Rural expressway intersection characteristics that contribute to a reduced safety performance

Garrett David Burchett

Iowa State University

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Rural expressway intersection characteristics that contribute to a reduced safety performance

By

Garrett David Burchett

A thesis submitted to the graduate faculty in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Transportation

Program of Study Committee:
Thomas Maze, Major Professor
   Michael Crum
   Neal Hawkins
   Dave Plazak
   Reginald Souleyrette

Iowa State University
Ames, Iowa
2005
Graduate College
Iowa State University

This is to certify that the master's thesis of

Garrett David Burchett

Has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy
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ABSTRACT

Expressways have been constructed in many states as a way to increase mobility without the expense of a full access-controlled or grade-separated facility. In most cases, it was assumed that these segments of highway would produce similar mobility and safety characteristics as other access-controlled facilities. However, recent research has found that there are problems with the safety performance of these systems. Although past research has been completed to examine the nature of crashes on these facilities, it is the purpose of this study to continue the research and analyze the common characteristics of the intersections. The intersections studied in this research were located throughout the state of Iowa. The objective of these analyses is to provide an identification of the major contributing factors that create problematic intersections in the state of Iowa.

From previous research, it is evident that factors in addition to roadway volume contribute to the safety performance of an at-grade, two-way, stop-controlled expressway intersection. This research identifies common characteristics that may increase or decrease the safety performance of a rural expressway intersection. The methodology used in this research includes the examination of 644 intersections throughout the state of Iowa. Through the use of a statewide database and crash information from 1996 to 2000, we were able to identify the 100 best- and 100 worst-performing intersections based on crash severity rate. With the 200 intersections, a statistical analysis was completed to determine the effects intersection design and surrounding land use have on the intersection’s safety performance. The safety performance of intersections located on vertical/horizontal curves, skewed intersections, and varying surrounding land use were studied to determine their effects on rural expressway intersections.

Following the completion of the analysis of the 200 intersections, 30 intersections with highest crash severity index rates were selected for more thorough, site-specific analysis. As part of this analysis, we examined the impact of land use adjacent to the intersection and the impact of peaking in hourly traffic volumes. The research identifies attributes that impact crash severity both negatively and positively. Through the identification of these attributes,
designers and planners can more adequately address safety concerns on rural expressway intersections.
1. INTRODUCTION

Rural expressways are typically four-lane, high-speed facilities. Rural expressway intersections are generally two-way, stop-controlled facilities. These intersections are often grade-separated or signalized near urban centers or at intersections with primary highways. Rural expressways are constructed in many states as a way to increase mobility at a lower cost in comparison to a fully access-controlled facility. In most cases, it is assumed that these segments of highway will provide similar safety and mobility characteristics as access-controlled facilities. However, Maze, Hawkins, and Burchett recently reported that there are problems with the safety performance of these rural expressway systems. Although research has been completed to examine the nature of crashes at rural expressway intersections, this research will identify the common characteristics of rural expressway intersections with poor and good safety performance. After identifying these characteristics, guidelines for the design of new intersections or redesign of existing intersections can be established.

Through observations made by Maze, Hawkins, and Burchett (1), the authors concluded that factors other than roadway volume contribute to the safety performance of a rural expressway intersection. They speculated that additional design characteristics at intersection approaches, including horizontal curves, vertical curves, intersection skew, and land use in relation to crash frequency and crash severity. These features will be referred to as intersection features of interest.

Initially, a database of expressway intersections was created. This database includes 644 at-grade intersections. From this set of intersections, the research team identified the 100 intersections with the best safety performance and the 100 intersections with the poorest safety performance for a comparative statistical analysis. After completing the analyses of these 200 intersections, the team then further analyzed the 30 worst-performing intersections. Through the intersection analyses, the team identified common characteristics that contribute to the safety performance of rural expressway intersections and were able to make recommendations based on the findings.
Through the identification of characteristics that create problematic intersections, highway designers will be able to identify attributes that can be corrected in the future to increase the safety performance of rural expressway intersections. This thesis observes that the most severe crashes on rural expressways occur at locations with a horizontal curve, vertical curve, skewed intersection, or locations where an intersection feature of interest is present. Commuting traffic, hourly peaking, and land use also impact the severity of an intersection crash. It is also apparent that land use and features of interest should be considered when reconstructing intersections to improve the safety performance of expressway intersections.

This thesis is organized into five sections. The first chapter is this introduction. The next chapter is a review of existing intersection design and rural expressway safety performance literature. The literature review was conducted by searching TRIS and other literature search software. The search focuses on current literature specific to the safety performance of expressways as well as the identification of characteristics that contribute to intersection crashes.

The third chapter outlines a descriptive and statistical analysis of 200 intersections. This chapter examines common trends in crash rates and types. Both intersection alignment and land use are examined. With this descriptive analysis, characteristics most likely to show statistical significance can be determined. Uncommon crash characteristics that may occur on horizontal curves for example, may require additional research and are noted in this section. Through this analysis, the research team determined that intersections located on horizontal curves tend to perform differently than other intersections. This descriptive analysis also demonstrates that right-angle crashes occur more frequently at intersections not on a vertical curve, horizontal curve, or intersection skew. This chapter also describes the statistical analysis of 200 rural expressway intersections that was conducted to determine the effect that each intersection design or location characteristic has on an intersection’s safety performance. From this analysis, the research team observed that geometric features of interest create situations of increased crash severity. The analysis also determined that specific land use types can increase the crash severity of an expressway intersection. Through
these observations, the research team was able to create a safety performance function that includes both intersection alignment and land use variables.

The fourth chapter includes an analysis of the 30 intersections with the poorest safety performance. More thorough data collection and analysis was performed on these 30 intersections. In addition, crash pattern and traffic volume analyses were completed to further define issues created at rural expressway intersections. The crash pattern and traffic volume analysis examined the frequency of near and far side crashes as well as the impact of traffic volume peaking to determine additional factors that may create an increased crash severity. It was observed that most crashes occur on the far side of tangent intersections and over half of all crashes occur during peak volume period.

The final chapter of this project includes a summary of characteristics that significantly contribute to the reduction in safety performance of expressway intersections. This chapter also includes recommendations for the improvement of expressway intersection design and suggestions for future expressway research.
2. LITERATURE REVIEW

2.1 Methodology

This literature review focuses on literature involving the safety performance of expressways as well as the identification of characteristics that contribute to intersection crashes. The review is limited to rural intersections and focuses on common characteristics that affect their safety performance. This review is not comprehensive and relies on previous reviews completed in earlier literature. The review has been divided into two sections:

1. **Safety impacts of intersection features.** Although limited research has been completed on the effects that roadway design features have on expressway intersections, significant research has been completed on these effects on rural highway intersections in general. This portion of the review will focus on documents that outline features of an intersection that tend to have the most impact on safety performance. This section includes both studies that examine observed relationships as well as the statistical relationships between characteristics and safety performance.

