Intersection 47	42	42	42	42	42	42	42	36	42	37	37

Table 37: Sensitivity Analysis Approaches Ranking Comparison of Segments in Buchanan County

Segment Number	Initial Ranking	Approach 1						Approach 2	Approach 3
		New Ranking 1	New Ranking 2	New Ranking 3	New Ranking 4	New Ranking 5	New Ranking 6	New Ranking	New Ranking
Segment 1	36	36	39	39	37	32	35	40	40
Segment 2	57	57	57	57	57	57	57	57	57
Segment 3	7	8	7	5	7	7	7	7	12
Segment 4	44	44	44	44	44	44	44	45	45
Segment 5	18	19	19	23	17	13	21	18	19
Segment 6	22.5	23.5	23.5	25	19	17.5	23	20	21
Segment 7	34	34	37	37	35	30	33	38	38
Segment 8	40	40	27	41	40	40	38	32	33
Segment 9	58	58	58	58	58	58	58	58	58
Segment 10	47.5	47.5	47.5	47.5	47.5	47.5	47.5	48.5	48.5
Segment 11	56	56	56	56	56	56	56	56	56
Segment 12	26	27	8	28.5	22	34	26	8	13
Segment 13	6	7	6	12	6	6	6	6	6
Segment 14	13	14	14	19	13	8	17	14	15
Segment 15	49.5	49.5	49.5	49.5	49.5	49.5	49.5	50.5	50.5
Segment 16	30	30	33	33	31	26	29	24	25
Segment 17	5	6	5	11	5	5	5	5	5
Segment 18	2	2	2	2	2	2	2	2	2
Segment 19	29	29	32	32	30	25	28	36	36
Segment 20	10	11	11	8	10	22	14	11	9
Segment 21	27	9	30	18	29	35	27	35	24
Segment 22	51	51	51	51	51	51	51	52	52
Segment 23	25	26	26	17	21	33	25	22	23
Segment 24	52.5	52.5	52.5	52.5	52.5	52.5	52.5	53.5	53.5
Segment 25	52.5	52.5	52.5	52.5	52.5	52.5	52.5	53.5	53.5
Segment 26	47.5	47.5	47.5	47.5	47.5	47.5	47.5	48.5	48.5
Segment 27	49.5	49.5	49.5	49.5	49.5	49.5	49.5	50.5	50.5
Segment 28	45	45	45	45	45	45	45	46	46
Segment 29	41	41	28	42	41	41	39	33	34
Segment 30	20	21	21	14	25	15	9	28	29
Segment 31	8	5	9	6	8	20	12	9	7
Segment 32	38	38	41	27	38	38	36	41	41
Segment 33	24	25	25	26	20	19	24	21	22
Segment 34	35	35	38	38	36	31	34	39	39

Table 37 Continued: Sensitivity Analysis Approaches Ranking Comparison of Segments in Buchanan County

Segment 35	54.5	54.5	54.5	54.5	54.5	54.5	54.5	43	43
Segment 36	46	46	46	46	46	46	46	47	47
Segment 37	42	42	29	43	42	42	40	34	35
Segment 38	19	20	20	24	18	14	22	19	20
Segment 39	17	18	18	22	16	12	20	17	18
Segment 40	33	33	36	36	34	29	32	37	37
Segment 41	9	10	10	7	9	21	13	10	8
Segment 42	39	39	42	28.5	39	39	37	42	42
Segment 43	54.5	54.5	54.5	54.5	54.5	54.5	54.5	55	55
Segment 44	1	1	1	1	1	1	1	1	1
Segment 45	11	12	12	9	11	23	15	12	10
Segment 46	12	13	13	10	12	24	16	13	11
Segment 47	43	43	43	30	43	43	41	44	44
Segment 48	37	37	40	40	28	37	43	31	32
Segment 49	22.5	23.5	23.5	16	27	17.5	11	30	31
Segment 50	28	28	31	31	23	36	42	23	14
Segment 51	21	22	22	15	26	16	10	29	30
Segment 52	32	32	35	35	33	28	31	26	27
Segment 53	31	31	34	34	32	27	30	25	26
Segment 54	3	3	3	3	3	3	3	3	3
Segment 55	4	4	4	4	4	4	4	4	4
Segment 56	16	17	17	21	15	11	19	16	17
Segment 57	14	15	15	20	14	9	18	15	16
Segment 58	15	16	16	13	24	10	8	27	28

