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An investigation of railroad-highway grade crossing consolidation rating in Iowa

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An investigation of railroad-highway grade crossing consolidation rating in Iowa

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DEDICATION

This thesis is dedicated to my parents, David and Ann, my brother Paul, and all of my family and friends for their support and inspiration throughout my education.

TABLE OF CONTENTS

		Page
LIST OF FIGURES		vi
LIST OF TABLES		vii
ACKNOWLEDGMENTS		viii
ABSTRACT		ix
CHAPTER 1	INTRODUCTION	1
	1.1 Motivation	1
	1.2 Thesis Objectives	3
	1.3 Thesis Organization	3
CHAPTER 2	LITERATURE REVIEW	4
	2.1 Overview of Crossing Consolidation	4
	2.2 Safety	4
	2.3 Crossing Consolidation Suitability	5
	2.4 Rating Formulas	7
	2.5 Iowa Efforts	8
	2.6 Factor Weighting Decisions	9
	2.7 Sensitivity Analysis	10
CHAPTER 3	METHODOLOGY	11
	3.1 Overview	11
	3.2 Formula Development	11
	3.2.1 Out of distance travel	12
	3.2.2 Proximity to schools	13

3.2.3 Proximity to EMS providers 15

3.2.4 Alternate route crash rate 16

3.2.5 Farm-to-market or primary road system status 17

3.2.6 Vehicle traffic 17

3.2.7 Other factors considered 18

3.3 Factor Weighting and Crossing Ranking 20

3.4 Sensitivity Analysis of Factor Weights 26

CHAPTER 4 RESULTS.. 29

4.1 Weighting Procedure Evaluation.. 29

4.1.1 Urban crossings... 29

4.1.2 Rural crossings.. 32

4.2 Magnitude of Rank Changes 34

4.2.1 Urban crossings... 34

4.2.2 Rural crossings.. 35

4.3 Impact of Factors.. 36

4.3.1 Urban crossings... 37

4.3.2 Rural crossings.. 41

CHAPTER 5 CONCLUSIONS 46

5.1 Key Findings 46

5.1.1 Robustness of weighting method 46

5.1.2 Impact of factors 47

5.1.3 Differences between urban and rural crossings 50

5.2 Future Work 50

APPENDIX CROSSING RANKING RESULTS 52

REFERENCES 54

LIST OF FIGURES

Page

Figure 1.1 Public, at-grade highway rail crossings in Iowa 2

Figure 3.1 Alternative path example for out of distance travel 13

Figure 3.2 Distribution of school locations by incremental distance......................... 14

Figure 3.3 Distribution of EMS locations by incremental distance........................... 16

Figure 4.1 Urban crossing rank changes by crossing 30

Figure 4.2 Rank changes of the top 15 originally ranked urban crossings 31

Figure 4.3 Rural crossing rank changes by crossing... 32

Figure 4.4 Rank changes of the top 15 originally ranked rural crossings.................. 33

Figure 4.5 Maximum absolute rank change of the top 15 originally ranked urban crossings 35

Figure 4.6 Maximum absolute rank change of the top 15 originally ranked rural crossings 36

Figure 4.7 Histogram of rank changes by iteration for the top 15 urban crossings ... 37

Figure 4.8 Rank by iteration of the top 15 originally ranked urban crossings........... 39

Figure 4.9 Histogram of rank changes by iteration for the top 15 rural crossings 41

Figure 4.10 Rank by iteration of the top 15 originally ranked rural crossings 42

LIST OF TABLES

Page

Table 2.1 Crossing consolidation candidate evaluation criteria 6

Table 3.1 Value scheme used to determine relative importance of factors 22

Table 3.2 Abbreviations used for factors 23

Table 3.3 Urban crossing weight matrix 24

Table 3.4 Rural crossing weight matrix 24

Table 3.5 Factor weights for urban and rural crossings 25

Table 3.6 Sensitivity analysis iterations 2-37 26

Table 3.7 Sensitivity analysis iterations 38-73 27

Table 3.8 Procedure used to change factor comparison values 27

Table 3.9 Factors modified in each sensitivity analysis iteration 28

Table 4.1 Iterations determined to commonly cause rank changes for urban crossings 38

Table 4.2 Iterations determined to commonly cause rank changes for rural crossings 43

Table 5.1 Factors with higher sensitivity 48

Table A.1 Top 15 originally ranked urban crossing ranking results 53

Table A.2 Top 15 originally ranked rural crossing ranking results 53

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ABSTRACT

Railroad-highway grade crossings present unique safety and operational challenges on both the rail and highway side. Consolidation of these crossings can be a valuable tool to improve safety, but is often a source of disagreement among interested parties. In order to better evaluate crossings to determine their suitability to be consolidated, a spreadsheet-based tool was developed to rank all public, at-grade crossings in Iowa using a number of factors related to potential consolidation impacts. The spreadsheet will act as a tool to provide an objective rating of each crossing for use in analysis and negotiation for crossing consolidation. This thesis will outline the development of the spreadsheet-based tool and conduct a sensitivity analysis on the final crossing rankings to determine the robustness of the formula and which factors have a higher sensitivity to weight changes.

Keywords: Grade crossing, railroad crossing consolidation, railroad crossing closure, consolidation rating formula, sensitivity analysis

CHAPTER 1

INTRODUCTION

1.1. Motivation

Railroad-highway grade crossings are a common occurrence in the transportation system. Crossings present unique safety and operational challenges on both the railroad and highway systems. Because of this, crossing closure, also referred to as crossing consolidation, has become a desire for many of the involved parties. The term consolidation is used to better reflect the action of crossing closure by describing it as removing unnecessary crossings and combining the access with other, more appropriate crossings. In most cases, rating formulas used to evaluate crossings for consolidation purposes has been conducted using a purely safety based rating. However, the consolidation of a crossing can have an effect on many other aspects of mobility. Crossing consolidation has also been a contentious issue among governments, railroads, and the public. Many parties involved disagree on the need to retain crossings or consolidate crossings (Murphy 1994).

From the most recent version of the Iowa statewide crossing database (2012), Iowa has approximately 4,300 public, at-grade railroad-highway crossings, which are shown in Figure 1.1 (Hans et al. 2015). In 2012, the Iowa Department of Transportation (DOT) wrote a safety action plan for railroad-highway grade crossings. Action G of this plan is to develop criteria to evaluate all public, at-grade railroad highway crossings in Iowa for potential consolidation (Iowa DOT 2012). From this action, a Microsoft Excel spreadsheet-based tool was developed to assist in evaluating crossings for potential consolidation on the basis of their impact to the public if consolidated. The tool evaluates crossings using several factors related to the essentiality of the crossing. The rating generated by the evaluation can then be used as a tool when negotiating with local governments and other agencies responsible for crossings on their road systems. During the development of the spreadsheet tool, a Technical Advisory Committee (TAC) consisting of representatives from government, railroads, and industry groups was utilized to identify potential factors for consideration to use in the rating, as well as determining a weighting scheme that should be applied to the factors to obtain final rankings for each crossing. The weighting scheme was determined through a consensus of the expert opinion of the TAC.

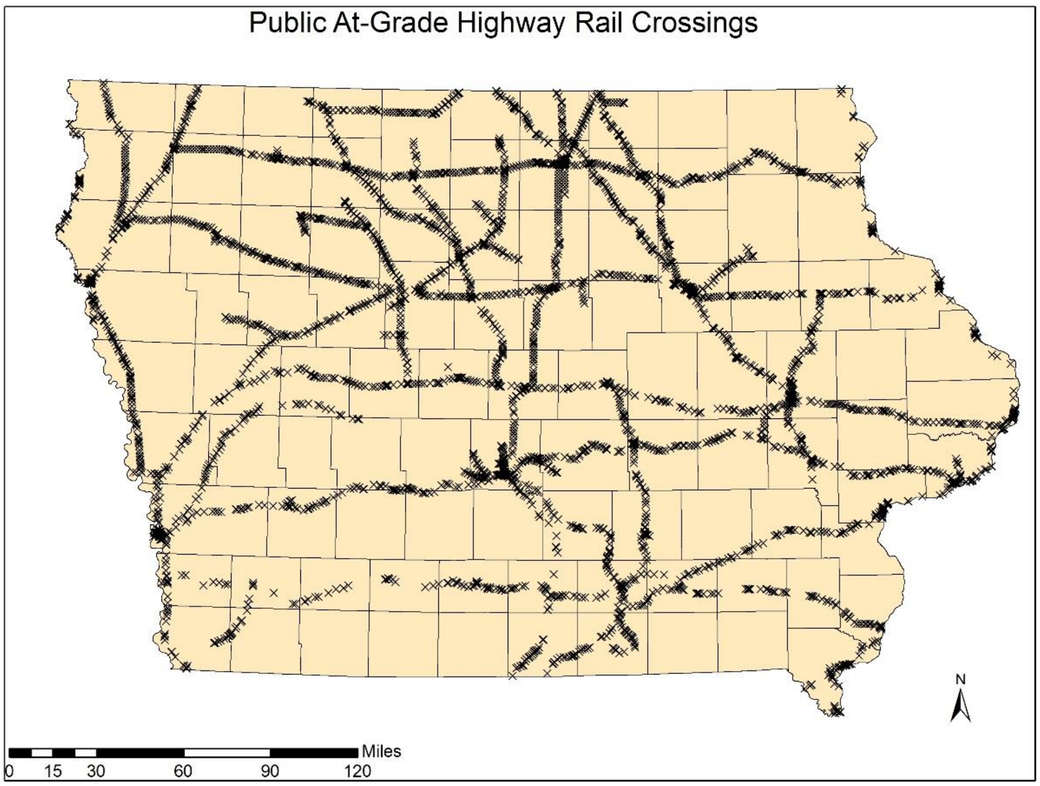

Figure 1.1: Public, at-grade highway rail crossings in Iowa (Hans et al. 2015).

1.2. Thesis Objectives

The objective of this thesis is to develop a formula to calculate a rating for public, at-grade railroad-highway crossings in Iowa, which will be ranked to enable crossings to be objectively evaluated for their suitability to be consolidated. A weighting procedure for the factors included in the formula will also be developed using the expert opinion of a Technical Advisory Committee (TAC). Finally, a sensitivity analysis on the final ranking of the crossings will be conducted. Because the method used to select weights for each factor in the rating will be developed using expert opinion, it is important to consider the effect that changing those weights due to changing opinion has on the rankings of crossings and to determine the robustness of the method. Identifying factors which have more sensitivity to change is also important to be able to make careful decisions when determining factor weights.

1.3. Thesis Organization

This thesis is organized into five chapters. Chapter 2 contains a review of literature related to crossing consolidation, previous efforts in Iowa to study crossing consolidation, factor weighting procedures, and sensitivity analysis methods. Chapter 3 is an overview of the methodology used to develop the spreadsheet ranking tool, the factors included in the rankings, the weighting procedure used, and the sensitivity analysis conducted of the weighting procedure. Chapter 4 details the results of the sensitivity analysis of the weighting procedure. Chapter 5 discusses conclusions that can be made about the results of the sensitivity analysis and possible future work.

CHAPTER 2

LITERATURE REVIEW

The literature review will provide an overview of several areas of the rail-highway consolidation process. A general overview of crossing consolidation and the motivation behind the desire to consolidate crossings as well as the considerations and formulas used to evaluate crossings will be presented in the literature review. Factor weighting and sensitivity analysis of factor weighting will also be presented.

2.1. Overview of Crossing Consolidation

As defined by the Texas Department of Transportation, the justification for closing highway-rail grade crossings is to "decrease unnecessary train traffic exposure to life and property, promote public safety, and improve traffic conditions" (TxDOT n.d.). Consolidation of highway-rail grade crossings results in multiple benefits including reducing the number of possible locations where trains and vehicles interact, thus removing the potential for a collision, providing a safety benefit at lower cost than adding warning signals and gates, and enabling the redirection of resources to remaining crossings (Murphy 1994). The preferred term for the closure or elimination of a highway-rail grade crossing is "consolidation" (Murphy 1994).

2.2. Safety

A primary goal of grade crossing consolidation is the improvement of safety. Several methods exist that are commonly used to predict accidents at a grade crossing. The US Department of Transportation accident prediction model takes into account crossing characteristics such as train traffic, road traffic, and speed to produce an initial collision prediction of collisions per year (FHWA 2007). A study by Mok and Savage estimated that closing 10 percent of crossings will reduce the number of incidents by 5.1 percent and fatalities by 2.7 percent (Mok 2005). Consolidating a crossing does not completely remove risk, as the traffic over the affected route is shifted to another crossing. The study further determined that 1,040 of the 8,276 decrease in total incidents at crossings from 1975 to 2001 can be explained by crossing closure (Mok 2005). Another study conducted by the Federal Railroad Administration (FRA) identified that there was a positive correlation indicating that closing a crossing affected the frequency of incidents. This study concluded that from 1994 and 2003, crossing closure had a 4.39 percent impact and a 15.20 percent reduction in grade crossing incidents (FRA 2009b).

Not directly related to safety at a crossing, the safety of the general public through emergency services can be impacted through the consolidation of crossings. The evaluation of a proposed crossing consolidation should consider the use of the road for emergency purposes, such as fire, police, medical, and evacuation routes (Oregon DOT Rail Division n.d.). A solution to retaining emergency access through a crossing is to convert it to a limited access crossing using a gate. Authorized users would have access and be responsible for closing and locking the gate (AASHTO 1995).