2. **Safety characteristics of rural expressway intersections.** Although limited, research has documented common trends in crash characteristics on rural expressways. This section will focus on common crash characteristics specifically associated with rural expressways. The section will again discuss both observed conclusions as well as statistical analyses of rural expressways.

2.2 Safety Impacts of Intersection Features

Significant research has been completed involving rural intersections. Although most of the reports describing this research do not directly discuss through stop-controlled intersections or expressway intersections, the literature does give valuable insight into the characteristics that may affect the safety of an expressway intersection. To first discuss intersections in general, a report completed by Baxter in 2004 explains that to reduce crashes in the United States, the Federal Highway Administration (FHWA) has created a strategic focus. As
part of this focus, the FHWA has highlighted intersection safety as one of the most significant areas for the reduction of crashes. According to FHWA, in 2002, intersection crashes represented 20% of all traffic fatalities and half of the injuries (1.5 million) observed.

Some studies observe that a large number of intersection crashes are due to human factors. In a study completed by Kansas State University, the researchers report that accidents at two-way stop-controlled intersections are more closely related to driver error, such as failure to accurately judge the speed of major roadway vehicles, than to roadway geometry, or sight distance. Their report does recognize, however, that although driver error is the major contributing factor, geometric design plays a vital role in intersection safety.

Among others, Preston and Storm have conducted research that reached similar conclusions. Their report conducted an analysis of rural two-way stop-controlled intersections in Minnesota. The report found that right-angle crashes accounted for more crashes than any other type. These crashes also represented the most severe crashes. The researchers concluded that many individuals were unable to judge proper gaps. Sight distance was analyzed as part of the report, but was found not to have a significant impact on the frequency of gap-related crashes. This report again suggests human factors are a contributing factor to intersection safety. Recognizing the importance of improper gap selection by drivers will be vital to the correct interpretation of the results presented in this thesis.

Additional research observed that many of the drivers involved in these crashes were local drivers. In a study completed by Solomon, the relationships between factors impacting the accident rates on major rural highways were analyzed. In this report, the researcher found that local drivers tend to have higher crash rates than other drivers. The report also mentions that these drivers typically have higher speeds and accept shorter gaps when maneuvering through an intersection. Solomon does not, however, discuss the effect that roadway features have on these types of crashes.

Other research relates geometric design to the likelihood of driver error. A synthesis completed by the Texas Transportation Institute in 2001 reviews the geometric design
research for improved safety and operations that had been competed since 1990. (6) One section of this report outlined the design of intersections and the common characteristics that lead to an increase in crashes. The report cites median widths, intersection sight distance, and vertical curves as contributing factors to the safety of an intersection. This report completed by the Texas Transportation Institute also cites research regarding the importance of sight distance at stop controlled intersections. This report also expresses concern for drivers’ ability to determine proper gaps before proceeding through an intersection.

A 2002 study conducted by Dewar found that the interaction between a driver and the presence of a geometric feature at an intersection increases improper judgment of gaps. (7) The author writes that a driver’s perception of the road can greatly affect the safety performance of an intersection if additional geometric features of interest are present. The author also reveals that this interaction between a driver’s perception and highway design contributes significantly to problems at intersections.

A 2003 research project completed by Wooldridge, Fitzpatrick, Harwood, Elefteriadou, and Torbic updates intersection design relationships to intersection crash frequency by examining the geometric consistency on high-speed rural two-lane roadways. (8) As part of a telephone survey, the researchers contacted 17 states. Respondents’ views on the geographic features most critical for design consistency purposes were incorporated into the survey results. Respondents were asked to rate geographic features from 1 to 10, 10 being the most influential on design consistency. Table 2.1 shows the average rankings of the features. This study is significant to our study because the characteristics listed in Table 2.1 are viewed as important elements for reducing or increasing the safety performance of an intersection. These rankings assisted the researchers in determining the characteristics that have the most impact on traffic safety.
### Table 2.1 Average score for responding states

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<td>4.2 Presence in general</td>
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<td>4.2 Lane makings (paint, buttons, etc.)</td>
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<td>5.6 Horizontal curve and an intersection</td>
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<td>1.9 Ditch shape</td>
<td>6.5 Vertical curve and an intersection</td>
<td>3.2 Lane marking transitions</td>
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<td>4.8 Superelevation (banking)</td>
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<td>5.5 Vision through curve</td>
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Within this study, the authors cite four sources that examine roadway design characteristics in-depth. In a document completed in 2000, the authors, Harwood, Council, Haur, Hughes,
and Vogt, state that on rural two-lane facilities, horizontal curves where the design speed is less than drivers’ desired speed, have higher crash rates or drivers tend to drive faster than the design speed through the curve. The article concludes that several factors are associated with the increased frequency of crashes on horizontal curves, including restricted sight distance, driver inattentiveness, speed estimation errors, and centerline crossover.

In a 2002 report, Harwood, Antonucci, Neuman, Potts, Kindler, and Wood, also discuss horizontal curvature. In the report, the researchers analyze horizontal curves that resulted in various crash frequencies at intersections. The study observed that crash rates along a curve tend to be higher when an intersection is located before or after a curve, rather than in the center of a curve.

Other reports also relate intersection safety to curve presence and intersection skew. One report by Glennon, Valenta, Thorson, and Azzeh reveals that “the angle at which the two roadways cross greatly impacts the safe operation of the intersection.” Specifically, the authors find that for intersections with large or small crossing angles, the conflict area, turning area, intersection exposure time are all increased while visibility is limited. These findings are related to an increase in crash frequency at skewed intersections.

Each of the projects described above document a descriptive analysis rather than a true statistical relationship. However, in other research, the researchers found clear statistical relationships between vertical curve, horizontal curve, or intersection skew and intersection safety performance. In a study completed by Oregon State University, researchers investigated the statistical relationship between crash activity and roadway design attributes on the Oregon state highway system. Crash models were estimated for highway segments distinguished by functional classification (freeway versus non-freeway) and location (urban versus non-urban). A number of design attributes were found to be statistically related to crash frequency in the various models, including the number of lanes, curve characteristics, vertical grade, surface type, median type, turning lanes, shoulder width, and lane width. The study found that each of these traits is significant in the prediction of crash frequency at an intersection.
Other studies have been completed to examine the statistical significance of curve locations or intersection skews in relationship to intersection safety. A study completed by Karlaftis and Golias in 2002 examines the effect roadway volume and roadway features have on crash rates.\(^{(13)}\) The authors use statistical method known as hierarchical tree-based regression, to examine the relationship between rural road geometric characteristics, crash rates, and their crash model predictions. The results of the study demonstrate the importance of isolating variables differs between two-lane and multilane roads, but geometric design features and pavement condition variables were found to be the two most important factors affecting crash rates on both single-lane and multilane highways.

