SYSTEMIC SAFETY METHODOLOGIES RISK FACTOR EVALUATION ON LOW-VOLUME RURAL PAVED ROADWAYS

Georges Bou-Saab
Graduate Research Assistant
2711 South Loop Drive, Suite 4700, Ames, Iowa, U.S.A
Phone: +1-515-231-4525 E-mail: gbousaab@iastate.edu

Keith Knapp, Iowa Local Technical Assistance Program Director

ABSTRACT

Majority of the fatal crashes in the United States occur on low-volume rural roadways. Therefore, prioritizing roadway elements in rural areas is critical to various transportation agencies due to the wide-spread nature of crashes. Systemic safety methodologies/tools are required in this case since the traditional "hot-spot" method only considers the crash data. Systemic approaches typically use regional data patterns, research findings and engineering judgment to evaluate and prioritize expected crash risk. This research project identified and examined one proactive systemic tool: Minnesota County Roadway Safety Plan (CRSP) which is currently described in the Federal Highway Administration (FHWA) *Systemic Safety Project Selection Toolkit*. The selected technique was applied on a sample of 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. Correlation analysis results showed a statistically insignificant difference between the initial and new ranking lists in all cases when the "weight" of the safety risk factors were changed. However, there was an impact on some of the locations in the "top 20" of the rankings and subsequent decision-making. The results of this research should be helpful to state and local transportation safety personnel as they apply the systemic safety tools/methodologies currently available.

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 (FHWA, 2011).

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 road network (Iowa DPS, 2014). 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 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) for low-volume rural roads. Proactive systemic safety improvement methodologies and tools are appropriate since they take into account both crash data and roadway features in order to estimate the risk and to identify as well as prioritize locations that require safety improvements.

Systemic safety tools/methodologies generally use system-wide, regional, and local crash data; the current state-of-knowledge on relationships between roadway characteristics and severe crashes; and/or, engineering judgment to proactively identify and prioritize locations that might be at a higher "risk" for crashes. Unfortunately, only a few completed research investigated the impacts on the results of systemic safety tools/methodologies due to the changes in decisions made during their application. In addition, almost all the knowledge available about systemic safety is focused on paved roadway applications. This research project was completed to address some of this gap in the knowledge.

1.1 Project Objectives

The systemic tools/methodologies incorporate various risk factors which are relevant to the characteristics of the roadway. The following objectives are acknowledged for the research project:

- Identify 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.
- Select 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. 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.

2. SYSTEMIC SAFETY METHODOLOGIES

The application of systemic safety approaches 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 are 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. Various systemic tools/methodologies are available for local roadway agencies and the following systemic tools/methodologies are identified:

- Minnesota County Roadway Safety Plan (CRSP) Approach (Minnesota DOT, 2011)
- Federal Highway Administration (FHWA) Systemic Safety Project Selection Toolkit (Preston et al., 2013)
- United States Roadway Assessment Program (usRAP) Safer Road Investment Plans (AAA Foundation of Traffic Safety, 2012)
- Development of a Systemic Road Safety Analysis Tool: Roadway Departure Crashes at Bridges in Salem County, New Jersey (Kaplan et. al, 2013)
- SafetyAnalyst (Harwood et al., 2010)

The systemic tools previously described are compared with the purpose to select one methodology for further investigation. The following factors are taken into consideration during the comparison and selection of the systemic tools:

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

The matrix shown in Table 1 identified these factors for each of the tools/methodologies. Consequently, the Minnesota CRSP tool is suitable for addressing the safety improvement requirements on rural paved roadway networks since 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. Although the Minnesota CRSP and FHWA systemic safety project toolkit are very similar, the latter methodology is not selected because it does not offer a specific approach to be used for a study or a research project and this selection was completed before the FHWA toolkit was officially released.

Table 1: Tool/Methodology selection matrix.

	Factors of Consideration				
Systemic Tool	**General Availability**	**Input Data Required**	**Ease of Use**	**Basis of Prioritization**	**Sensitivity Analysis Potential**
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

2.1 Minnesota County Roadway Safety Plan (CRSP) Approach

The Minnesota Department of Transportation (2011) funded the development of County Roadway Safety Plans (CRSPs) for every county in the state. The tool assisted in prioritizing paved rural roadway segments,

horizontal curves, and stop-controlled intersections, and identifying extensive low cost safety improvements implementation with the intention to reduce fatalities and severe injuries along the county roadway systems. These three main roadway elements were selected for evaluation due to the overrepresentation of crashes on them and they had the greatest opportunity for crash reduction. Their methodology is based on a star ranking system that prioritized at risk locations.