2.3. Crossing Consolidation Suitability

Crossings to be consolidated are evaluated on a set of criteria that are relevant to determining the candidate’s suitability to be consolidated. The criteria used to evaluate crossings by several agencies is found in Table 2.1.

Table 2.1: Crossing consolidation candidate evaluation criteria

Report	**Criteria**
Texas Rail Grade Crossing Consolidation Program (TxDOT n.d.)	Accident history Vehicle traffic Train traffic Road type Economic impact Alternative access Adjacent property type Crossing geometry Sight distance Crossing surface
FRA Crossing Consolidation Guidelines (FRA 2009a)	Number of road lanes Number of tracks ADT Accident history Proximity to other crossings Alternative access
Federal Highway Administration (FHWA) Rail-Highway Grade Crossing Handbook- Section 4, Identification of Alternatives (FHWA 2007)	ADT Train traffic Alternative access Number of adjacent crossings
FHWA Rail-Highway Grade Crossing Handbook - Section 5, Selection of Alternatives (FHWA 2007)	Alternative access Cost of upgrade vs alt. access Track class Train traffic AADT Rail operational characteristics
Kansas Rail-Highway Grade Consolidation (Russell and Mutabazi 1998)	Road type ADT Accessibility Obstruction Crossing angle Approach horizontal alignment Approach vertical alignment Rideability

Table 2.1 continued

Report	Criteria
Oregon Highway-Rail Grade Crossing Elimination Process (Oregon DOT Rail Division n.d.)	Road classification Use for emergency purposes Engineering concerns AADT Train traffic Train type Impact to businesses Alternative access

As can be seen, common criteria found in the literature fall into four categories: vehicle traffic, train traffic, alternative access, and crossing geometry. The Federal Highway Administration (FHWA) Railroad-Highway Grade Crossing Handbook (FHWA 2007) outlines criteria for both identifying crossings for potential closure in section 4 of the handbook and criteria for selecting crossings to be considered for closure from those identified are outlined in section 5 of the handbook (FHWA 2007).

2.4. Rating Formulas

Several rating formulas have been previously developed to generate candidate lists for crossing consolidation or grade separation. An example of a formula used to evaluate crossings for consolidation is found in a report by Russell and Mutabazi, which details the Kansas Grade Crossing Consolidation Study (Russell and Mutabazi 1998). This study identified eight variables to include in a model, road type, Average Daily Traffic (ADT), accessibility, obstruction, crossing angle, approach horizontal alignment, approach vertical alignment, and rideability. Road type, ADT, and accessibility were used as elimination variables to reduce the list of candidates during the first phase of the model process. The remaining variables were weighted and used to generate a rank for each crossing. After the initial ranking of crossings, the cutoff values for the eliminating variables were adjusted for four large cities so that crossings in those cities were better represented in the rankings (Russell and Mutabazi 1998).

The California Public Utilities Commission uses a formula to evaluate crossings for either consolidation or grade separation. The formula includes factors for annual average daily traffic, train traffic, light rail train traffic (if applicable), accident history at the crossing, a special conditions factor, and the project cost share to be allocated from the grade separation fund (CPUC 2013).

The Texas Priority Index is used by the state of Texas to evaluate grade crossings for prioritization of federal crossing upgrade funds. This formula uses factors to represent average daily traffic, 24-hour train counts, train speed, existing crossing protection, and the number of crashes at the crossing in the previous five years. The crossing protection factor ranges from 0.10 for crossings with gates to 1.00 for crossings with only crossbucks or other protection. If switching operations occur over the crossing, an index is calculated for both the switching and mainline movements and the two results are added together to represent the total priority index for the crossing (TxDOT 1998).

2.5. Iowa Efforts

In 2002, a study was conducted of the Union Pacific west-east mainline corridor by the Iowa Department of Transportation, Office of Systems Planning (Iowa DOT 2002). This study made recommendations to grade separate 34 crossings on the Commercial and Industrial Network. The study also found that it may be advisable to close crossings in addition to grade separations. It was recommended that a benefit-cost analysis is conducted in the process of determining potential closure locations (Iowa

DOT 2002). Iowa currently uses a benefit-cost ratio to evaluate crossings for safety. The calculation of the benefit-cost ratio takes into account the number of daily highway vehicles, the number of daily trains, the number of switching movements, roadway pavement type, the number of highway lanes, the number of tracks, train speed, whether a crossing is in an urban or rural area, and the number of collisions in the past five years. The benefit-cost ratio puts high sensitivity on historical collisions to predict future collisions (Iowa DOT 2012). A study conducted by the FRA noted that Iowa reduced the number of public crossings by 14.2 percent between 1994 and 2003, from 5,290 to 4,632. During this same period, the number of incidents at public crossings experienced a decline of 60.5 percent (FRA 2009b). As part of a safety action plan prepared by the Iowa Department of Transportation in 2011, a standardized formula to evaluate low volume, at-grade crossings for closure is to be developed and is intended to be used as a tool for negotiation and analysis (Iowa DOT 2012).

2.6. Factor Weighting Decisions

In the Kansas study previously discussed, factors used in the formula were given relative weights using the expert opinion of an advisory panel (Russell and Mutabazi 1998). The relative weights were assigned based on the potential of a factor to be unsafe, a higher weight indicated a more unsafe condition. Factor values were divided into ranges and relative weights were assigned to each range. For example, a crossing with a roadway approach grade between 4 and 6 percent received a raw weight of 4, later normalized on a percentage based scale to 7.1 in final phase of the model development. The rating of a crossing is the sum of its factor weights, as the factor values are accounted for in the weight (Russell and Mutabazi 1998).

2.7. Sensitivity Analysis

There are many methods that can be used to conduct sensitivity analyses, depending on the application and constraints on time and cost. One method to evaluate the sensitivity of factor weights for a multi-criteria decision making process is outlined in an article by Chen et al. (2010). The study described in this article uses a one-at-a-time approach to vary weights on a GIS based land suitability model in order to determine sensitive criteria and the impacts of changing weights on the outcome of the model. During each simulation run, each criteria weight was varied one at a time, while the other criteria weights remained at the base condition. Two of the four areas of interest that the study was focused on are “investigating the stability of an evaluation by introducing a known amount of change to criteria weights” and “identifying criteria that are especially sensitive to weight changes” (Chen et al. 2010). The study used a series of changes to criteria weights generate a summary of model results that can be analyzed based on the areas of interest. The study used four suitability categories and identified the number of raster cells that were contained in each category during each simulation run, for each criteria. Plots of the number of cells in each category were generated to determine the change in suitability seen in each simulation run by criteria, and therefore determine the sensitivity of each criteria.

CHAPTER 3

METHODOLOGY

3.1. Overview

To assist with formula development and to provide guidance, the project utilized a Technical Advisory Committee (TAC). The TAC was comprised of city and county engineers, agricultural industry representatives, railroad representatives, and Iowa Department of Transportation (DOT) representatives. The TAC provided input on potential factors to include in the formula, as well as providing input on developing the weights used for each factor in the final ranking. Descriptions of factors and procedures in sections 3.2 and 3.3 are summarized from Hans et al. (2015).

3.2. Formula Development

The process of developing the rating formula had three major components: building datasets, evaluating factors, and weighting factors. During the dataset building phase, types of data needed for use in the rating formula were identified and sources of this data were located. The data used in the formula was either obtained from outside sources or derived internally.

The major source of crossing attribute data was obtained from the 2012 version of the Iowa DOT rail crossing database. The crossing database includes elements from the Federal Railroad Administration (FRA) inventory as well as Iowa specific attributes. Factors obtained from the rail crossings database for use in the formula included AADT and truck percentage. A source of roadway data was the Iowa DOT Geographic Information Management System (GIMS). The GIMS database was used to obtain the road system data used in determining the primary and farm-to-market road system status of the crossing.

Several factors used in the formula were derived internally. These include: out of distance travel, proximity to schools, proximity to emergency services (EMS) providers, and alternate route crash rate.

3.2.1. Out of distance travel

Out of distance travel is defined as the difference between the shortest alternative path to travel from one side of a closed crossing to the other and the original distance to travel over the crossing. The shortest alternative path was calculated using the Network Analyst extension in ArcMap. A network of links was built using the Iowa DOT Linear Referencing System (LRS). This network represents all public roads and was limited to the roads within 10 km of a rail line in order to create a more manageable network. The network was not set up with turn restrictions or grade separations, so these issues were handled by observation of the operator. The LRS provided a set of nodes that represented intersections on the network. The Network Analyst extension has a routing tool that was used to generate the shortest path between the nearest intersection (node) on either side of the crossing. To simulate a crossing closure, the point feature representing the crossing was set as a point restriction in the routing tool. This prevents the tool from routing on the network through the crossing. The resulting shortest alternative path was exported and assigned to the crossing using the unique crossing identification number. The length of the original road segment that is carried over the crossing is then subtracted from the alternative path distance to obtain the out of distance travel. In cases where no alternative path is possible, such as a dead end road or a public crossing that serves a private industry, a flag was applied to the crossing to denote this condition. Crossings that were identified as having no alternative path were excluded from the final ranking. An example of the alterative path determined in the out of distance travel process is seen in Figure 2.1. In Figure 2.1, the road segment marked in red is the segment that would be closed in the case of crossing consolidation. The road segments marked in blue represent the shortest alternative path for this crossing.

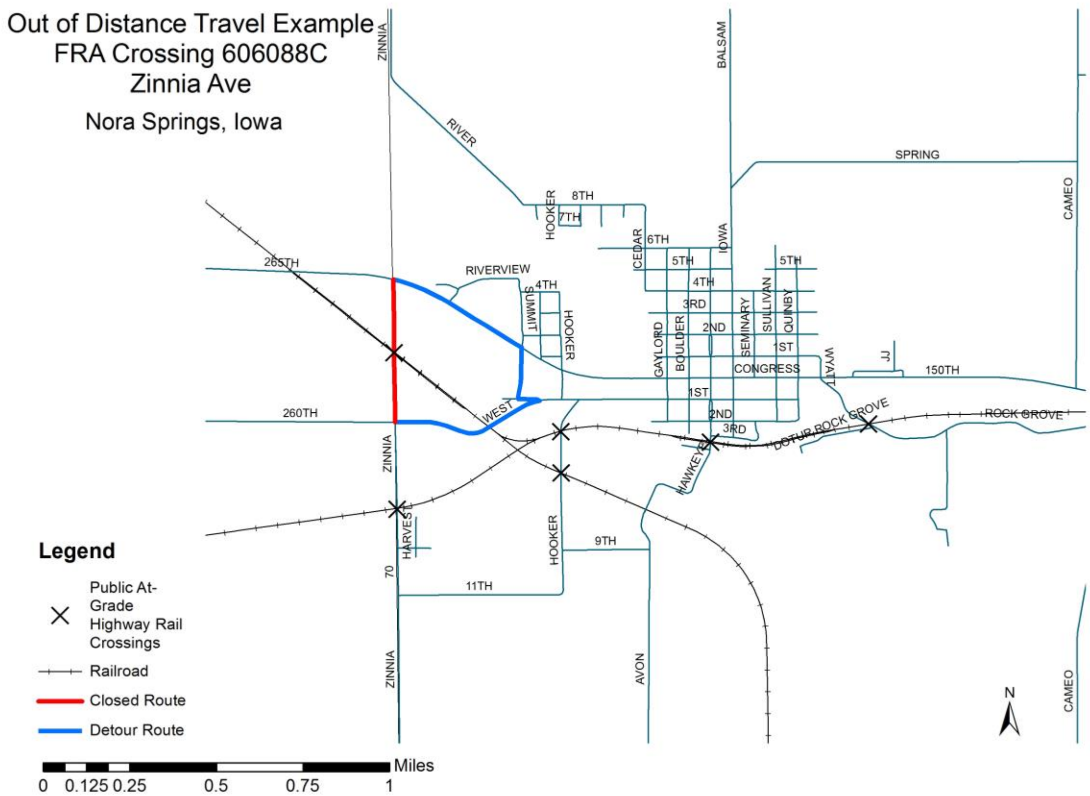

Figure 3.1: Alternative path example for out of distance travel (Hans et al. 2015).

3.2.2. Proximity to schools

The proximity of a school building to a crossing was computed using the Near Table function in ArcMap. Using the average area of a school district, a radius of 15 miles, as Euclidian distance was used to generate the near table. The result was a table of all school locations within 15 miles of each crossing, identified by crossing. This table was further refined to sort the school locations into bins of 0.5 miles, and 1 to 15 miles in 1-mile increments, providing a cumulative count of schools at each distance. The distance to the nearest school location was also calculated for each crossing. The initial dataset used to compute this variable was obtained from the Iowa Department of Natural Resources (DNR) and contained all public and private school locations as point features. The reasoning behind including school proximity is that the effect of closing a crossing near a school has a greater impact than a crossing further away from a school. Using the count of school locations within a certain radius of the crossing can denote the impact that closing the crossing will have on multiple schools. The radii used for the count of school locations for urban and rural crossings were determined by examining the distribution of school locations (Figure 3.1) in the incremental distances, from 0.5 miles to 15 miles. Through this examination, it was determined that a radius of 2 miles would be used for urban crossings and a radius of 6 miles would be used for rural crossings. These distances contained approximately 90 percent of crossings for both urban and rural.