In a report completed by the Midwest Research Institute, researchers discuss a before-and-after analysis of the safety effects of providing left- and right-turn lanes for at-grade intersections.\(^{(14)}\) The researchers analyzed geometric design, traffic control, traffic volume, and traffic accident data for 280 improved intersections and 300 similar intersections that were not improved during the study period. The types of improvement projects evaluated in the project included the installation of left-turn lanes, right-turn lanes, and extension of the length of existing left- or right-turn lanes. The researchers observed an increased safety performance due to addition of turn lanes. The report also notes the improved safety of a deceleration lane.

In a study conducted in 1999 by Vogt, the researcher observes that the significant variables in the prediction of the crash frequency of an intersection include major and minor road volume, peak major and minor left-turn percentage, peak truck percentage, number of driveways, channelization, intersection median widths, vertical alignment, and, in the case of signalized intersections, the presence or absence of protected left-turn phases.\(^{(15)}\) Curvature or horizontal/vertical alignment was also found to impact crash frequency.
2.3 Safety Performance of Rural Expressway Intersections

Rural expressway intersection research is relatively limited. However, two specific reports completed in the last year provide valuable insight into performance of these routes. In a report completed by Maze, Preston, Storm, Hawkins, and Burchett, the researchers examine a number of rural expressway segments in both Minnesota and Iowa. This paper concludes that the crash rate of an expressway segment increases with the average mainline daily traffic of the route. The research notes that as volume increased, a majority of total crashes involved intersections. The paper calls for improved design and efforts to make these intersections safer.

Maze, Hawkins, and Burchett continued their research on rural expressway intersections in 2004. In the report, the researchers examine 644 rural through-stop-controlled intersections in Iowa. Specifically, the researchers used a database that includes the following:

- Major roadway volume
- Minor roadway volume
- Median width (measurement in feet)
- Presence of left turn lane (yes/no)
- Presence of right turn lane (yes/no)

This database was used to model the crash frequency of an intersection as well as the crash severity. When predicting the crash frequency of an intersection, the researchers observed that minor roadway volume was strongly related to intersection crash frequency, followed by major roadway volume and median width. However, specific characteristics of the turn lanes were not included. This finding supports earlier research stating that drivers often have difficulty in determining proper gaps at rural expressway intersections.

The researchers continued to analyze expressways intersections by examining the ten best-and worst-performing intersections. Of the top ten worst-performing intersections, five are located on horizontal curves, two are located near the base of a vertical curve, and one is a
skewed intersection with no expressway horizontal or vertical curve. This analysis was completed to determine if there are common characteristics that contribute to the poor performance of the intersection by documenting that many high crash intersections are located at intersections where feature of interest are located. As part of the conclusion to the report, the authors describe a need for planners and designers avoid these features during corridor planning and to correct these features during reconstruct rural expressway intersections.

To summarize, many reports discuss the possible impacts geometric characteristics may have on intersections, but few provide clear statistical analysis of the impact of these characteristics. Furthermore, recent research indicates that there may be problems with these geometric features of interest; however, due to project constraints, this research has not been completed and current literature does not properly document the impacts of the geometric features of interest. State transportation agencies need to understand the full implications of their designs to better plan for increased rural expressway volumes and additional miles of expressway. Although sample analyses have been completed, this report will attempt to fill this gap in available literature and document the safety impacts of each geometric feature of interest and land use.
3. RURAL EXPRESSWAY CRASH ANALYSIS

This chapter is divided into five sections. The first section includes a discussion of methods used to create a crash database. This database was used for all analyses reported in this chapter. The second section is a general safety discussion of 200 rural expressway intersections. The third section includes descriptive statistics that explore the crash performance differences of intersection geometric features of interest that are thought to be related to increased crash severity. Next, additional descriptive statistics are created to document land use characteristics found adjacent to rural expressway intersections. The descriptive analysis is used to determine the relationships between safety performance and intersection attributes to guide candidate statistical model specification. The final section in this chapter is an analysis where statistical models were created to better understand how intersection features and land use affect expressway intersection safety.

3.1 Database Development

A GIS-based rural expressway database was created to allow for easy access to crash information. Records from the following five databases were combined to create the expressway database:

- Iowa DOT Roadway Inventory Database
- Iowa video log imagery
- Iowa Department of Natural Resources color infrared imagery
- Iowa Department of Natural Resources land coverage imagery
- Iowa DOT crash record database (Accident Location and Analysis System—ALAS)

For the analysis, the research team analyzed at-grade, two-way, stop-controlled expressway intersections. All of the analyzed intersections shared the following criteria:

- Located on a multi-lane, non-interstate divided facility
- Partially access-controlled
- Two-way stop-controlled
The Iowa DOT Roadway Inventory Database was used to locate all expressway segments within Iowa. Once these segments were located, the Accident Location and Analysis System was used to identify all intersections along the routes. These intersection points were then validated through visual inspection of infrared imagery and video log imagery. Due to the age of the database, a number of intersection points were added or deleted based on this visual inspection to increase the accuracy of our database. After the intersection point database was completed, crash information was added through the crash record database using a buffer radius of 150 feet. Crash records are included from 1996 to 2000. This 5-year period was selected to ensure consistency with other expressway intersection research completed in Iowa by Maze, Hawkins, and Burchett.(1)

For this project, additional information was required to maintain the accuracy of the database. Additional visual inspection of aerial photography and the Iowa DOT’s roadway inventory and personal observations of intersections were required to populate the database with additional data regarding features of the intersection such as the skew between the expressway and the intersecting roadway, horizontal curve locations, vertical curve locations, and the land use adjacent to the intersection. This information was added to the over 100 other attributes already contained in the expressway database.

Specifically, the features of interest locations were determined through a similar use of the Iowa DOT roadway inventory database and the Iowa Department of Natural Resources color infrared imagery. Intersection skew was determined through the use of infrared imagery and roadway inventory projections. Using the measurement tools in ArcMap we determined the intersections to be perpendicular to the major roadway or skewed. This information was then validated through the infrared imagery. Skewed intersections observed a less then eighty-five degree interior angle between the minor roadway and the major roadway. Horizontal curve locations were located in a similar fashion. The curves were measured in ArcMap using degree of curvature per one-hundred feet of highway. The minimum allowable curvature was 1.5 degrees. Vertical curves were determined through a contour land coverage map. Any intersection located on a vertical curve greater than or equal to four percent was added to the
database. Last, land use was determined through infrared photography. The land use selection process is further discussed as part of the land use descriptive analysis.