2.1.1 Rural Roadway Horizontal Curves Prioritization

Analysis of curve related crashes in Minnesota supported the notion that traditional "hot spot" reactive methods were not efficient to prioritize at risk locations along low-volume rural roadways. A new approach was hence used to evaluate the risk at curves. Different roadway features were used in Otter Tail County to prioritize rural roadway horizontal curves. Assessment of the horizontal curves was based on the following five risk factors:

- Curve Radius – Rural roadway horizontal curves with a radius between 500 and 1,200 feet received a star rating due to the overrepresentation of severe crashes, i.e. fatal and major injury, on these curves.
- Traffic Volume – Horizontal curves with an average daily traffic (ADT) between 200 and 600 vehicles per day (vpd) received a star since this range of volume accounted for 51 percent of severe crashes.
- 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.
- Visual Trap – Presence of a visual trap increased the risk of being involved in a crash and these curves received a star.
- Crash Experience – A horizontal curve experiencing a severe crash 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.

2.1.2 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 Minnesota 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. At risk locations were prioritized using seven risk factors:

- Geometry of Intersection – An intersection received a star if it had a skewed approach greater than 15 degrees measured from 90 degrees.
- Geometry of Roadway – An intersection located on or near (within 150 feet) a horizontal curve received a star.
- Presence of a Commercial Development – If an intersection had a commercial development in any of the quadrants, it was assigned a star.
- Distance to Previous Stop Sign – 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.
- 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.

- Railroad Crossing on Minor Approach – An intersection received a star if it had a railroad crossing one of its minor leg approaches.
- Crash History – A star was assigned to an intersection if it experienced any type of crash during the five year period analysis (2005 – 2009).

Crash costs were used as a tie-breaker if locations had the same star rating. Intersections with a total rating of three stars or more were considered for safety improvement projects.

2.1.3 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 according to consistency in speed limits, traffic volume 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 – Segments between 600 and 1,200 vpd accounted for almost 35 percent of severe roadway departure crashes and they received a star since they are susceptible to increase the level of risk.
- Access Density – Roadway segments received a star if they had an access density greater than 10.8 access points per mile.
- 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.
- Critical Radius Curve Density – Any roadway segment with a horizontal curve density greater than 0.35 curves per mile received a star.
- Edge Risk Assessment – Segments with a roadside severity rating of two or three (no useable shoulder or clear zone and roadside has fixed obstacles) received a star.

Segments that received three stars or more were considered "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 determination of the risk factors and their application criteria were defined through an evaluation of national, statewide, and/or regional data and research. 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 the higher priority locations. The safety improvements proposed for a location were based on the crashes to be addressed and the characteristics of the location. The star rating used essentially weight each risk factor equally.

3. SITE SELECTION AND DATA COLLECTION PROCESS

Early in this research project two Iowa counties, Dallas and Buchanan, were potential sites for systemic safety data collection and evaluation. The engineers had expressed interest in the process and agreed to be involved. The engineers of these counties agreed to collaborate with this research project and were also on its Technical Advisory Committee (TAC). 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.

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. Roadway, roadside and crash data were collected along these roadways. However, the visualization

capabilities were only available for a sample of the roadway mileage. Overall, the roadway network consisted of 197 miles in Buchanan County and 156 miles in Dallas County. Some data were collected at the district level while other data were collected through various means for the specific horizontal curves, intersections and segments at the county level.

3.1 Minnesota CRSP Approach Input Data

Buchanan County had 82 rural horizontal curves identified as part of the secondary paved rural road network while Dallas County had 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 since the number of crashes were very few to serve as a consistent indicator of risk.

In addition, Buchanan County had 52 through/stop-controlled intersections while Dallas County had 47 of them identified along secondary paved rural roadways.

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 traffic volume, 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. A star ranking was awarded to each element if the criteria of the risk factor was satisfied.

Detailed explanations for defining the input criteria for each risk factor are available in Appendix A.

4. PRIORITIZATION RESULTS

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. 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, 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 the results (average ranking and standard deviation) that both counties have a relatively good roadway system since all segments had an average value of less than two stars.

5. SENSITIVITY ANALYSIS AND STATISTICAL EVALUATION

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. 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, also known as 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 (Nelsen, 2011). 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 (Prokhorov, 2014). 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.

5.1 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 in the entire list. 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.

The first scheme is 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 is 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. 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 the Kendall Tau-b coefficient is computed. 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 are identified. The weight of these risk factors were doubled and new rankings were produced. The process would be terminated if the Kendall Tau-b coefficient is still positive and the least statistical test value (Kendall Tau-b coefficient) would be recorded.