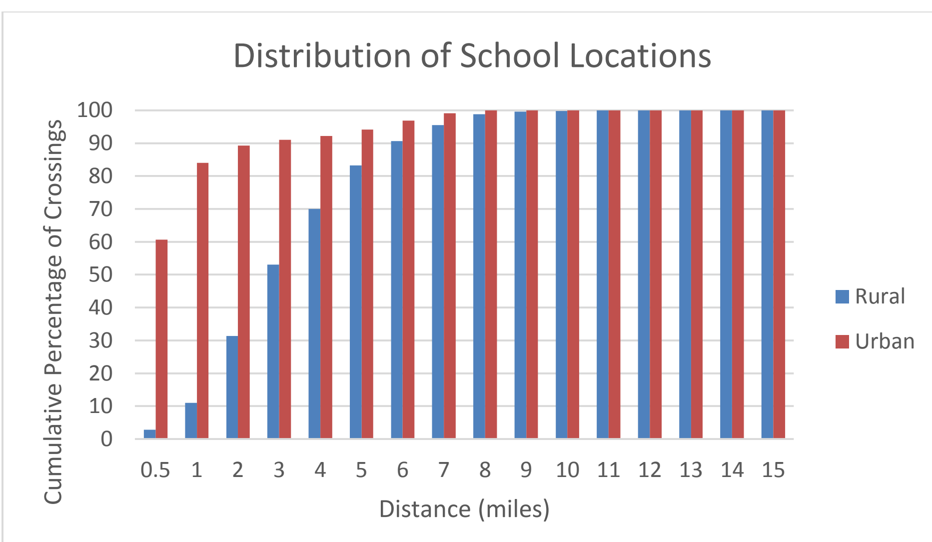

Figure 3.2: Distribution of school locations by incremental distance

3.2.3. Proximity to EMS providers

The proximity of an EMS provider to a crossing was computed using a similar approach to the proximity to schools. A 15-mile radius as Euclidian distance was used to generate a near table. The resulting table was then sorted into bins of 0.5 miles, and 1 to 15 miles in 1-mile increments, providing a cumulative count of providers at each distance. The distance to the nearest provider was also calculated for each crossing. The dataset for this variable was generated internally by geocoding a table of approximately 800 EMS provider addresses obtained from the Iowa Department of Health. The geocoding used ESRI's StreetMap North America Data Composite US Locator. This tool automatically located most of the provider addresses, but several locations were located manually by identifying the fire station in the respective city using satellite imagery or Google Streetview. Further, the geocoding locator placed some locations that did not have an adequate address or only provided a Post Office Box at the centroid of the ZIP code. This amounted to less than 20 percent of locations. The reasoning behind this factor is that the closure of crossings near an EMS provider could negatively impact emergency response time. Using the proximity to a crossing, as the distance from the provider increases, the provider has more alternative routes to avoid a closed crossing, thereby decreasing the impact that the closed crossing has on that particular provider. Using the count of providers within a certain radius of the crossing can denote the effect that closing the crossing will have on multiple providers. The radii used for the count of EMS locations for both urban and rural crossings were determined by examining the distribution of EMS locations (Figure 3.2) within the incremental distances from 0.5 miles to 15 miles. From this examination, it was determined to use a 3 mile radius for urban crossings and a 6 mile radius for rural crossings. These distances contained approximately 90 percent of crossings for both urban and rural.

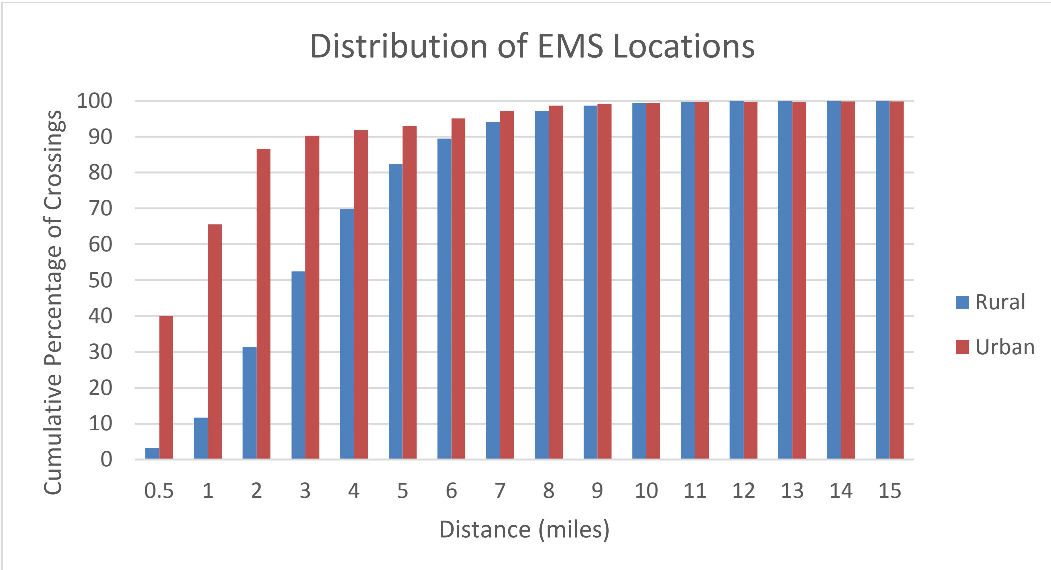

Figure 3.3: Distribution of EMS locations by incremental distance

3.2.4. Alternate route crash rate

The crash history of the alternate route was included as the alternate route crash rate. This rate was computed using the mainline crash history of the roads that are used for the alternative route as well as the intersections used for the alternative route. The crash history took into account the previous 5-year period. The mainline crash history was obtained from the Iowa statewide crash database. The intersection data was obtained from the Iowa DOT Statewide Improvement Candidate List (SICL). In order to assign crashes to the appropriate road segments and intersections, the transport links and nodes used as the alternate route to determine the out of distance travel for each crossing were associated with the crossing. Using the SICL dataset, intersection crashes on the alternate route were assigned to intersections used as part of an alternate route. Mainline crashes were identified using the Iowa statewide crash database and assigned to the corresponding alternate route transport link. The alternate route crash rate for each crossing was then calculated using the crash frequency on the alternate route and the vehicle miles traveled (VMT) associated with the alternate route.

3.2.5. Farm-to-market or primary road system status

As defined in Iowa Code section 306.3, the farm-to-market road system is made up of intracounty and intercounty roads which serve principal traffic generating areas and connect such areas to other farm-to-market roads and primary roads. These roads are designated as part of the system by a farm-to-market review board. The board has to review all proposed modifications to the system. This designation was determined to be a factor of interest in the evaluation of crossings for consolidation because of the difficult process needed to make modifications to the system. Crossings on the primary road system were determined to be of interest because of the lower probability that a primary road would be closed. In this case, it would be more likely that the crossing would be upgraded with a higher level of protection or grade separated.

The status of crossings on either of these systems was determined using the SYSCODE (road system code) attribute of the Iowa DOT GIMS database. Crossings were given a value of 0 or 1 in this factor if their system code was determined to be either on the primary or farm-to-market road systems.

3.2.6. Vehicle traffic

Annual Average Daily Traffic (AADT) was obtained directly from the rail crossing database. The 2012 version of the rail crossing database was used, however, the AADT year is not reported in the database. The rail crossing database includes an attribute for the percentage of trucks using the crossing. Because of the differences that percentage of AADT can have depending on AADT, it was determined that the truck

AADT (TAADT) was a better representation of truck usage of the crossing than truck percentage to use in the ranking, so that value was estimated using the AADT and the truck percentage to obtain the TAADT.

3.2.7. Other factors considered

Several other factors were initially considered for use in the formula, but ultimately excluded. During initial formula development, it was found that a safety based benefit-cost rating is already calculated by the Iowa DOT for each crossing, and it was decided to avoid duplication of this rating. This excluded several factors that are primarily safety based, including crossing skew angle, crossing collision history, and predicted risk. The exposure index included in the cost-benefit rating is a function of factors such as the number of daily trains, timetable train speed, crossing angle, and number of tracks. These factors were initially considered for use in the formula and found in other rating methods in the literature.

An attribute identified by the TAC as important was the humped crossing condition. A humped crossing is one which has steep approach grades on both sides of the crossing. This can cause problems for long vehicles, as well as vehicles towing trailers. The "HUMPSIGN" attribute in the rail crossing database denotes crossings that have a humped crossing sign present, which can be used as a proxy to the humped crossing condition. During exploration of this attribute, it was found that only 10 of the 3,978 crossings to be ranked indicated that a humped crossing sign was present, with most crossings having a value of "Unknown" or no value at all. Several crossings that were noted as having a humped crossing sign were examined using Google Streetview and found to not have a humped crossing sign and in some cases, the crossing was not humped. Because of the uncertainty in this attribute, it was decided to not include the humped crossing condition in the final ranking.

The proximity of a crossing to an intersection was considered for use in the formula. Crossings that are located close to an intersection can cause problems for long vehicles that are unable to fit in the space between the crossing and the intersection. Traffic can also stop on the crossing when waiting to proceed through the intersection, which is a safety hazard. This factor was ultimately not included in the formula, but the rail crossing database attribute that contains it was retained for use in site specific evaluation.

Several metrics were calculated and considered for use in the formula to represent the roadway crash history, which was ultimately reduced to only the alternate route crash rate discussed in section 3.3.4. The original metrics considered were crash frequency, crash rate, and crash severity. These metrics were calculated for both the alternate and closed routes. Crash frequency was calculated as the number of crashes on each route during the 5-year period used for analysis. Crash severity was calculated using the reported severity level of crashes on each route. The number of crashes at each level is then multiplied by a factor and all are summed to result in the severity index of each route.

To represent the demographics and population of an area, it was considered to incorporate US Census data for the area surrounding each crossing. This was found to be infeasible due to the large size of census blocks and tracts, which would have limited the precision of disaggregating the data to a level small enough to represent the area specific to an individual crossing. The impact of crossing consolidation on surrounding businesses was considered as a potential factor. The North American Industry Classification System (NAICS) was proposed to be used as a dataset for this factor. This was also found to be infeasible to obtain and was removed from consideration in the formula. The AADT of the crossing was ultimately selected for use as a proxy in representing the activity level and population of the area surrounding a crossing.

3.3. Factor Weighting and Crossing Ranking

After assembling the dataset, 9 factors were identified to be included in the crossing rankings, shown in the list below.

- AADT
- Out of distance travel
- Truck AADT (TAADT)
- Primary or farm-to-market road system status
- EMS location proximity count
- Distance to nearest EMS location
- School location proximity count
- Distance to nearest school location
- Alternate route crash rate

Normalization of each factor was done using two procedures, depending on the intent of the factor. For AADT, out of distance travel, TAADT, primary or farm-to-market road system status, EMS location proximity count, school location proximity count, and alternate route crash rate, the normalization was computed by dividing the factor value for each crossing by the maximum value for that factor and subtracting the result from one. This gave a normalized value closer to one when the factor value is lower. When the normalized values are ranked, a normalized value closer to one results in a rank closer to one. The intent of these factors is that a lower factor value is more desirable from a consolidation standpoint. For the distance to nearest EMS location and the distance to the nearest school location, the normalized value was computed by dividing the factor value for each crossing by the maximum value for that factor. This gave a normalized value closer to one when the factor value is higher. Again, when the normalized values are ranked, a normalized value closer to one results in a rank closer to one. The intent of these factors is that a higher factor value is more desirable from a consolidation standpoint.

The weighting scheme for the factors was determined using a modified Pugh matrix or a decision matrix. This method was suggested during the TAC evaluation process. A Pugh matrix is a method that can "logically compare different options" (Cervone 2009). In this method, a group of people can use the decision matrix to determine the relative importance of each option and an overall weight for each option can be calculated from the resulting matrix (Cervone 2009). The Pugh matrix is commonly used in multi-attribute decision making processes involving selection of alternatives (e.g. Mavris and Kirby 1999, Hill et al. 2004). In this project, the method was modified slightly, to change the scoring used to determine the relative importance of each factor. The decision matrix was constructed with each factor represented in a row and a column. Each row factor is compared to the importance of each column factor and a corresponding value is assigned in the matrix cell at the intersection of the row and column of the factors being compared. For example, if Factor 1 is the row factor being compared to Factor 2, which is the column factor, and it is determined that Factor 1 is more important than Factor 2, a value of "2" is placed in the cell at their intersection. The value scheme used in the method is found in Table 3.1.

Table 3.1: Value scheme used to determine relative importance of factors

Situation	Value
Row factor less important than column factor	0.5
Row factor equally important as column factor	1
Row factor more important than column factor	2

Factor comparisons were assigned these values based on the judgment of their relative importance by the TAC members. For this process, the factor comparisons were introduced to all members and a consensus on the value that the comparison should receive was reached. Values to the right of the diagonal were evaluated using the process outlined, while values to the left of the diagonal were given the inverse of the corresponding value to the right of the diagonal. Once all rows had been compared to columns, the values in each row were summed in the total column and the total column was summed. A percentage of the total column sum was calculated for each row. This percentage is used as the weight for each factor. During the comparison process, it was decided that some factors would carry different weight if considered on an urban and rural basis, so two weighting schemes were created, one for urban crossings and one for rural crossings. The separation of urban and rural crossings was done using the NEARCITY attribute of the Rail Crossing Database, which is an indicator of a crossing being either within or outside of an incorporated area. Rural crossings are defined as being located outside of an incorporated area and urban crossings are defined as being located within an incorporated area. The urban definition does not take into account any population or development factors of the incorporated area. School proximity, school count, EMS proximity, EMS count, and road system were given different weights depending on their urban or rural location. The EMS and school location proximity radii were also different for the urban and rural cases. For the urban case, a 3-mile radius was used for EMS locations and a 2-mile radius was used for school locations. For the rural case, a 6-mile radius was used for both EMS and school locations. The urban and rural weight matrices are shown below in Tables 3.3 and 3.4. The abbreviations used in the matrices are given in Table 3.2.