In total, the original database included 644 expressway intersections. Between 1996 and 2000, 327 of those intersections observed crashes. An initial query of the database allowed the creation of an intersection severity index for each intersection. This is a simple index that was that Maze, Hawkins, and Burchett found to work well in the analysis of safety performance of expressway intersections (1)

- Fatal injury crash = 5
- Major injury crash = 4
- Minor injury crash = 3
- Possible injury crash = 2
- Property damage-only crash = 1

Through the use of this severity index a severity crash rate was created. From this severity crash rate the 100 highest and 100 lowest severity intersections were selected from the 327 intersections that had experienced a crash during the five year study period. This set of 200 rural expressway intersections is the subject of all analyses reposted in this chapter.

3.2 Descriptive Analysis of 200 Rural Expressway Intersections

Maze, Hawkins, and Burchett observed that crash rates on rural expressways increase with increasing mainline volumes.(1) The researchers also observed that crash severity increases with increasing minor roadway volume. To determine how the 200 selected intersections rank, an analysis of crash, severity, and fatality rates was completed. The rates were calculated using million entering vehicles for crash rate and severity rate, while 100 million entering vehicles was used for the fatality rate.

Figure 3.1 compares the high and low severity intersections to the average Iowa expressway intersection rates. Observe that the two datasets are the high and low cases, rather than the averages. It is our assumption that a comparison of the attributes of the well and poorly
performing intersections will allow for the isolation of characteristics that result in good and poor safety performance. The overwhelming difference in crash rate, although related to higher intersection volumes, also exhibits the need to better understand the hazards associated with rural expressway intersections to improve the safety of these intersections.

Figure 3.1 Crash, severity index, and fatality rate comparison

3.3 Geometric Features Descriptive Analysis

By using the database created, we examined the effects that geometric features of interest have on expressway safety performance. As discussed above, horizontal curve, vertical curve, and intersection skew were all added to the database. Due to limited resources, the information was introduced into the database through feature presence: if the intersection was located on a curve or the intersection was not perpendicular to the expressway route, a
presence variable was added to the database. This method allowed us to observe characteristics specific to each type of intersection.

The intersections were divided into four types: intersections located on a vertical curve, intersections located on a horizontal curve, intersections with non-perpendicular minor legs (skewed intersections), and intersections on a tangent. Some intersections included multiple geometric features of interest, so Figure 3.2 includes totals larger than our dataset. The resultant possible interaction between variables will be documented as part of the statistical analysis. Figure 3.2 describes the count of each intersection type observed at both high and low severity intersections. Notice that half of the low-severity intersections lie on a tangent, where the most frequent high-severity intersections are at skewed intersections.

![Figure 3.2 Intersection type distribution](image-url)
Figure 3.3 shows the average crash rates observed for each geometric feature of interest at high-severity index locations. Notice that all of the intersections have similar crash rates, but that severity and fatality rates increase on vertical, horizontal, and skewed locations when compared to tangent intersections. Intersections on horizontal curves and skewed intersections have a much higher fatality rate than vertical curve locations.

<table>
<thead>
<tr>
<th>Collision Rate</th>
<th>Crash Rate (per MEV)</th>
<th>Severity Rate (per MEV)</th>
<th>Fatality Rate (per HMEV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Curve</td>
<td>0.53</td>
<td>1.54</td>
<td>2.20</td>
</tr>
<tr>
<td>Horizontal Curve</td>
<td>0.61</td>
<td>1.63</td>
<td>2.17</td>
</tr>
<tr>
<td>Skewed Intersection</td>
<td>0.60</td>
<td>1.84</td>
<td></td>
</tr>
<tr>
<td>Tangent Intersection</td>
<td>0.54</td>
<td>1.42</td>
<td>1.47</td>
</tr>
</tbody>
</table>

**Figure 3.3 High-severity geometric location crash, severity, and fatality rates**

The results of an identical analysis of the low-severity index locations is presented in Figure 3.4. Again, observe that skewed intersections tend to affect crash severity more than the other features. Based on the information at low-severity locations, horizontal curve and skewed intersections seem to create the most severe crashes. It is important to note that the low-severity intersections observe a much lower range in total crashes than that observed at the high-severity locations.
Additional analysis was completed to determine the effects that geometric features of interest have on intersection safety. Specifically, an analysis of crash type was completed to discover any trends that might relate to an increase in severity or fatality rates shown in Figures 3.2 and 3.3. To remain consistent with previous research, the crash types were grouped for easy comparison. The 16 crash types represented in the Iowa DOT database were grouped into 4 crash types: head-on, right-angle, rear-end, and sideswipe, as defined in Table 3.1.
Table 3.1 Crash type conversion

<table>
<thead>
<tr>
<th>Original crash type</th>
<th>Aggregated crash type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head-on</td>
<td>Head-on</td>
</tr>
<tr>
<td>Sideswipe/right-turn</td>
<td>Sideswipe</td>
</tr>
<tr>
<td>Sideswipe left-turn</td>
<td>Sideswipe</td>
</tr>
<tr>
<td>Sideswipe/dual left-turn</td>
<td>Sideswipe</td>
</tr>
<tr>
<td>Sideswipe/dual right-turn</td>
<td>Sideswipe</td>
</tr>
<tr>
<td>Sideswipe/both left-turning</td>
<td>Sideswipe</td>
</tr>
<tr>
<td>Sideswipe/opposite direction</td>
<td>Sideswipe</td>
</tr>
<tr>
<td>Sideswipe/same direction</td>
<td>Sideswipe</td>
</tr>
<tr>
<td>Broadside/right-angle</td>
<td>Right-angle</td>
</tr>
<tr>
<td>Broadside/right-entering</td>
<td>Right-angle</td>
</tr>
<tr>
<td>Broadside/left-entering</td>
<td>Right-angle</td>
</tr>
<tr>
<td>Broadside/left-turn</td>
<td>Right-angle</td>
</tr>
<tr>
<td>Rear-end</td>
<td>Rear-end</td>
</tr>
<tr>
<td>Rear-end/right-turn</td>
<td>Rear-end</td>
</tr>
<tr>
<td>Rear-end/left turn</td>
<td>Rear-end</td>
</tr>
<tr>
<td>Other</td>
<td>Other</td>
</tr>
</tbody>
</table>