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. 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. 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 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 are considered as high risk levels and assigned a coefficient of two. However, the under-represented data points are believed to have an influence on the risk level. Therefore, they are considered moderate risk level and assigned a coefficient of one.

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.

Although the same point system is used in this approach but there are some differences between the first and second sensitivity analysis approaches. All risk factors are taken into consideration in the second approach instead of selected ones as seen in the first approach. Additionally, the defined input data criterion is 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 is based on a computed ratio.

The assignment process of coefficients to the different risk factors in each sensitivity analysis approach is further clarified in Appendix B.

5.2 Minnesota CRSP Approach Statistical Results

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. A summary of the statistical analysis results are in Table 2. 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.

Overall, the results presented in Table 2 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.

Table 2: Statistical results of sensitivity analysis approaches in Buchanan and Dallas Counties.

Transportation Element	Sensitivity Analysis Approach	Buchanan County Kendall Tau-b	Dallas County 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

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.

5.2.1 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 selected 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 3 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.

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. 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 in some cases.

Table 3: 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 "top 20" group of locations is representative of those considered to be higher priority for potential safety improvements. Therefore, any shifts within this group could be viewed as a measure of the potential decision-making impacts if this tool were used.

6. CONCLUSIONS AND RECOMMENDATIONS

This study evaluated systemic safety tools on paved low-volume rural roadways. Three tasks were completed as part of this research project. The tasks included a literature review, data collection process, prioritized list of locations and sensitivity analysis results. The previous three sections of this 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 the report (third section).
- 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 the fourth section. 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. The descriptive statistics would have more practical meaning to the local transportation agencies and state DOTs. Although the Kendall test showed no statistical significance after changing the weights of the risk factors, the "top 20" prioritization list indicated that there is a reasonable shift in the position of the transportation elements within the ranking systems.

6.1 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. 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.

7. REFERENCES

AAA Foundation for Traffic Safety, United States Road Assessment Program (2012). *Guide to Using usRAP Star Ratings and Safer Roads Investment Plans*. Washington, D.C.

AAA Foundation for Traffic Safety, United States Road Assessment Program (2012). *Guide to Producing usRAP Star Ratings and Safer Roads Investment Plans*. Washington, D.C.

AAA Foundation for Traffic Safety, United States Road Assessment Program (2012). *usRAP Coding Manual for Star Ratings and Safer Roads Investment Plans*. Washington, D.C.

Harwood, D. W., D. J. Torbic, K. R. Richard and M. M. Meyer (2010). *SafetyAnalyst^{TM}: Software Tools for Safety Management of Specific Highway Sites*. U.S. Department of Transportation Federal Highway Administration (FHWA). Report No. FHWA-HRT-10-063, McLean, Virginia.

Iowa Department of Public Safety (2014). *High Five Rural Traffic Safety Project to Begin*. Des Moines, Iowa. http://www.dps.state.ia.us/commis/pib/Releases/2014/04-01-2014_GTSB_HighFive.htm. Accessed June 2014.

Kaplan, A., E. J. Gonzales, J. Cato, A. Ghafoori, J. Marandino and P. Ott (2013). *Development of a Systemic Road Safety Analysis Tool: Roadway Departure Crashes at Bridges in Salem County, New Jersey*. Rutgers Center for Advanced Infrastructure and Transportation (CAIT). New Jersey, U.S.A.

Minnesota Department of Transportation (2011). *Otter Tail County Roadway Safety Plan*. http://www.dot.state.mn.us/stateaid/trafficsafety/county/ottertail-crsp-final-aug2011.pdf. Accessed March 2013.

Nelsen, R. B. Kendall tau metric (2011). *Encyclopedia of Mathematics*. http://www.encyclopediaofmath.org/index.php/Kendall_tau_metric. Accessed September 2014.

Preston, H., R. Storm, J. D. Bennett and B. Wemple (2013). *Systemic Safety Project Selection Tool*. U.S. Department of Transportation Federal Highway Administration (FHWA). Report No. FHWA-SA-13-019, Washington, D.C.

Prokhorov, A. V. (2011). Kendall coefficient of rank correlation. *Encyclopedia of Mathematics*. http://www.encyclopediaofmath.org/index.php/Kendall_coefficient_of_rank_correlation. Accessed September 2014.

U.S. Department of Transportation Federal Highway Administration (2011). *A Focused Approach to Safety Guidebook*. Report No. FHWA-SA-11-44, Washington, D.C.