Table 3.2: Abbreviations used for factors

Factor	Abbreviation
AADT (vehicles)	AADT
Out of Distance Travel (miles)	ALTDIST
Truck AADT (vehicles)	TAADT
Farm-to-Market or Primary Road System Status	RDSYS
EMS Location Count by Radius (miles)	EMSFRQ(Radius)
EMS Proximity (miles)	EMSDIST
School Location Count by Radius (miles)	SCHFRQ(Radius)
School Proximity (miles)	SCHDIST
Alternative Route Crash Rate	ALTRATE

As an example, using the urban crossing weight matrix, AADT was determined to be equally important as ALTDIST (Out of Distance Travel), and was assigned a value of "1" in the corresponding cell. AADT was also determined to be more important that TAADT (Truck AADT), and was assigned a value of "2" in the corresponding cell. In the TAADT row, a value of "0.5" was assigned in the cell comparing TAADT to AADT, which represents the inverse of the value assigned when AADT was compared to TAADT.

Table 3.3: Urban crossing weight matrix

URBAN	AADT	ALTDIST	TAADT	RDSYS	EMSFRQ3	EMSDIST	SCHFRQ2	SCHDIST	ALTRATE	TOTAL	WEIGHT
AADT		1	2	1	2	2	2	2	2	14	0.16185
ALTDIST	1		2	2	2	2	2	2	2	15	0.17341
TAADT	0.5	0.5		0.5	0.5	0.5	0.5	0.5	0.5	4	0.04624
RDSYS	1	0.5	2		1	1	0.5	0.5	1	7.5	0.08671
EMSFRQ3	0.5	0.5	2	1		1	2	2	2	11	0.12717
EMSDIST	0.5	0.5	2	1	1		2	2	2	11	0.12717
SCHFRQ2	0.5	0.5	2	2	0.5	0.5		1	0.5	7.5	0.08671
SCHDIST	0.5	0.5	2	2	0.5	0.5	1		0.5	7.5	0.08671
ALTRATE	0.5	0.5	2	1	0.5	0.5	2	2		9	0.10405

Table 3.4: Rural crossing weight matrix

RURAL	AADT	ALTDIST	TAADT	RDSYS	EMSFRQ6	EMSDIST	SCHFRQ6	SCHDIST	ALTRATE	TOTAL	WEIGHT
AADT		1	2	1	2	2	2	2	2	14	0.16185
ALTDIST	1		2	2	2	2	2	2	2	15	0.17341
TAADT	0.5	0.5		0.5	0.5	0.5	0.5	0.5	0.5	4	0.04624
RDSYS	1	0.5	2		1	1	2	2	1	10.5	0.12139
EMSFRQ6	0.5	0.5	2	1		1	2	2	2	11	0.12717
EMSDIST	0.5	0.5	2	1	1		2	2	2	11	0.12717
SCHFRQ6	0.5	0.5	2	0.5	0.5	0.5		1	0.5	6	0.06936
SCHDIST	0.5	0.5	2	0.5	0.5	0.5	1		0.5	6	0.06936
ALTRATE	0.5	0.5	2	1	0.5	0.5	2	2		9	0.10405

Table 3.5: Factor weights for urban and rural crossings

Factor	Urban	Rural
AADT	0.16185	0.16185
ALTDIST	0.17341	0.17341
TAADT	0.04624	0.04624
RDSYS	0.08671	0.12139
EMSFRQ3	0.12717	-
EMSFRQ6	-	0.12717
EMSDIST	0.12717	0.12717
SCHFRQ2	0.08671	-
SCHFRQ6	-	0.06936
SCHDIST	0.08671	0.06936
ALTRATE	0.10405	0.10405

The weights for each factor are multiplied by the normalized value of the factor and these weighted values are added to obtain a composite score that is ranked, as shown in the equations below. A higher rank is given to a composite score closer to 1.

Urban ranking formula: $Composite\ Score = 0.16185 * AADT + 0.17341 * ALTDIST + 0.04624 * TAADT + 0.08671 * RDSYS + 0.12717 * EMSFRQ3 + 0.12717 * EMSDIST + 0.08671 * SCHFRQ2 + 0.08671 * SCHDIST + 0.10405 * ALTRATE$

Rural ranking formula: $Composite\ Score = 0.16185 * AADT + 0.17341 * ALTDIST + 0.04624 * TAADT + 0.12139 * RDSYS + 0.12717 * EMSFRQ6 + 0.12717 * EMSDIST + 0.06936 * SCHFRQ6 + 0.06936 * SCHDIST + 0.10405 * ALTRATE$

The rankings generated by the spreadsheet are based on current conditions and data at the time of assembling the dataset. Factor values can be replaced with updated data to reflect changes in conditions. Factor values can also be replaced with forecasted values to evaluate crossings for some future point in time. As the factor weights are based on the relative importance of the factors, updating the input data for the formula will not necessitate a change to the weights. The ranking of crossings can change accordingly based off of changes in the factor values.

3.4. Sensitivity Analysis of Factor Weights

In order to determine the effect that changes to the weighting of factors has on crossing rankings, a sensitivity analysis of the weights was conducted. The analysis used the decision matrix developed for the original weighting discussions and used the weights determined by the TAC as the base condition. The analysis was conducted by changing the value in the decision matrix for each factor comparison so that each possible value (0.5, 1, or 2) was included once, resulting in 73 iterations, with the base condition being iteration one. The factor comparison that was modified in each iteration is given in Tables 3.6 and 3.7.

Table 3.6: Sensitivity analysis iterations 2-37

	AADT	ALTDIST	TAADT	RDSYS	EMSFRQ6	EMSDIST	SCHFRQ6	SCHDIST	ALTRATE
AADT		2	3	4	5	6	7	8	9
ALTDIST			10	11	12	13	14	15	16
TAADT				17	18	19	20	21	22
RDSYS					23	24	25	26	27
EMSFRQ						28	29	30	31
EMSDIST							32	33	34
SCHFRQ								35	36
SCHDIST									37
ALTRATE									

Table 3.7: Sensitivity analysis iterations 38-73

	AADT	ALTDIST	TAADT	RDSYS	EMSFRQ6	EMSDIST	SCHFRQ6	SCHDIST	ALTRATE
AADT		38	39	40	41	42	43	44	45
ALTDIST			46	47	48	49	50	51	52
TAADT				53	54	55	56	57	58
RDSYS					59	60	61	62	63
EMSFRQ						64	65	66	67
EMSDIST							68	69	70
SCHFRQ								71	72
SCHDIST									73
ALTRATE									

The values in the decision matrix for each factor comparison were changed according to the procedure outlined in Table 3.8.

Table 3.8: Procedure used to change factor comparison values

Iterations	**If value equals**	**Change value to**	**If value equals**	**Change value to**	**If value equals**	**Change value to**
2-37	0.5	1	1	2	2	1
38-73	0.5	2	1	0.5	2	0.5

The analysis was conducted in Microsoft Excel and was conducted with urban and rural crossings separated, as in the actual ranking. During each iteration, the ranks for all crossings in each set were recorded in a separate worksheet. Once completed, the ranks for each iteration were compared to the ranks found in the base condition to determine the change in rank. The number of rank changes was computed for each crossing by counting the number of iterations that the change was not equal to zero. To provide an indicator of the magnitude of the changes, the maximum absolute change for each crossing was computed. Plots of the number of changes by crossing were generated for the entire dataset to visually determine the effect of weighting changes on the ranks. Plots of the maximum absolute change were generated for the top 15 originally ranked crossings in each set.

A primary goal of the sensitivity analysis is to determine which factors have a greater sensitivity on the resulting crossing ranks. Because of the structure of the matrix, each iteration affects two factors. In order to determine which iterations are associated with each factor, the iteration numbers given in Tables 3.6 and 3.7 were mirrored so that each row contained all iterations that affect the factor given in that row. Each factor was affected by the same number of iterations, 16. These iterations are summarized in Table 3.9. The number of crossings that changed rankings in each iteration was calculated to determine which iterations had the greatest effect on crossing rankings. Plots of the ranks of the top 15 originally ranked crossings in each set were also created to show the effect that each iteration had on the crossing rank. The iterations that were determined to commonly cause a rank change were identified and the factors included in those iterations were further investigated to determine possible causes of sensitivity.

Table 3.9 Factors modified in each sensitivity analysis iteration

Factor	**Modified in Iterations**
AADT	2-9, 38-45
ALTDIST	2, 10-16, 38, 46-52
TAADT	3, 10, 17-22, 39, 46, 53-58
RDSYS	4, 11, 17, 23-27, 40, 47, 53, 59-63
EMSFRQ	5, 12, 18, 23, 28-31, 41, 48, 54, 59, 64-67
EMSDIST	6, 13, 19, 24, 28, 32-34, 42, 49, 55, 60, 64, 68-70
SCHFRQ	7, 14, 20, 25, 29, 32, 35, 36, 43, 50, 56, 61, 65, 68, 71, 72
SCHDIST	8, 15, 21, 26, 30, 33, 35, 37, 44, 51, 57, 62, 66, 69, 71, 73
ALTRATE	9, 16, 22, 27, 31, 34, 36, 37, 45, 52, 58, 63, 67, 70, 72, 73

CHAPTER 4

RESULTS

In order to determine the effect that changes in weight have on the ranking of the crossings, a sensitivity analysis was conducted by changing the values in the decision matrix to reflect changes in the level of importance of each factor relative to another. The resulting rankings were recorded and analyzed. Urban and rural crossings were separated in the sensitivity analysis, as in the actual ranking process. To start, the crossings were ordered by rank according to the original weights determined from the TAC evaluation. In the analysis, the original ranking refers to the ranking that the crossing received using the weighting scheme determined by the TAC.

4.1. Weighting Procedure Evaluation

To determine the effect that changing weights has on crossing rankings, the number of rank changes from the base condition that a crossing experienced during the analysis was counted. A plot of the number of rank changes by crossing is found in Figure 4.1 for urban crossings and in Figure 4.3 for rural crossings.

4.1.1. Urban crossings

For the urban case, it can be seen that overall, the weighting procedure seems robust for crossings that ranked higher during the base condition and lower during the base condition, but not for crossings that fall in the middle range. This shows that crossings that rank at the high or low ends based on the original weighting scheme will generally rank at the high or low ends, respectively, independent of the weight applied. This high end falls at an original rank of approximately 200 and the low end at an original rank of approximately 1,640. For crossings that have an original rank between

200 and 1,640, the effect of changing weights seems to have a drastic effect on the rank of the crossing. Approximately 152 out of 1,768 urban crossings experienced a total number of rank changes equal to 72, indicating that the rank changed during all iterations. Other methods of determining weights may be necessary for crossings that fall in this area. The average number of rank changes for the entire urban case is 65.9.