Figures 3.5 and 3.6 represent the crash distributions at high- and low-severity index intersections. Observe that almost 60% of the crashes occurring at both high- and low-severity intersections are right-angle when a geometric feature of interest is present. These right-angled crashes may account for the increased severity rate observed in Figure 3.3 and 3.4. The tangent routes observe 25% fewer right-angle crashes than other geometric features of interest. Tangent intersections experience a higher percentage of rear-end or other types of crashes. In this case, “other” crashes are assumed to be single vehicle or fixed-object crashes.
Figure 3.5 High-severity intersection crash type

Figure 3.6 Low-severity intersection crash type
To complete the descriptive analysis of the geometric features, we examined the type of injury accident associated with each type of intersection. In Figure 3.7 and 3.8, we observe the percentage of injury type observed at the intersections. At high-severity index locations, more minor and major injury crashes occur where geometric features of interest are present rather than at the tangent locations. However, at low-severity index locations, this does not remain true. Although the crash type percentages for the tangent intersections remain somewhat consistent, the remaining intersection types do not. Further analysis shows that low-severity index intersections have a relatively low number of accidents and the crash rate is 0.09 per million entering vehicles. Through continued examination, we assume that a combination of increased volume and the presence of a geometric hazard would increase the crash severity.

![Figure 3.7 High-severity intersection injury distribution](image-url)
Both the increased right-angle crashes and high crash severity indicate the reduced safety performance created by geometric features of interest. It would appear from this descriptive analysis that intersection skew and horizontal curve may reduce the intersection safety performance the most. These features are further examined in the statistical analysis completed in Chapter 4.

3.4 Land Use Descriptive Analysis

In this section, we will analyze the effect of land use presence in relation to expressway intersection safety. Specifically, we looked at three different types of land use: agricultural, commercial, and residential. This analysis was completed using two methods: the first was to determine the percentage of land covered by each land use within one mile of each expressway intersection. The second was to determine the presence of each land use type
within one mile of the expressway intersection. It was observed that most intersections were mainly rural or urban, not a mix. Therefore, the land use percentage of each intersection was relatively constant. This means that intersections located near an area of commercial land use were bordered by large commercial developments, including gas stations, box retail stores, and fast food restaurants. To demonstrate the dominance of a single land use, an example of each land use type is included in Figures 3.9, 3.10, and 3.11. In Figure 3.9 we observe regional farm land and no development. Notice the “big box” retail development in the commercial land use of Figure 3.10 and the medium density residential development in Figure 3.11. The clear clustering of the land uses made the discrimination of the predominate land use surrounding an intersection easy. Land use dictates trip generation and in this case acts as a proxy for peaking of traffic volumes. It is expected that volume from residential developments should result in the greatest peaking characteristics during the morning and afternoon commuting times while traffic volumes near commercial land use will be less peaked, no peaking is expected around agricultural land use.

Figure 3.9 Agricultural land use example on US 218
Figure 3.10 Commercial land use example on US 20

Figure 3.11 Residential land use example on US 61
Figure 3.12 shows the distribution of land use types among the intersections. Notice that a majority of the low-severity intersections are bordered by agricultural land use, whereas the high-severity locations are bordered by residential or commercial land uses.

After examining the raw distribution of data, a descriptive analysis is then conducted to examine the crash rates for both the high and low severity index locations. The crash rate, crash severity rate, and fatality rates are shown for all groups in Figures 3.13 and 3.14. For the high severity intersection, the fatal crash rate for residential land use is 76 percent higher than the rate for the agricultural land use and 30 percent higher than the fatal crash rate for commercial land use.
Figure 3.13 High-severity intersection land use rates

Figure 3.14 Low-severity intersection land use rates
Additional analysis was completed in an attempt to discover a trend associated with land use. As shown in Figures 3.15 and 3.16, the crash type remains relatively uniform between the three land uses. Again, no clear pattern differentiates the land uses. Upon further analysis, it was observed that although many of our 200 intersections may be in rural areas, these routes still observe a relatively high traffic volume. A number of these intersections are county highways or major collectors within the region and volume is not included as a variable in this analysis. Although the descriptive statistics do not demonstrate a clear intersection safety trend, further documentation through statistical analysis may reveal a trend.

Figure 3.15 High-severity intersection land use crash type
3.5 Statistical Analysis of Land Use and Features of Interest

This section documents a statistical analysis where safety performance functions are estimated for our set of expressway intersections. Specifically, all 200 intersections were included in the analysis. The statistical analysis was completed using the software package LIMDEP version 7.0. This program allows the estimation of negative binomial models. Typically crash data are over-dispersed (e.g. variance of the dependant variable (crash frequency) is greater than its mean). Over-dispersion within the dataset is a problem for Poisson Regression, which is also commonly used to model count data, but not a problem for negative binomial regression. Crash frequency and crash severity index were both tested to determine the “best” model. The crash severity index was created using a simple index ranging from 1 (property damage only) to 5 (a fatal injury crash). This index was used to remain consistent with previous research. Both crash frequency and crash severity were based on a five year average from 1996 to 2000.
Features of Interest Statistical Analysis

As determined in previous research, both major and minor roadway volumes have strong statistical relationships to crash frequency and severity. Therefore, our analysis includes both major and minor roadway volumes to better determine the safety performance function of the 200 intersections. Below each equation or model in this report, a Rho-squared value was calculated to determine the "goodness-of-fit" of the model. Similar to an R-squared value, the Rho-squared value ranges from 0.0 to 1.0 and measures the model’s ability to account for the variance in the dependent variable. The closer the value is to 1.0, the better the model represents the dataset. Also included in each equation is the statistical significance of the parameter estimate. This is known as the P-value and can be observed in parentheses below each variable.