Table 38: Sensitivity Analysis Approaches Ranking Comparison of Segments in Dallas County

Segment Number	Initial Ranking	Approach 1						Approach 2	Approach 3
		New Ranking 1	New Ranking 2	New Ranking 3	New Ranking 4	New Ranking 5	New Ranking 6	New Ranking	New Ranking
Segment 1	30	14	34	36	36	18	29	22	20
Segment 2	58	58	58	58	58	58	58	58	58
Segment 3	57	57	57	57	57	57	57	57	57
Segment 4	34	36	38	40	20	22	33	41	37
Segment 5	20	9	25	10	29	31	23	16	27
Segment 6	28	30	32	34	15	16	27	36	32
Segment 7	8	15	18	17	8	5	16	23	11
Segment 8	40	41	22	46	42	43	38	29	25
Segment 9	43	44	44	28	45	46	41	46	54
Segment 10	50	51	50	50	51	38	48	51	45
Segment 11	48	49	49	48	49	36	45	50	43
Segment 12	45	46	46	30	47	48	43	48	49
Segment 13	56	56	56	56	56	56	56	56	56
Segment 14	27	13	30	33	14	37	46	21	31
Segment 15	46	47	47	31	48	49	44	33	41
Segment 16	26	12	29	32	34	15	26	20	19
Segment 17	4	10	3	2	4	12	3	7	16
Segment 18	44	45	45	29	46	47	42	47	48
Segment 19	17	23	12	7	27	28	10	15	26
Segment 20	3	6	2	6	3	2	2	4	2
Segment 21	33	35	37	39	19	21	32	40	36
Segment 22	41	42	42	26	43	44	39	44	47
Segment 23	6	11	14	4	6	3	4	17	18
Segment 24	51.5	52.5	51.5	51.5	35	52	52	52.5	51
Segment 25	54	54	54	54	54	54	54	43	38
Segment 26	14	5	9	23	24	25	19	3	7
Segment 27	37	17	39	43	39	42	50	26	23
Segment 28	9	16	5	18	9	23	17	10	12
Segment 29	35	37	19	41	37	40	34	24	21
Segment 30	2	2	1	5	2	6	5	1	1
Segment 31	13	21	8	22	23	10	8	13	6
Segment 32	39	40	41	45	41	26	37	28	14
Segment 33	11	19	6	20	21	8	6	11	4
Segment 34	19	24	24	9	11	30	22	30	39

Table 38 Continued: Sensitivity Analysis Approaches Ranking Comparison of Segments in Dallas County

Segment 35	31	33	35	37	17	19	30	38	34
Segment 36	32	34	36	38	18	20	31	39	35
Segment 37	22	26	27	12	12	32	24	32	40
Segment 38	47	48	48	47	33	50	51	49	50
Segment 39	42	43	43	27	44	45	40	45	53
Segment 40	23	27	15	13	31	33	13	18	29
Segment 41	10	18	21	19	10	7	18	27	13
Segment 42	18	8	23	8	28	29	21	6	15
Segment 43	12	20	7	21	22	9	7	12	5
Segment 44	29	31.5	33	35	16	17	28	37	33
Segment 45	25	29	28	15	13	35	25	34	42
Segment 46	55	55	55	55	55	55	55	55	55
Segment 47	5	3	13	3	5	14	12	8	17
Segment 48	36	38	20	42	38	41	35	25	22
Segment 49	53	31.5	53	53	53	53	53	54	52
Segment 50	21	25	26	11	30	13	11	31	28
Segment 51	15	22	10	24	25	11	9	14	8
Segment 52	38	39	40	44	40	24	36	42	24
Segment 53	16	7	11	25	26	27	20	5	9
Segment 54	1	1	4	1	1	1	1	2	3
Segment 55	7	4	17	16	7	4	15	9	10
Segment 56	49	50	31	49	50	51	47	35	44
Segment 57	51.5	52.5	51.5	51.5	52	39	49	52.5	46
Segment 58	24	28	16	14	32	34	14	19	30