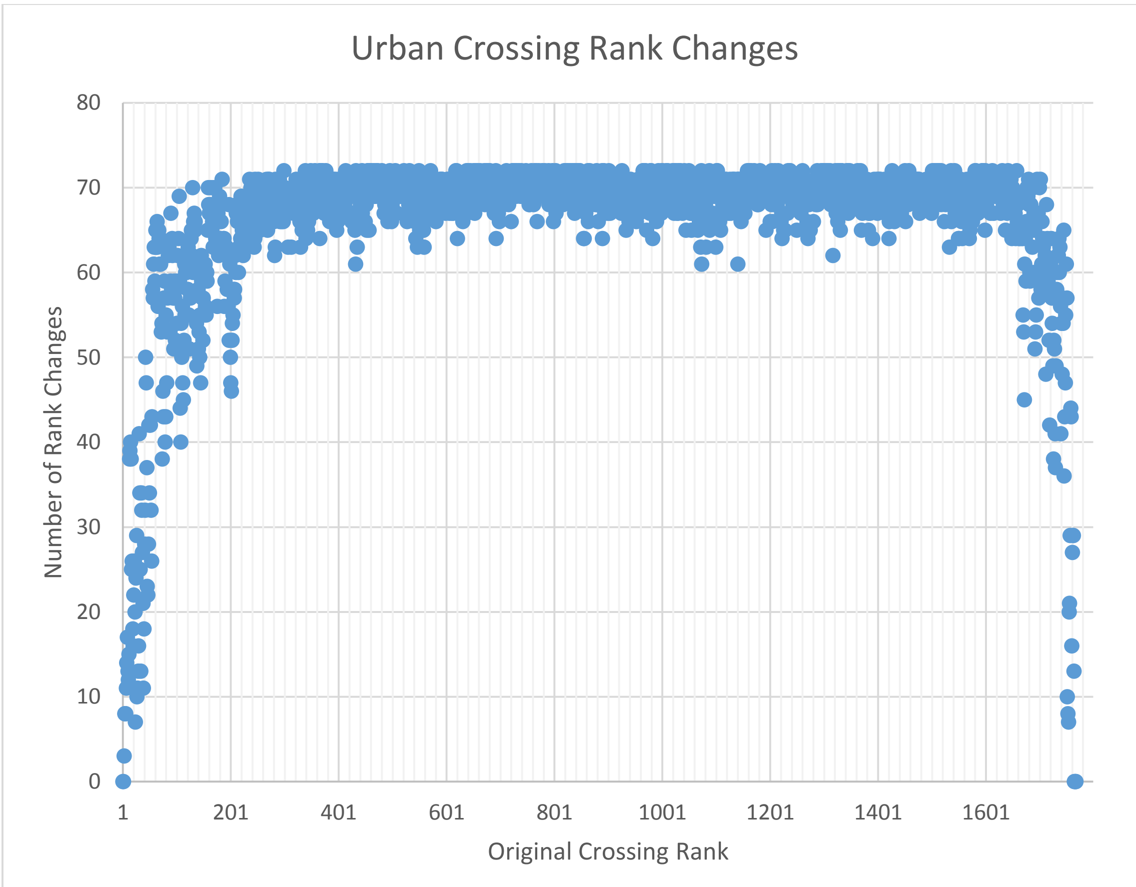

Figure 4.1: Urban crossing rank changes by crossing

A subset of the urban crossings, which represents the top 15 crossings in the original ranking was plotted separately. This group of crossings represents those that are more likely to be further evaluated for consolidation, due to their high ranking. A plot of the number of rank changes for these crossings is presented in Figure 4.2. This figure shows that the ranks are generally consistent, with the number of rank changes increasing with the original crossing rank. A sharp increase in the number of rank changes occurs at crossing 13, from 15 rank changes for crossing 12 to 38 rank changes for crossing 13. Looking at the data for crossings 13-15 compared to crossings 1-12, a possible explanation for the jump in the number of rank changes is that the distance to the nearest EMS location and the distance to the nearest school for crossings 13 and 14 is significantly different from the previous 12 crossings. Crossing 15 has similar values to crossings 1-12 for these factors, but has a larger alternate route crash rate and truck AADT. These differences may contribute to the larger number of rank changes experienced by these crossings. Crossings 1 and 2 both experienced zero rank changes across the 72 iterations.

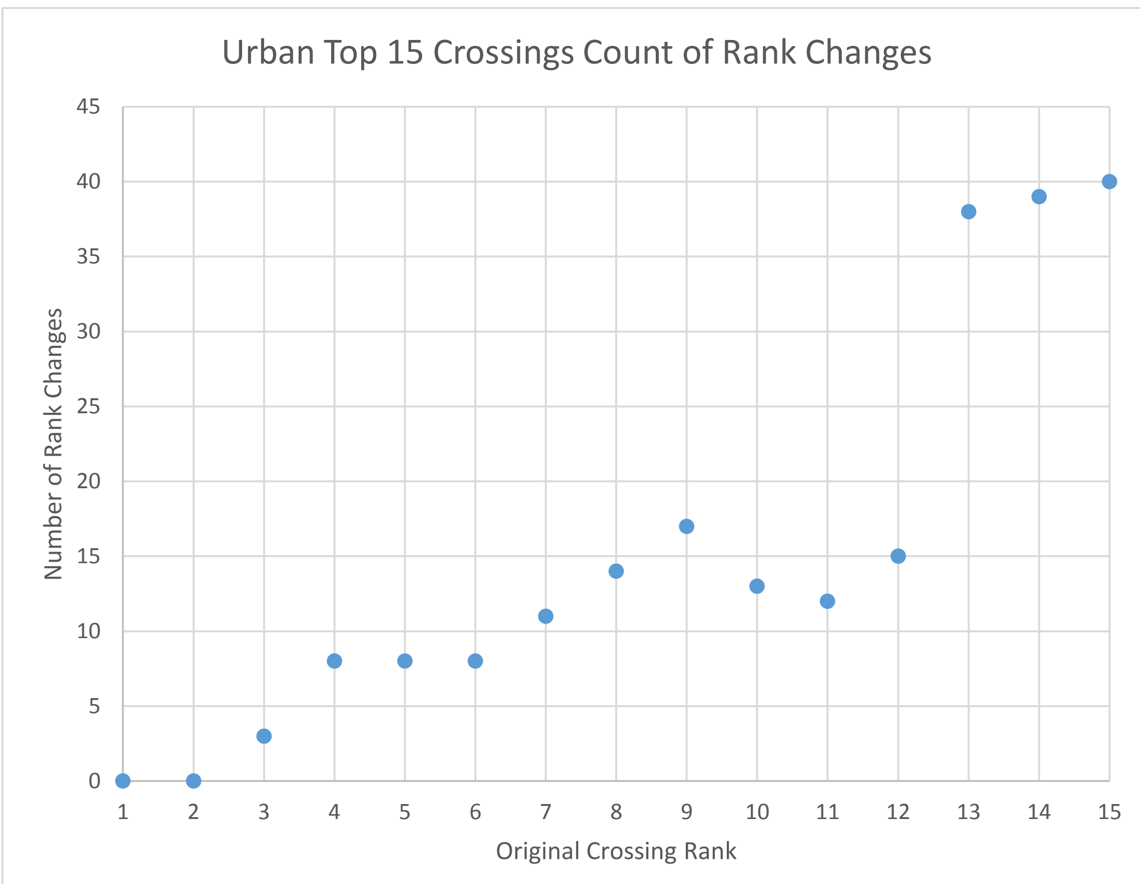

Figure 4.2: Rank changes of the top 15 originally ranked urban crossings

4.1.2. Rural crossings

For the rural case, Figure 4.3 shows that there is a similar pattern to the crossing rank changes, with the number increasing, somewhat leveling off, and decreasing again. However, there seems to be more variability in the number of rank changes than in the urban case. There is also a small trend of a decrease in the number of rank changes for crossings with an original rank between approximately 1,400 and 1,600. Only 16 of the 2,021 crossings included in the rural set experienced 72 rank changes, which indicates a rank change during every iteration. The average number of rank changes for the rural case is 61.3. The pattern displayed by this plot indicates that the weighting procedure again seems robust for the high and low ends of the rankings, but less robust for the middle range of rankings.

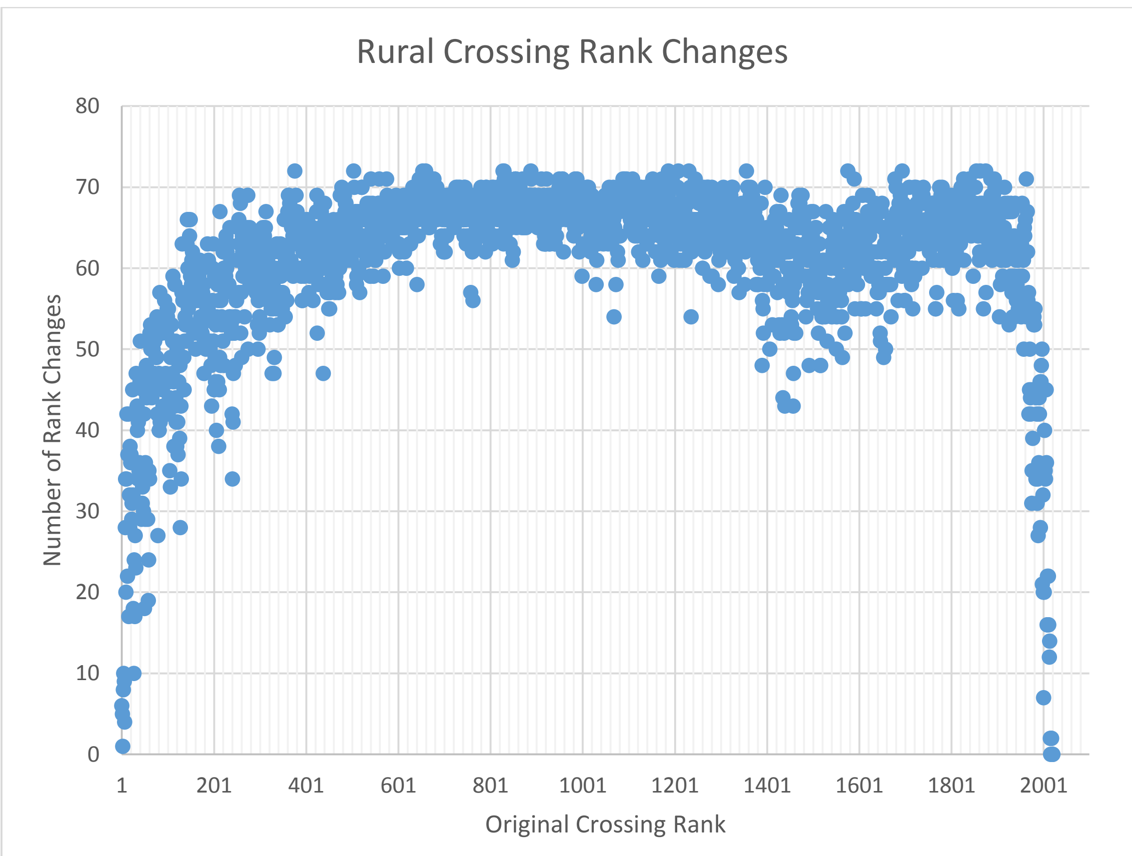

Figure 4.3: Rural crossing rank changes by crossing

Figure 4.4 shows a subset of the top 15 originally ranked crossings. Again, there seems to be more variability in the number of rank changes compared to the urban case. The number of rank changes generally increases with original crossing rank, but can widely vary in magnitude. No crossings had zero rank changes. The lowest number of rank changes in the original top 15 crossings is crossing number 3, with one change. There is a large jump in the number of rank changes from crossing number 7 to crossing number 8, from 4 rank changes to 28.

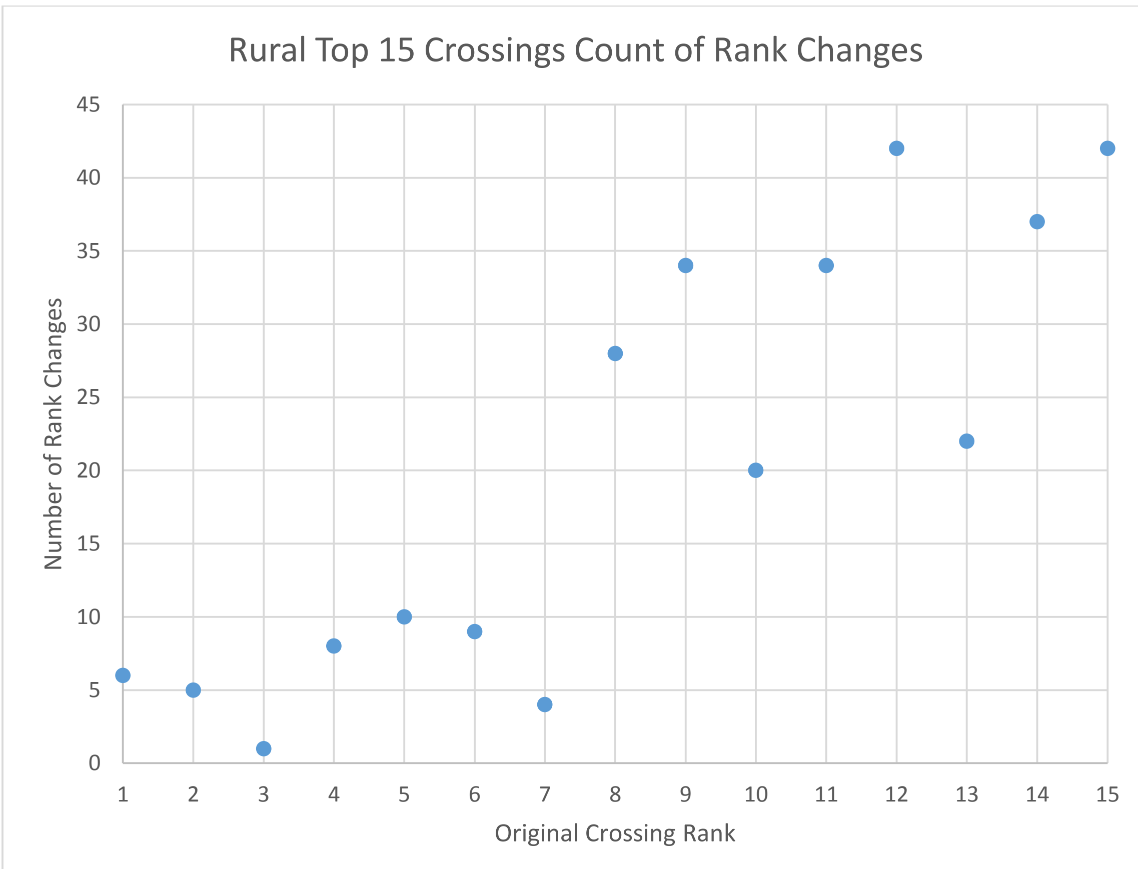

Figure 4.4: Rank changes of the top 15 originally ranked rural crossings

4.2. Magnitude of Rank Changes

To provide context for the number of rank changes, the maximum absolute rank change experienced by each crossing was computed. The evaluation of this effect was again focused on the top 15 originally ranked crossings because of their higher likelihood of being investigated for consolidation. Urban and rural crossings were evaluated separately.

4.2.1. Urban crossings

In the urban case, shown in Figure 4.5, the maximum absolute rank change was relatively consistent and followed a similar pattern to the number of rank changes experienced by the top 15 urban crossings discussed in the previous section. This shows that, although some of the crossings experienced a larger number of rank changes, the magnitude of these changes is low. For example, the crossing originally ranked 15th experienced 40 rank changes, but these changes only varied by 3 positions.