The first analysis completed was an examination of the effects of a vertical curve on expressway intersections. Both the crash frequency and severity index were tested through a dummy variable (0 or 1). In Equation 1 we observe the Crash frequency model where in Equation 2, we observe the crash severity prediction model. Notice that the Rho-squared value is much higher for the crash severity index equation. Also observe that the vertical curve variable is more significant in Equation 2. It is evident through the significance of the variable that vertical curve is significant in predicting the intersection crash severity index. However, the parameter estimate for the major roadway ADT is only significant at the 13 percent level. Furthermore, these equations demonstrate how intersection severity and crash frequency increase exponentially based on the exponential equation.

\[
\text{Crash Freq} = e^{(0.9759 + (0.00004\times\text{Major ADT}) + (0.0002\times\text{Minor ADT}) + (0.5125\times\text{Vertical}))} \tag{1}
\]

\[
\text{Crash Sev} = e^{(2.1735 + (0.00003\times\text{Major ADT}) + (0.0002\times\text{Minor ADT}) + (0.6693\times\text{Vertical}))} \tag{2}
\]

Rho-Squared Value = 0.324

Rho-Squared Value = 0.606
The next analysis examined the presence of horizontal curves. Again two models for crash frequency and severity index are estimated. Observe that the presence of a horizontal curve is significant in increasing both crash frequency and crash severity. It is again evident that the crash severity index generates a better model. However, notice that the presence of a horizontal curve does not increase crash severity as much as the presence of a vertical curve. This is demonstrated by values of the parameter estimates for the vertical curve variable being greater in equations 1 and 2 than the horizontal curve variable in equations 3 and 4. This trend was also observed in our descriptive analysis. However, in equation 4, the estimates for the parameters of the major roadway ADT and the horizontal curvature variable have low statistical significance.

\[
\text{Crash Freq} = e^{(1.023 + (0.00004 \times \text{Major ADT}) + (0.0002 \times \text{Minor ADT}) + (0.2822 \times \text{Horizontal}))}
\]

\text{Rho-Squared Value} = 0.324

\[
\text{Crash Sev} = e^{(2.2536 + (0.00002 \times \text{Major ADT}) + (0.0002 \times \text{Minor ADT}) + (0.2218 \times \text{Horizontal}))}
\]

\text{Rho-Squared Value} = 0.617

The following analysis was created to model the effect of intersection skew on expressway crash frequency and crash severity. In equations 5 and 6 it can be observed that skew is significant in predicting crash frequency and crash severity index. Notice that Intersection Skew demonstrates a larger coefficient or impact than horizontal curve. Also, observe that the severity index model continues to be the model which offers the best fit. It is clear that each of these features determine the severity of the expressway intersection, however, the statistical relationship with horizontal curvature is much weaker than the others.
Crash Freq = $e^{(0.9271 + (0.00003 \times \text{Major ADT}) + (0.00002 \times \text{Minor ADT}) + (0.4645 \times \text{Int Angle}))}$ (5)

Rho-Squared Value = 0.340

Crash Sev = $e^{(2.1553 + (0.00002 \times \text{Major ADT}) + (0.00002 \times \text{Minor ADT}) + (0.5412 \times \text{Int Angle}))}$ (6)

Rho-Squared Value = 0.611

After the completion of the individual analysis a "best model" was created. It was determined that vertical curvature and intersection skew have a statistically significant relationship with the crash severity index. Although earlier models predicting crash frequency were acceptable, it was determined through the Rho-squared values that features of interest improved prediction quality of the crash severity model. Also a model was estimated with the horizontal curvature variable, however this variable did not provide a statistically significant parameter estimate. After further analysis of the data it appears that horizontal curve locations tend to include a more dispersed set of collisions and will need to be further analyzed as part of the sample analysis in Chapter 4. In Equation 7 we observe the best fit model for roadway geometric features of interest. Again this model demonstrates the significance that both intersection skew and vertical curve location have on crash severity, although major roadway ADT is not statistically significant. The Rho-Squared value of 0.619 demonstrates a more than acceptable goodness-of-fit for this type of analysis.

$C_{\text{Sev}} = e^{(2.137 + (0.00021 \times \text{Minor ADT}) + (0.5951 \times \text{Int Angle}) + (0.7069 \times \text{Vertical}))}$ (7)

Rho-Squared Value = 0.619

**Land Use Statistical Analysis**

Next a statistical analysis of land use was completed. Again crash frequency and crash severity are examined using the same processes used for equations 1 - 7. However, unlike
the intersections features of interest, the land use variables are mutually exclusive (two of the three dummy variable are known, the third has been identified) all three dummy variables can not appear in a regression equation simultaneously. An initial analysis was completed for each type of land use individually to determine the specific nature of the statistical relationship for each. The first analysis completed was for agricultural land. Although these intersections are located in rural areas, some roadways observe high roadway volumes. Typically these routes are county highways or paved collectors. Both equation 8 and 9 demonstrate that intersections enclosed by agricultural land use decreases the crash frequency and severity of the intersection. In both equations the agriculture variable’s parameter estimate is statistically significant and negative. It is possible that the lack of peaking in traffic volumes tends to reduce crash frequency and crash severity rate. Although the Rho-squared value for crash frequency is relatively low.

\[
\text{Crash Freq} = e^{(1.5926 + (0.00002*\text{Major ADT}) + (0.0002*\text{Minor ADT}) - (0.9141*\text{Agricultural}))}
\]

\[
\text{Rho-Squared Value} = 0.281
\]

\[
\text{Crash Sev} = e^{(2.7774 + (0.00002*\text{Major ADT}) + (0.0001*\text{Minor ADT}) - (0.9850*\text{Agricultural}))}
\]

\[
\text{Rho-Squared Value} = 0.566
\]

Next a statistical analysis of the commercial land use variable was completed using both crash severity and crash frequency models. In equations 10 and 11 it is observed that the commercial land use variable has a statistically significantly parameter positive estimate for both frequency and severity. It is assumed that intersections located near a commercial center would present relatively high crash severities. Although not clear through the descriptive statistics in the earlier section, the significance is apparent through these models.
An analysis of residential land use through statistical modeling is illustrated in equations 12 and 13. This group of intersections is commonly located outside of urban areas. A large number of intersections were bordered by small developments that were located five to ten miles outside of an urban center. It is assumed that these areas would observe more crashes during peak hours and be statistically significant in predicting crash frequency and severity index. In Equation 12 and 13 it is observed that residential land use has statistically significant parameter estimates for frequency and severity models. It is also interesting to note that regression parameter for major roadway volume is again statistically significant. The Rho-Value for the severity index model continues to demonstrate that land use is a better predictor of crash severity than crash frequency.
Again a “best fit” model was created to determine the most precise prediction model for crashes at expressway intersections. Since the residential and commercial variables were positively and strongly related to crash severity, it was decided to leave them in the model rather than including agricultural land use. In Equation 14, observe the significance of commercial and residential land use variables. Also observe that we again have a relatively high Rho-squared value of 0.639. This prediction model demonstrates the correlation between land use and expressway collisions.

\[
C_{Sev} = e^{(1.8768 + (0.00016*\text{Minor ADT}) + (0.7601*\text{Comm}) + (0.7471*\text{Res}))} \\
Rho-Squared Value = 0.639
\]

To complete the statistical analysis, a combined model or final model was created to incorporate both the geometric variables and land use variables. Both horizontal curve and agricultural land use were again removed from the prediction model. In Equation 15, note that the parameter estimate for the major roadway volume is not statistically significant and thus major roadway volume is dropped. The final model is observed in Equation 16. All parameter estimates are statistically significant and Rho-squared value is very high for an analysis of this type.

\[
CS = e^{(1.683 + (0.000008*\text{M1}) + (0.0002*\text{M2}) + (0.5872*\text{S}) + (0.5993*\text{V}) + (0.7634*\text{C}) + (0.5926*\text{R}))} \\
Rho-Squared Value = 0.545
\]

Where:
- \( CS = \text{Crash Severity} \)
- \( M1 = \text{Major Roadway ADT} \)
- \( M2 = \text{Minor Roadway ADT} \)
- \( S = \text{Intersection Skewed (0 or 1)} \)
- \( V = \text{Presence of a vertical curve (0 or 1)} \)
- \( C = \text{Predominately commercial land use (0 or 1)} \)
- \( R = \text{Predominately residential land use (0 or 1)} \)
To conclude this chapter it is clear that land use and geometric features of interest play a significant role in expressway intersection safety performance. Specifically, the proportion of right angle collisions that occur on vertical curves and at skewed intersections increases result in more severe crashes. Also, the significance that each variable demonstrated in the Safety Performance Functions explains the need for intersection planning at expressway intersections. It would also appear that in the design of these routes, intersection skew may have been overlooked as a safety problem and this could have been easily remedied during the corridor planning when additional right-of-way could have been purchased to remove the intersection skew.

4. RURAL EXPRESSWAY SAMPLE ANALYSIS

Through observations made in the descriptive and statistical analysis, it was evident that additional research was needed to better analyze the effects of both geometric features of interest and land use variables on expressway intersections. A sample set of the 30 worst intersections was selected to obtain additional crash and volume information. We visited each of the 30 intersections or “sample set” to collect specific land use and geometric features of interest information. These data were then used in a crash analysis to determine additional key factors effecting expressway intersections.

4.1 Hourly Volume Analysis

Through the analysis of the land use, it was observed that a more detailed analysis of hourly volumes was needed to determine the true effects of roadway volume peaking. From the Iowa DOT, hourly volumes were obtained for the sample set intersections. These roadway volumes are documented each summer on one-third of Iowa’s primary road network. Each count was taken for 24 hours on a Tuesday, Wednesday, or Thursday. These volumes were then used to determine the morning and evening peak hours. On average, the morning peak
occurred between 6am and 9am, while the evening peak volumes occur between 4pm and 7pm. Once the peak hour was determined for each intersection, crash information was extracted from the expressway intersection database. It was found that these intersections observed a similar trend in crash rates and distribution as observed in our Chapter 3 analyses. The crashes at each intersection were then calculated for a peak hour crash percentage versus an off-peak hour crash percentage. It was determined that 51.75% of the accidents at the sample set intersections occurred during the peak volumes. These peak volumes averaged 45.20% of the total daily traffic volume. This demonstrates that during the highest volumes of the day, the crash rates of the intersection peak. Although this is a sample of the larger set of intersections, it is speculated that this peaking again demonstrates the significance of land use and roadway volumes on the safety performance of expressway intersections.

4.2 Near-Side vs. Far-Side Crashes

Through the INTERSECTION MAGIC version 6.60 software package, each of the sample set intersections was analyzed to determine if the crash occurred on the near-side of the expressway to the minor approach or the far-side of the expressway. Crashes were grouped into three categories: near-side, far-side, and other crashes. The “other” category is limited to single-vehicle, rear-end, or fixed-object crashes. Due to the limitation of the available data, only information from 1996 to 1999 was used; however, 4 years of data should be sufficient to minimize the impact of random spikes in crash activity. Figure 4.1 demonstrates the location of the far-side and near-side collisions at a three approach expressway intersection.
In Figure 4.2, we observe the average of all sample set intersections. Notice that almost 50% of the total crashes that occurred at these 30 intersections were far-side crashes. Also, observe that there are a high number of “other” crashes in comparison to near-side crashes.

Figure 4.1 Near-Side / Far-Side Demonstration

Figure 4.2 Sample set intersection near-side vs. far-side crash distribution
As discussed in Chapter 3, horizontal curve intersections seem to perform differently than vertical or skewed intersections and an analysis of these intersections was completed to determine possible differences within the data. Out of the 30 intersections researched, 7 were located on horizontal curve. None of the 7 intersections were located near major commercial or residential development, but were typically part of a bypass. These horizontal curves were measured at 3 degrees or more of curvature per 100 feet of expressway. In each case, the intersections were 4-legged, but presented a higher volume on one of the minor legs. An analysis of these 7 intersections was completed to determine the possible difference in the intersections. In Figure 4.3, we observe that horizontal curves are equal rather than presenting a high far-side crash percentage. Rather, the distribution is relatively constant. Also notice that when horizontal curve locations are removed from the remaining intersections, the far-side crash percentage increases.

![Figure 4.3 Far-side vs. near-side comparison of horizontal curve intersections](image-url)
Further examination of the horizontal curve locations shows that over 60% of the crashes occur on the intersection leg with the highest volume. The lower volume minor roadway had 25% of the volume typically observed on the remaining minor leg. Each of the 7 horizontal curve locations were similar in design and location. From these observations, it is clear that horizontal curves create a unique hazard for drivers and expressway designers. These curves are located throughout the state and are typically found on bypasses around cites, but not all include access-controlled intersections. Although this is a small percentage of the total intersections in the state, it is clear that they are unique in that they do not follow the trends of other intersection geometric features.

This sample analysis of 30 intersections demonstrates the added influence of geometric features and land use on crashes at expressway intersections. Although a small sample was used, this analysis demonstrates a need for further research and determination of key influencing factors of expressway crashes. The clear trends shown in right-angle and far-side crashes demonstrate the predictions calculated through the statistical models. Crash severity at expressway intersections is clearly related to intersection design and surrounding land use.
5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Through this research, we observed that many expressway intersections in Iowa are observing a larger variance in safety performance. It is apparent that intersection features of interest and land use are tied to these raised crash severities. Four important conclusions can be drawn from this research. First, the safety performance of a two-way stop controlled intersection declines when geometric features of interest are present. Second, the safety performance of a two-way stop controlled intersection also declines when commercial or residential land uses are located near the intersection. Third, most accidents associated with two-way stop controlled intersections typically occur on the far side of an intersection. Fourth, intersections located near a horizontal curve observe a decreased safety performance and provide designers and planners with a unique safety concern when compared to other expressway intersection types.