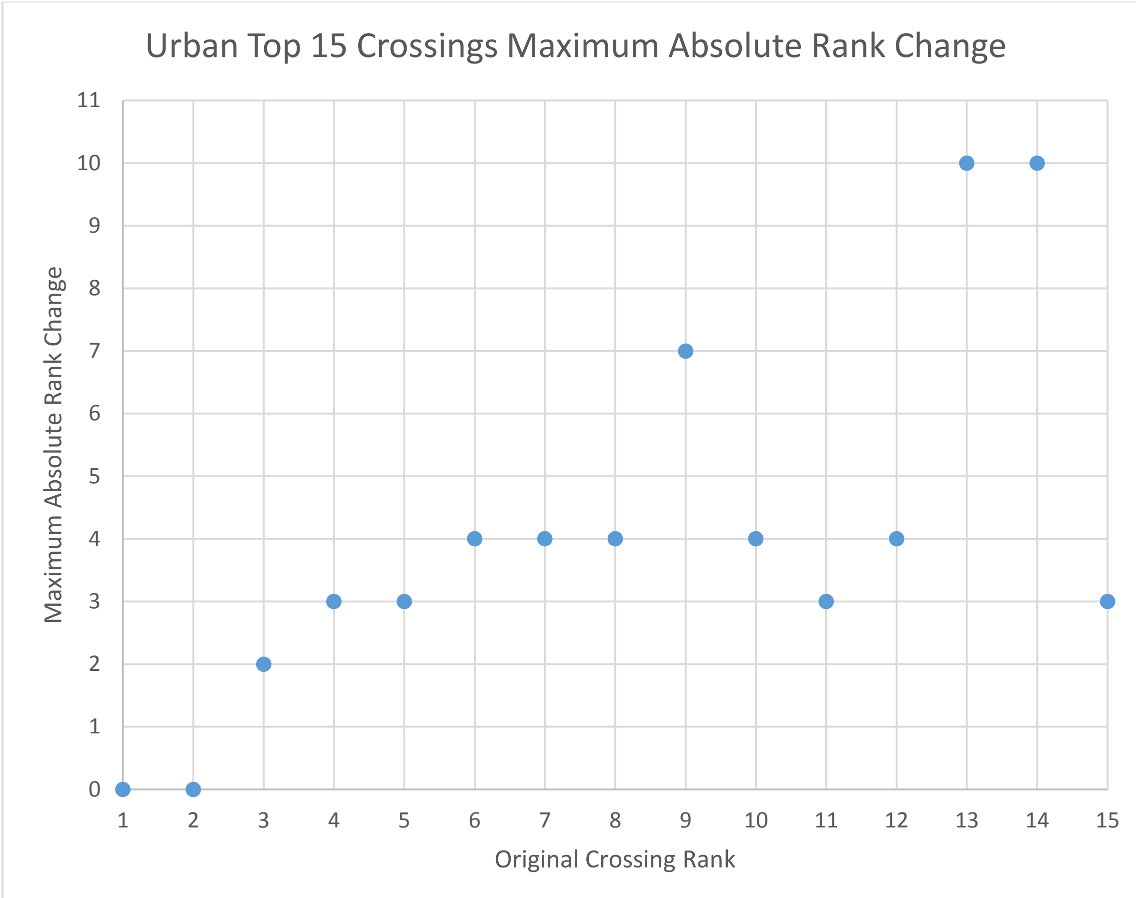

Figure 4.5: Maximum absolute rank change of the top 15 originally ranked urban crossings.

4.2.2. Rural crossings

For the rural case, shown in Figure 4.6, the maximum absolute rank change plot also shows a similar pattern to the number of rank changes experienced by the rural top 15 crossings. The crossing originally ranked 12th and 15th experienced 42 rank changes, however these rank changes only varied by 4 and 9 positions, respectively.

Although this portion of the analysis focused on the top 15 originally ranked crossings, it should be noted that for crossings in the middle range of original rankings, the magnitude of the maximum absolute rank change can be quite large. This reflects the variability found in the number of rank changes for this same subset of crossings. For the urban case, the average maximum absolute rank change is 58.4 and 37.7 for the rural case. Both the urban and rural cases had outliers with a maximum absolute rank change of up to 400.

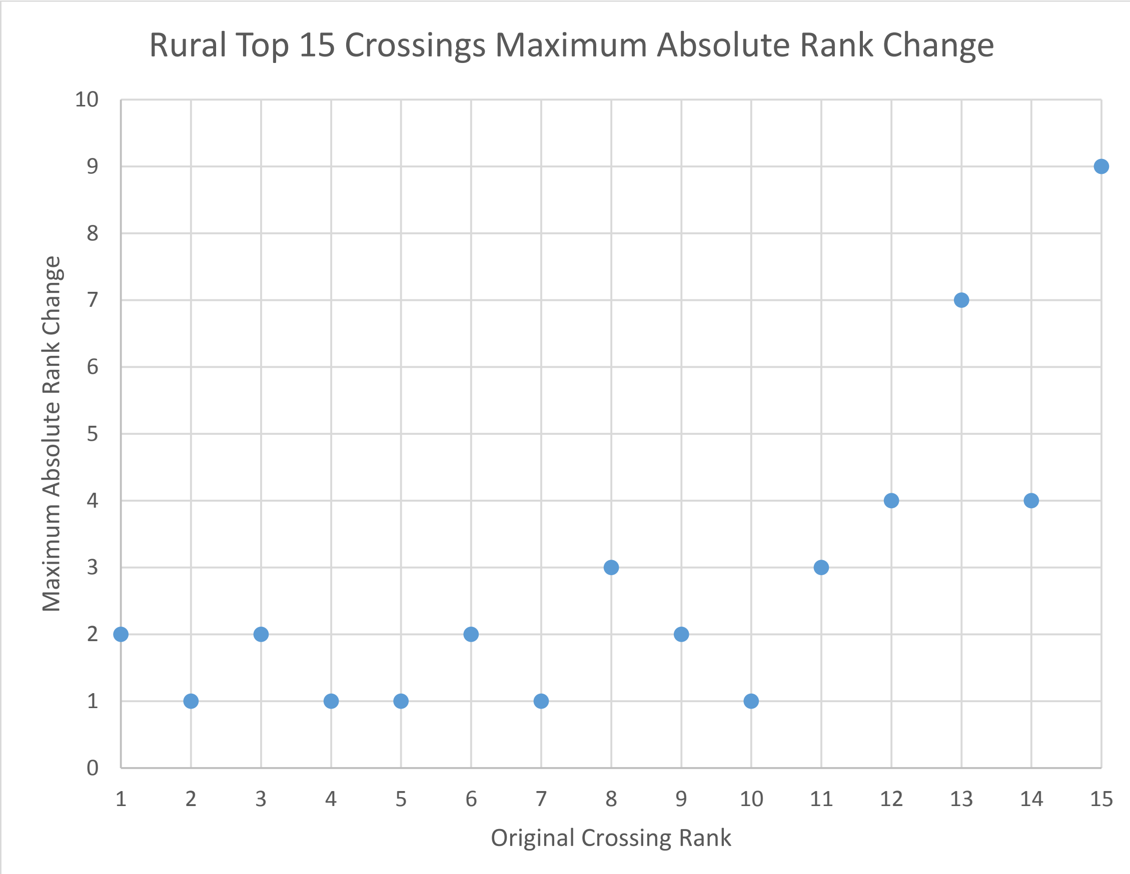

Figure 4.6: Maximum absolute rank change of the top 15 originally ranked rural crossings.

4.3. Impact of Factors

The impact that an individual factor has on the rankings can be seen from analyzing the ranks by iteration. As noted previously, each iteration affected two factors because of the structure of the matrix. As with the previous measures, the top 15 originally ranked crossings in each set were evaluated for factor impact. The rank of each of these crossings was plotted by iteration. Using the resulting graph, it can be seen which iterations caused changes in the rank of each crossing. By identifying which iterations commonly caused rank changes, it can be seen which factors have a larger impact on the rank of a crossing and a higher sensitivity. Again, urban and rural crossings are evaluated separately.

4.3.1. Urban crossings

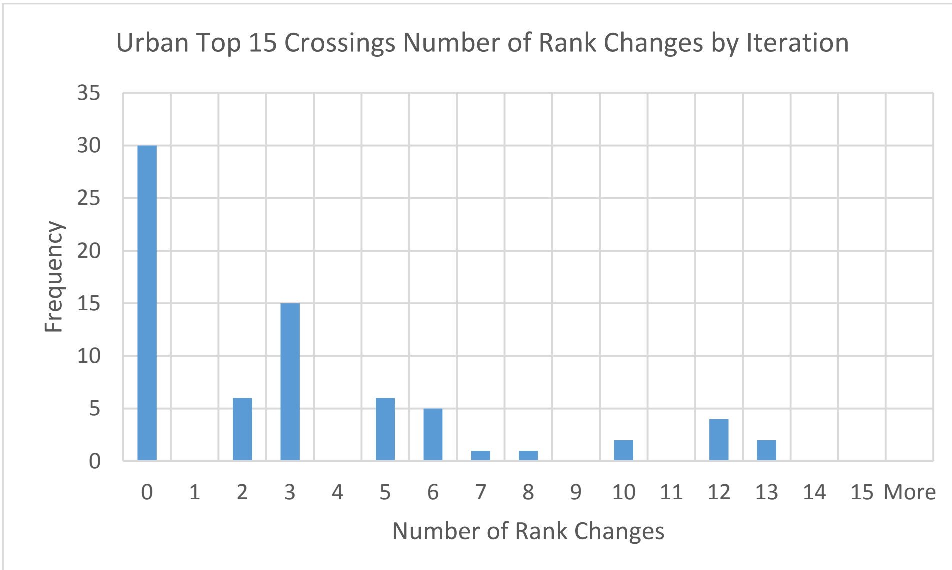

Figure 4.7: Histogram of rank changes by iteration for the top 15 urban crossings.

Figure 4.7 shows a histogram of the number of rank changes by iteration for the urban case. To develop this histogram, each iteration was compared to the base condition to determine the number of crossings in that iteration that have a rank different from its rank in the base condition. The most frequent number of rank changes in a single iteration is zero, with 30 iterations. The maximum number of rank changes seen is 13, experienced by two iterations. Figure 4.8 shows a plot of the rank of the top 15 originally ranked urban crossings. Common rank changes are seen in iterations 21, 26, 42, 49, 57, and 62. Using Table 3.9, the factors that are included in these iterations are TAADT, SCHDIST, RDSYS, AADT, and EMSDIST. The factor combinations modified in iterations 21 and

26 are the same as those modified in iterations 57 and 62, with TAADT/SCHDIST in iterations 21 and 57 and RDSYS/SCHDIST in iterations 26 and 62. Iterations 21, 26, 42, and 49 experienced 12 rank changes, while iterations 57 and 62 experienced 13 rank changes. A summary of the iterations determined to commonly cause rank changes is found in Table 4.1, discussion of these iterations follows.

Table 4.1: Iterations determined to commonly cause rank changes for urban crossings.

Iteration	Factor Pair Modified
21	TAADT/SCHDIST
26	RDSYS/SCHDIST
42	AADT/EMSDIST
49	ALTDIST/EMSDIST
57	TAADT/SCHDIST
62	RDSYS/SCHDIST

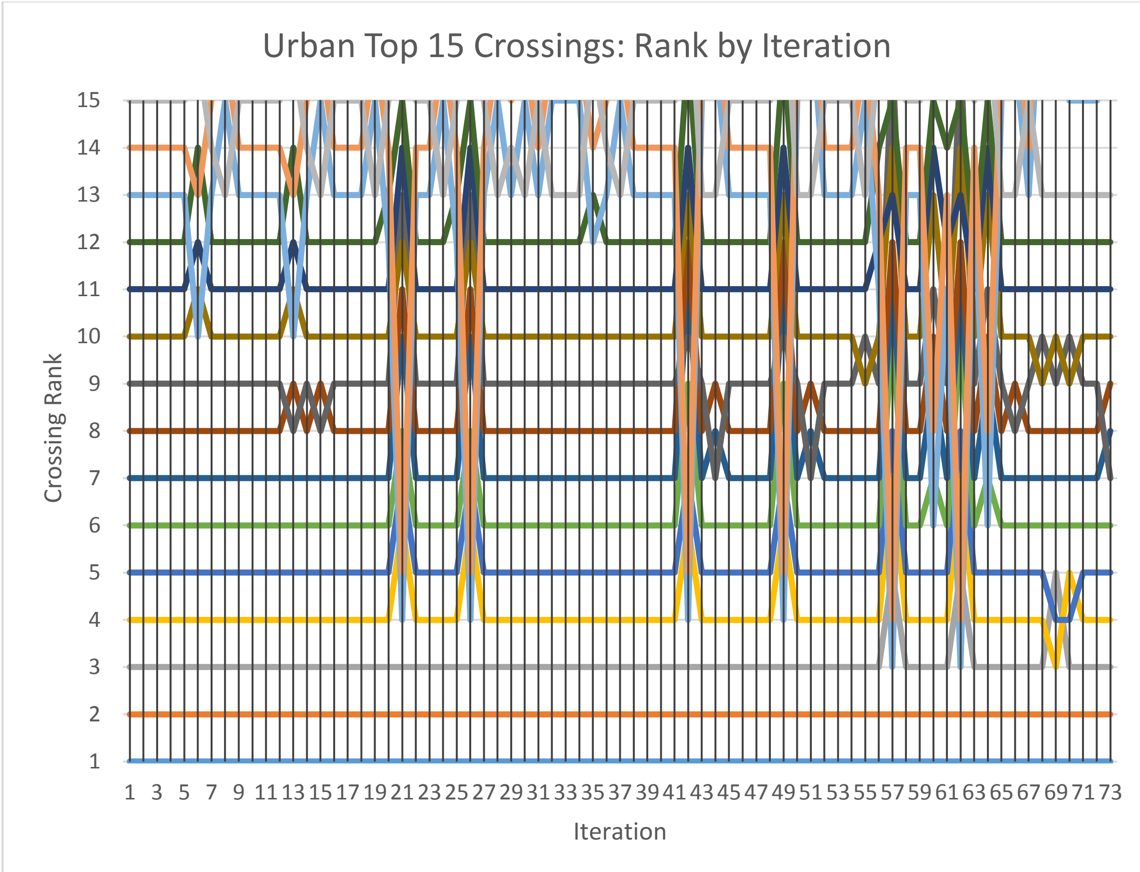

Figure 4.8: Rank by iteration of the top 15 originally ranked urban crossings.