5.2 Recommendations

This research suggests that engineers and planners understanding of two-way stop controlled intersections should continue to improve to allow for pre-construction and intermediate steps to increase the safety of problematic expressway intersections. Specifically, through our analysis of different land uses we were able to demonstrate how traffic peaking and commuter traffic patterns can decrease the safety performance of an intersection. Thus, expressway intersections have performed well at lower speeds (1) and along tangent segments, however, designers and planners should account for changes in land use near intersections as well as changing designs to allow for increased sight distance near an expressway intersection. For instance during the planning and design phase of a new expressway bypass, both planners and designers should attempt to limit horizontal and vertical curvature while constructing intersections with additional turn lanes, larger medians, and controlled access near larger city developments. However, most states will be looking to increase safety along already problematic corridors, therefore intermediate steps will be needed. By purchasing additional right-of-way to correct the skew of an intersection, state
transportation agencies can make an intermediate changes to reduce the rising crash severities at the intersection before implementing strategies such as signalization or the construction of an interchange. Other strategies for planners and designers would include, preventing direct access from large developments along expressway corridors to reduce peaking characteristics. Planners and designers also need to account for the problem that most drivers seems to have in judging gaps in the far lanes, except on horizontal curves, where drivers have equal difficulty judging gaps in both the far-side and near-side lanes. Planners and designers should account for this problem when analyzing possible lane configurations.

The next phase should be to complete additional research leading to the creation of an expressway intersection “handbook” that will provided a practical approach to expressway intersection safety. State transportation agencies now need to construct and evaluate intersection improvements such as additional lanes, or reduction of intersection skew, to provide planners and engineers with a toolbox for future projects. State officials should be equipped with a variety of alternative designs to correct the already failing intersections. Previous research little was known about rural expressway safety. However, through recent articles state agencies can better understand the factors that can cause a problematic intersection. We as professionals need to be able to correct these hazards. Through the consolidation of current research and additional research that would examine locations in the United State other than Iowa, we can further document characteristics that can elevate the relationships that may cause crashes. Through the creation of a detailed handbook these conditions can be avoided during corridor planning, while existing problematic conditions can be more proactively addressed by planners and engineers to improve current conditions.
APPENDIX

Below are the Safety Performance Functions created to determine statistical significance of each variable in the prediction of crash frequency or crash severity.

1. Crash Freq = $e^{(0.9759 + (0.00004*\text{Major ADT}) + (0.0002*\text{Minor ADT}) + (0.5125*\text{Vertical}))}$
   Rho-Squared Value = 0.324

2. Crash Sev = $e^{(2.1735 + (0.00003*\text{Major ADT}) + (0.0002*\text{Minor ADT}) + (0.6693*\text{Vertical}))}$
   Rho-Squared Value = 0.606

3. Crash Freq = $e^{(1.023 + (0.00004*\text{Major ADT}) + (0.0002*\text{Minor ADT}) + (0.2822*\text{Horizontal}))}$
   Rho-Squared Value = 0.324

4. Crash Sev = $e^{(2.2536 + (0.00002*\text{Major ADT}) + (0.0002*\text{Minor ADT}) + (0.2218*\text{Horizontal}))}$
   Rho-Squared Value = 0.617

5. Crash Freq = $e^{(0.9271 + (0.00003*\text{Major ADT}) + (0.0002*\text{Minor ADT}) + (0.4645*\text{Int Angle}))}$
   Rho-Squared Value = 0.340

6. Crash Sev = $e^{(2.1553 + (0.00002*\text{Major ADT}) + (0.0002*\text{Minor ADT}) + (0.5412*\text{Int Angle}))}$
   Rho-Squared Value = 0.611
7. $C_{Sev} = e^{(2.137 + (0.00021 \times \text{Minor ADT}) + (0.5951 \times \text{Int Angle}) + (0.7069 \times \text{Vertical})/(0.00001)(0.00001)(0.0051)}$

Rho-Squared Value = 0.619

8. $\text{Crash Freq} = e^{(1.5926 + (0.00002 \times \text{Major ADT}) + (0.0002 \times \text{Minor ADT}) - (0.9141 \times \text{Agricultural})/(0.00001)(0.0589)(0.00001)}$

Rho-Squared Value = 0.281

9. $C_{Sev} = e^{(2.7774 + (0.00002 \times \text{Major ADT}) + (0.0001 \times \text{Minor ADT}) - (0.9850 \times \text{Agricultural})/(0.00001)(0.2275)(0.00001)}$

Rho-Squared Value = 0.566

10. $\text{Crash Freq} = e^{(1.0225 + (0.00002 \times \text{Major ADT}) + (0.0002 \times \text{Minor ADT}) + (0.6688 \times \text{Commercial})/(0.00001)(0.0865)(0.00001)}$

Rho-Squared Value = 0.292

11. $C_{Sev} = e^{(2.2177 + (0.00002 \times \text{Major ADT}) + (0.0002 \times \text{Minor ADT}) + (0.5942 \times \text{Horizontal})/(0.00001)(0.2973)(0.00001)}$

Rho-Squared Value = 0.602

12. $\text{Crash Freq} = e^{(0.7924 + (0.00002 \times \text{Major ADT}) + (0.0002 \times \text{Minor ADT}) + (0.5776 \times \text{Residential})/(0.00001)(0.0039)(0.00001)}$

Rho-Squared Value = 0.323

13. $C_{Sev} = e^{(1.9588 + (0.00002 \times \text{Major ADT}) + (0.0002 \times \text{Minor ADT}) + (0.1433 \times \text{Residential})/(0.00001)(0.0581)(0.00001)}$

Rho-Squared Value = 0.604
14. \[ C_{Sev} = e^{(1.8768 + (0.00002^{*} \text{Major ADT}) + (0.0001^{*} \text{Minor ADT}) + (0.7308^{*} \text{Comm}) + (0.7522^{*} \text{Res}))} \]

Rho-Squared Value = 0.567

15. \[ CS = e^{(1.683 + (0.00008^{*} M1) + (0.0002^{*} M2) + (0.5872^{*} \text{LA}) + (0.5993^{*} V) + (0.7634^{*} C) + (0.5926^{*} R))} \]

Rho-Squared Value = 0.545

16. \[ \text{Cash Sev} = e^{(1.683 + (0.00016^{*} M2) + (0.59910^{*} S) + (0.5988^{*} V) + (0.7762^{*} C) + (0.5896^{*} R))} \]

Rho-Squared Value = 0.558
REFERENCES


4. Preston, H., and R. Storm. “Reducing Crashes at Rural Thru-Stop-Controlled Intersections.” Proceedings of the Mid-Continent Transportation Symposium, Center for Transportation Research and Education, Iowa State University, Ames, Iowa, August 2003, on CD.