Looking closer at these factors provides an explanation of the impact on rankings that is caused. TAADT, the truck AADT for the crossing, is often a low value. For the top 15 crossings evaluated here, the average TAADT is 2, compared to the overall urban crossing average TAADT of 130. SCHDIST, the distance to the nearest school can widely vary from crossing to crossing. Because the definition of an urban crossing is one which is located within an incorporated area, many urban crossings are located in smaller towns, which may or may not have a school. This would result in some urban crossings having a relatively large distance to the nearest school. Looking at the specific crossings evaluated here, the average distance to a school is 5.8 miles, compared to the overall urban crossing average distance to a school of 0.94 miles. These results show that the

TAADT/SCHDIST factor pair has a higher sensitivity to modification of its value in the decision matrix. Both iterations containing this factor pair were shown to commonly cause a rank change. This indicates that the sensitivity of this pair is not dependent on which factor is judged to be of higher importance.

RDSYS, the road system of the crossing, is an indicator factor which has a value of 0 or 1, 0 if the crossing is not on either the primary road system or the farm-to-market road system and 1 otherwise. For the top 15 crossings evaluated here, all crossings have a value of 0, indicating that they are not on the primary or farm-to-market systems. The factor pair of RDSYS/SCHDIST commonly produced a rank change. As with TAADT/SCHDIST, this factor pair commonly produced a rank change for both of its associated iterations, 26 and 62. This indicates that the sensitivity of the RDSYS/SCHDIST factor pair is not dependent on which factor is judged to be of higher importance. Because the normalized value of RDSYS for the top 15 urban crossings is 0, the impact that this factor has on the total composite value for the crossing which is ultimately ranked is zero. Changes seen in rankings because of the RDSYS/SCHDIST factor pair come only from changing the weight of the SCHDIST factor.

For the remaining two factor pairs that were found to commonly cause a change in rankings, each pair was only found to cause a change in one of the iterations associated with it. The finding that only iteration 42, and not the associated iteration 6, commonly produces a rank change indicates that the AADT/EMSDIST factor pair is more sensitive when AADT is judged to be a less important factor than the distance to the nearest EMS location, as iteration 42 changed the factor importance value from 2, indicating that AADT is more important, to 0.5, indicating that EMSDIST is more important. A similar conclusion can be reached for iteration 49 and the ALTDIST/EMSDIST factor pair. In iteration 49, the factor importance value was changed from 2, indicating that ALTDIST, the alternative route distance, is more important, to 0.5, indicating that EMSDIST is more important. This indicates that the ALTDIST/EMSDIST factor pair is more sensitive when ALTDIST is judged to be a less important factor than EMSDIST.

In general, for urban crossings, it can be seen that the SCHDIST and EMSDIST factors have a higher sensitivity, as factor pairs that they are included in caused distinct changes in rankings multiple times in the sensitivity analysis. The weights of these factors for the urban case should be carefully considered. Also, from looking at the plot of ranks by iteration in Figure 4.8, it can be seen that the magnitude of the common rank changes in a single iteration are larger than a single rank, which indicates that the urban case as a whole is more sensitive.

4.3.2. Rural crossings

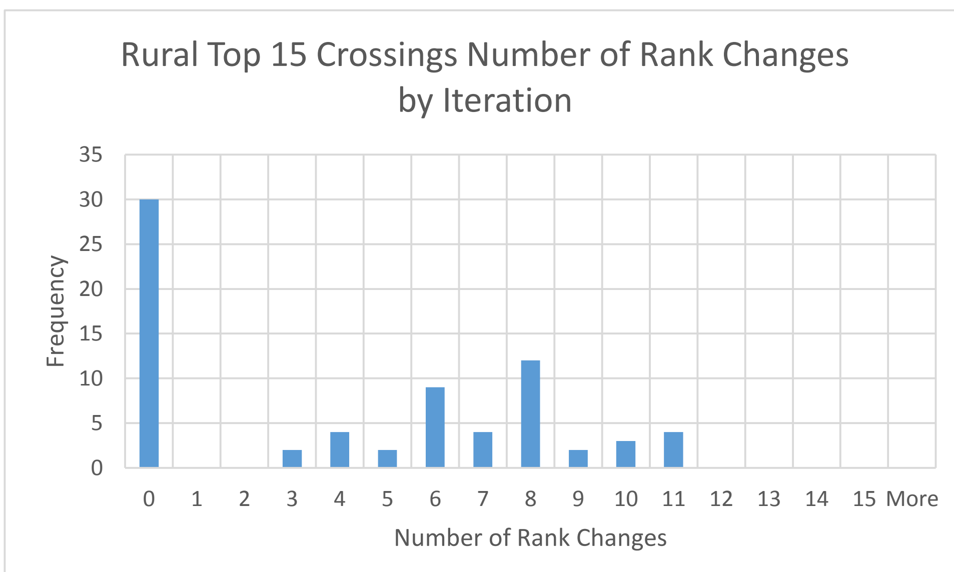

Figure 4.9: Histogram of rank changes by iteration for the top 15 rural crossings.

Figure 4.9 shows a histogram of the number of rank changes by iteration for the original top 15 crossings in the rural case. As was found with the urban case, the most frequent number of rank changes in a single iteration is zero, with 30 iterations. The maximum number of rank changes in a single iteration is 11, experienced by 4 iterations.

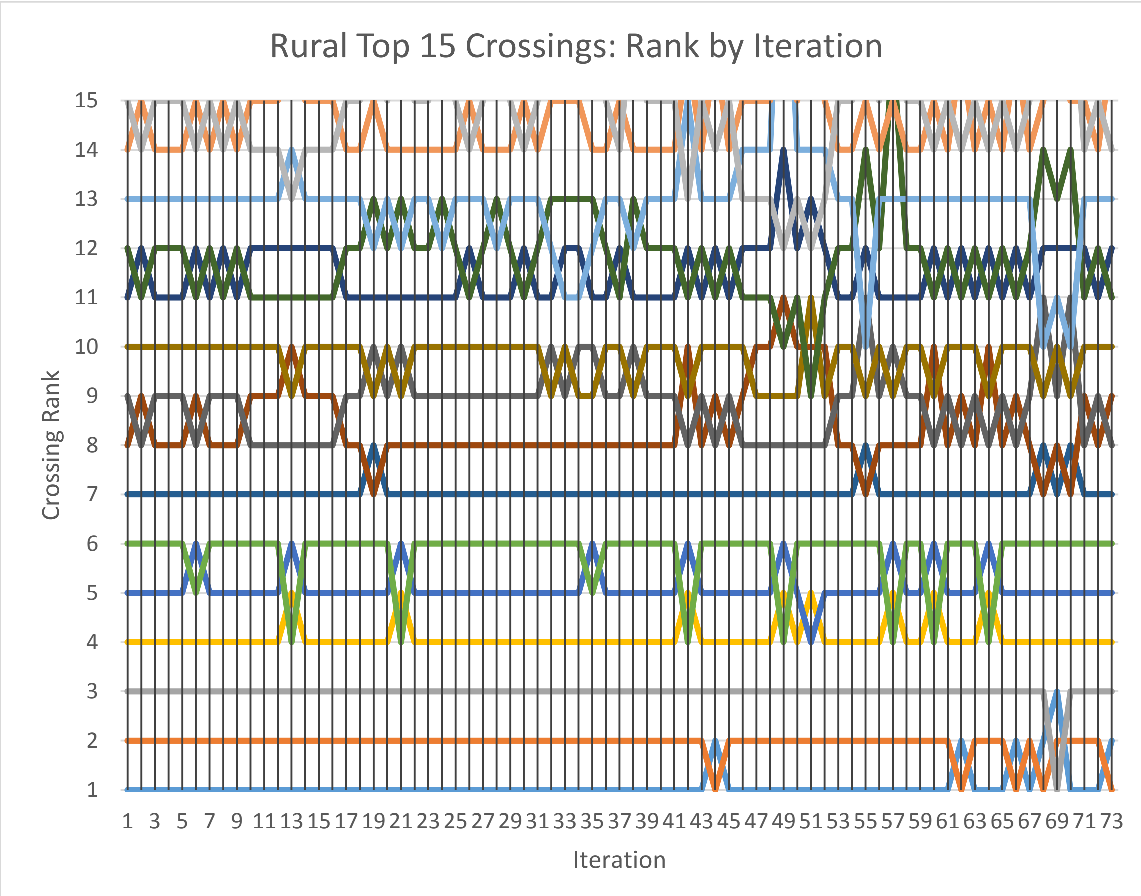

Figure 4.10: Rank by iteration of the top 15 originally ranked rural crossings.

Figure 4.10 shows a plot of the rank of the top 15 originally ranked rural crossings. Common changes are not as pronounced as the urban case, so a visual determination of what iterations commonly cause changes is difficult. Most of the rank changes seen in Figure 4.10 are small magnitude changes, as opposed to the urban case, where crossings frequently changed ranks by nine or more positions in a single iteration. To determine which iterations commonly caused changes in the rural case, a comparison was made between each iteration and the base condition to determine the number of crossings that changed rank during each iteration. The maximum number of crossings that changed rank during a single iteration is 11, as seen in Figure 4.9. Iterations 13, 42, 49, and 68 all had 11 crossings that changed ranks. From Table 3.9, the factors that are included in the commonly changing iterations are EMSDIST, ALTDIST, AADT, and SCHFREQ. Of these iterations, only iterations 13 and 49 are associated with the same factor pair, ALTDIST/EMSDIST. A summary of the iterations that commonly caused rank changes is found in Table 4.2, discussion of these iterations follows.

Table 4.2: Iterations determined to commonly cause rank changes for rural crossings.

Iteration	**Factor Pair Modified**
13	ALTDIST/EMSDIST
42	AADT/EMSDIST
49	ALTDIST/EMSDIST
68	EMSDIST/SCHFRQ

In iterations 13 and 49, which modify the ALTDIST/EMSDIST factor pair, it was found that sensitivity is not dependent on which factor was judged to be more important in the decision matrix. For the top 15 crossings analyzed here, the average EMSDIST value is 8.40 miles, compared to an average of 3.23 miles for all rural crossings. The average ALTDIST value for the top 15 crossings is 1.23 miles, compared to an average of 2.36 miles for all rural crossings.

Iteration 42 modified the AADT/EMSDIST factor pair by changing the value in the decision matrix from 2, indicating that AADT is more important than EMSDIST, to

0.5, indicating that EMSDIST is more important than AADT. From this, it can be seen that the AADT/EMSDIST factor pair is more sensitive when EMSDIST is judged to be more important than AADT. This same result was found for the urban case as well.

The final iteration that caused 11 crossings to change ranks was iteration 68, which modified the EMSDIST/SCHFREQ factor pair. This iteration changed the value in the decision matrix for the factor pair from 2, indicating that EMSDIST is more important than SCHFREQ, to 0.5, indicating that SCHFREQ is more important than EMSDIST. This shows that the EMSDIST/SCHFREQ factor pair is more sensitive when SCHFREQ is judged to be more important than EMSDIST. In the rural case, a 6-mile radius is used to determine the frequency of schools. For 14 out of the 15 rural crossings analyzed here, there are zero schools within a 6-mile radius. This results in a normalized factor value for SCHFREQ equal to zero for these crossings, rendering the increased weight applied to the SCHFREQ factor because of it being judged more important useless. Because iteration 68 shows that there is more sensitivity when SCHFREQ is judged to be more important than EMSDIST, and the SCHFREQ value used in the ultimate ranking for the majority of these crossings is zero, it can be seen that the sensitivity comes from the reduced weight on EMSDIST. As noted in the comparison of iterations 13 and 49, the average value of EMSDIST for these crossings is 8.40 miles, compared to an overall rural average of 3.23 miles. By reducing the weight on EMSDIST and having one factor in the formula zero, the overall ranked score for the crossing is decreased, causing a rank change.

In general for the rural case, it can be seen that EMSDIST is a sensitive factor, as it is found in all four iterations with a high number of rank changes. This can be explained by the relatively large distances to the nearest EMS location found in the 15 crossings analyzed. When the weight of EMSDIST is changed, it can greatly increase or decrease the overall ranked score for a crossing. As for the magnitude of rank changes, looking at Figure 4.10, for the most part, the magnitude of the rank changes experienced in each iteration is much lower than in the urban case. Most crossings changed ranks by only one position. Although several changed ranks by multiple positions, these rank changes were not at a common iteration as in the urban case.

For both the urban and rural cases, it can be seen that the EMSDIST factor is a more sensitive factor, as it is included in a majority of the iterations identified as commonly causing rank changes. The reason for this can be attributed to the relatively large values found for this factor in the crossings analyzed.

CHAPTER 5

CONCLUSIONS

From the results of the sensitivity analysis conducted on the weighting scheme used to rank the crossings, several conclusions can be made about the robustness of the weighting method, factors that have higher sensitivity, and the segregation of urban and rural crossings. Future work in this area is also discussed in this chapter.

5.1. Key Findings

5.1.1. Robustness of weighting method

For the urban case, it can be concluded that the weighting procedure is robust. For crossings that are highly ranked in the base condition, there is less variability in the changes in ranking that occurred during the sensitivity analysis. Out of a total of 1,768 urban crossings included in the ranking spreadsheet, it was found during the analysis that crossings that were originally ranked from 1 to approximately 200 and crossings that were originally ranked from approximately 1,640 to 1,768 had a relatively low number of rank changes during the sensitivity analysis. The average number of rank changes for the entire urban case was 65.9, out of a possible 72. Approximately 152 of the 1,768 urban crossings experienced a rank change during every iteration in the sensitivity analysis. For the top 15 urban crossings, which is a representation of those which have a higher likelihood of being considered for consolidation, the number of rank changes is very low and mostly consistent for all 15. The magnitude of rank changes, shown by the maximum absolute rank change of each crossing, is also low and relatively consistent for the top 15 urban crossings.

For the rural case, it can also be concluded that the weighting procedure is robust. The rural case followed a similar pattern to the urban case in that crossings that are highly ranked in the base condition have less variability in rank changes that occurred during the sensitivity analysis. There is, however, overall more scattering of the number of rank changes in the rural case than the urban case. The leveling off of the plot of crossing changes occurs at a larger original rank value than the urban case, at an original rank of approximately 600. There is again a steep drop in the number of rank changes when approaching an original rank of approximately 1,900. The average number of rank changes for the rural case was 61.3 out of a possible 72, less than the urban case. The rural case had only 16 crossings that experienced a rank change during every iteration. For the top 15 rural crossings, which have a higher likelihood of being considered for consolidation, the number of rank changes is low. There is more scattering of the number of rank changes than in the urban case for crossings 8-15. Crossings 1-7 are consistently low, while crossings 8-15 exhibit a higher number of rank changes, but not consistently increasing with crossing rank. It can still be concluded that the weighting is robust, due to the relatively low number of rank changes.

Overall, the weighting procedure can be concluded to be robust for both the urban and rural cases because of the low number of rank changes for crossings ranked highly in the base condition.

5.1.2. Impact of factors

The sensitivity analysis identified several factors that were found to have a greater sensitivity on the ultimate crossing rank when factor weights were changed. These factors are summarized in Table 5.1.

Table 5.1: Factors with higher sensitivity

Factor	Sensitive for Urban, Rural or Both
AADT	Both
ALTDIST	Both
EMSDIST	Both
RDSYS	Urban
SCHDIST	Urban
SCHFRQ	Rural
TAADT	Urban

From this list, it can be seen that AADT, ALTDIST, and EMSDIST are sensitive for both urban and rural crossings. In both the urban and rural cases, AADT was found to be a sensitive factor when it was paired with EMSDIST. It was also found that this factor pair was more sensitive when EMSDIST was judged to be a more important factor than AADT. This result is due to the relatively large values of EMSDIST in the top 15 urban and top 15 rural crossings compared to the relatively small values of AADT for the same crossings. In the both the urban and rural cases, ALTDIST was found to be sensitive when paired with EMSDIST. However, the ALTDIST/EMSDIST pair was found to be sensitive only when ALTDIST is judged to be a less important factor than EMSDIST in the urban case. For the rural case, the factor pair was found to be sensitive independent of which factor was judged to be of greater importance.

RDSYS, SCHDIST, and TAADT were found to be sensitive for only the urban case. For these factors, the sensitive pairs were found to be RDSYS/SCHDIST and TAADT/SCHDIST. In the RDSYS/SCHDIST pair, the sensitivity was found to be independent of which factor was judged to be of higher importance, but it was also determined that the sensitivity arises because of the change in SCHDIST weight. This is due to the RDSYS value of all top 15 urban crossings being equal to zero, effectively removing the factor from inclusion in the composite score calculation. The TAADT/SCHDIST pair was also found to have higher sensitivity independent of which factor was judged to be of greater importance. In this case, neither of the factors is lost due to zero values, so there is not much of a conclusion that can be drawn as to which factor is more responsible for the sensitivity.

SCHFRQ was the only factor found to be sensitive only in the rural case. It was found to be sensitive when paired with EMSDIST. The EMSDIST/SCHFRQ pair was found to be sensitive when SCHFRQ is judged to be of higher importance than EMSDIST. As was found with the RDSYS value in the urban case, SCHFRQ has a value of zero for 14 of the top 15 rural crossings, which effectively removes it from the composite score calculation. Because of this it can be concluded that the sensitivity in this factor pair is caused by reducing the weight on EMSDIST.

This analysis can be used to provide guidance in the determination of the relative importance of each factor. Because RDSYS and SCHFRQ can often contain values of zero, these factors can cause other, larger factors to have a greater impact due to the removal of the RDSYS and SCHFRQ factors from the composite score. EMSDIST is found in all of the sensitive factor pairs in the rural case and two of six in the urban case. A probable cause of this sensitivity is the varying distance that is found for the distance to EMS locations due to not all incorporated areas in the state having an EMS location. A similar conclusion can be made for the SCHDIST factor, which appears in four of six sensitive factor pairs in the urban case. Due to the method used to segregate crossings into urban and rural sets, which was purely based on the presence of a crossing either inside or out of an incorporated area, many crossings that are classified as urban crossings are in very small incorporated areas. Many small incorporated areas in the state have no school located in them and this can result in a larger variability in the distance to the nearest school location for urban crossings. AADT and TAADT can both vary widely among crossings and generally depend on the classification of the road. In summary, the factors shown in Table 5.1 should be given a higher level of discretion when determining factor weights, due to their impacts on the final ranking of crossings.

5.1.3. Differences between urban and rural crossings

It can be concluded through examining the plots of rank changes for the urban and rural cases and the factors determined to have higher sensitivity that urban and rural crossings have differences that affect their performance when being evaluated through a rating formula. The decision to apply different weighting schemes to urban and rural crossings appears to be justified through this analysis. However, it can be seen that in some situations, the definition of urban and rural as being inside or outside of an incorporated area may not be the best representation of what the actual urban or rural status of a crossing is. This is particularly evident for crossings in small incorporated areas which may effectively be a rural crossing, due to their location. This is a possible explanation for why the urban case had a higher number of crossings that changed ranks more frequently.

5.2. Future Work

A possible area of future work may be to re-evaluate crossings to determine a different criteria to segregate them on the basis of urban and rural status. Possible methods that can be used to perform this could involve a definition relating to the population of the incorporated area that an urban crossing is located in. Another potential area of future work could involve the consideration of new safety technologies being implemented in the railroad industry, such as Positive Train Control (PTC). Furthermore, to allow the evaluation of multiple factor combinations changing, rather than the one at a time method that was used in this analysis, a Monte Carlo simulation method may be used to conduct the sensitivity analysis. The one at a time method was used in this case due to the large number of combinations involved with other simulation methods.

As was noted in the discussion of factors in section 3.2.7, several factors that were considered for inclusion in the formula were excluded due to data limitations. Other data sources can be explored to find appropriate data for these factors. Future crossing inventories may result in more accurate values for the humped crossing condition attribute in the Rail Crossing Database that can be included in the weighting formula. Other population metrics may be used to disaggregate population data in the area surrounding the crossing to enable a factor related to population to be included in the formula.

APPENDIX

CROSSING RANKING RESULTS

This appendix contains the ranking results for the top 15 urban and top 15 rural crossings, as ranked using the original weighting scheme, referred to in the sensitivity analysis as the base condition. Urban crossing results are presented in Table A.1 and rural crossing results are presented in Table A.2.

Table A.1: Top 15 originally ranked urban crossing ranking results

Weight	1		0.16		0.05		0.09		0.17		0.13		0.13		0.09		0.09		0.10
RANK		AADT		TAADT		RDSYS		ALTDIST		EMSFRQ3		EMSDIST		SCHFRQ2		SCHDIST		ALTRATE	
Composite Score	Overall Rank	Value	Factor Rank	Value	Factor Rank	Value	Factor Rank	Value	Factor Rank	Value	Factor Rank	Value	Factor Rank	Value	Factor Rank	Value	Factor Rank	Value	Factor Rank
0.931044662	1	289	316	0	1	0	1	0.13	161	0	1	8.07	19	0	1	6.87	20	0.00	1
0.925951647	2	50	27	0	1	0	1	0.13	188	0	1	7.22	41	0	1	7.03	15	0.00	1
0.914603212	3	270	296	8	489	0	1	0.26	670	0	1	7.42	35	0	1	6.03	53	0.00	1
0.912550437	4	190	216	0	1	0	1	0.39	921	0	1	6.53	64	0	1	6.86	21	198.06	519
0.912360825	5	110	112	6	419	0	1	0.39	936	0	1	6.47	65	0	1	6.80	23	92.01	289
0.911411695	6	289	316	3	370	0	1	0.13	145	0	1	6.21	72	0	1	6.68	27	0.00	1
0.910457691	7	250	275	3	366	0	1	0.13	148	0	1	6.15	76	0	1	6.62	29	0.00	1
0.910272214	8	70	51	1	331	0	1	0.13	157	0	1	6.09	78	0	1	6.57	31	0.00	1
0.909499797	9	660	717	0	1	0	1	0.79	1265	0	1	6.78	57	0	1	7.06	14	260.45	683
0.908786315	10	25	6	0	1	0	1	0.21	557	0	1	6.18	74	0	1	6.41	35	0.00	1
0.907963023	11	60	37	2	356	0	1	0.25	616	0	1	6.64	62	0	1	5.96	58	0.00	1
0.907098475	12	289	316	3	370	0	1	0.23	594	0	1	6.76	58	0	1	5.88	62	0.00	1
0.905818685	13	110	112	1	339	0	1	0.35	868	0	1	13.44	1	3	587	0.94	308	129.17	384
0.904929379	14	152	178	2	349	0	1	0.17	441	0	1	13.29	2	3	587	0.81	373	118.57	353
0.904636886	15	289	316	9	501	0	1	0.11	50	0	1	5.97	86	0	1	6.44	33	283.98	746

Table A.2: Top 15 originally ranked rural crossing ranking results

Weight	1		0.16		0.05		0.12		0.17		0.13		0.13		0.07		0.07		0.10
RANK		AADT		TAADT		RDSYS		ALTDIST		EMSFRQ6		EMSDIST		SCHFRQ6		SCHDIST		ALTRATE	
Composite Score	Overall Rank	Value	Factor Rank	Value	Factor Rank	Value	Factor Rank	Value	Factor Rank	Value	Factor Rank	Value	Factor Rank	Value	Factor Rank	Value	Factor Rank	Value	Factor Rank
0.93539452	1	50	836	6	1093	0	1	2.07	1205	0	1	13.22	1	2	366	5.10	321	60.69	508
0.933779904	2	100	1279	4	930	0	1	1.98	780	0	1	12.19	2	0	1	6.14	179	146.82	1134
0.92294225	3	15	132	2	401	0	1	2.28	1293	0	1	8.58	37	0	1	11.13	1	1103.89	1981
0.917572472	4	50	836	3	643	0	1	0.23	44	0	1	7.11	107	0	1	7.83	34	0.00	1
0.917398747	5	25	328	1	132	0	1	0.32	64	0	1	7.12	106	0	1	7.93	28	0.00	1
0.91731439	6	40	656	2	388	0	1	0.37	76	0	1	7.46	80	0	1	7.52	46	0.00	1
0.912710757	7	150	1417	17	1515	0	1	2.03	1168	0	1	8.98	28	0	1	7.81	36	45.13	439
0.910988818	8	10	37	2	494	0	1	0.28	54	0	1	7.05	117	0	1	7.10	82	263.34	1569
0.910606654	9	60	957	7	1184	0	1	2.01	1103	0	1	8.80	32	0	1	7.61	43	65.28	542
0.91028416	10	210	1504	15	1486	0	1	0.94	219	0	1	8.09	54	0	1	6.92	98	265.45	1575
0.90817941	11	10	37	0	1	0	1	0.65	144	0	1	7.16	103	0	1	7.20	74	261.77	1565
0.907772677	12	45	752	5	1028	0	1	2.14	1238	0	1	8.31	44	0	1	8.20	19	141.19	1086
0.90752486	13	15	132	0	1	0	1	0.20	42	0	1	6.41	162	0	1	7.21	72	0.00	1
0.906034632	14	15	132	2	401	0	1	0.99	246	0	1	7.36	89	0	1	7.02	87	0.00	1
0.90571616	15	90	1232	4	868	0	1	1.99	825	0	1	8.14	49	0	1	7.83	33	86.80	719

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