Rural Expressway Intersection Characteristics that Contribute to Reduced Safety Performance

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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 mobility and safety characteristics similar to other access-controlled facilities. However, recent research has found that there are problems with the safety performance of these systems associated with conventional at-grade, median-opening intersections. 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 identify 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. For the 200 intersections, a statistical analysis was completed to determine the effects of intersection design and location has on safety performance. The safety performance of vertical/horizontal curve location, intersection skew, and land use were studied to determine the effects on rural expressway intersections.

Following the completion of the analysis of the 200 intersections, 30 intersections with the 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.

Key words: intersection—rural expressway—safety performance
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. Maze, Hawkins, and Burchett (2004) recently reported that there are problems with the safety performance of these rural expressway systems. The purpose of the present research is to compare and contrast the characteristics of rural expressway intersections that exhibit poor and good safety performance.

Through observations, Maze, Hawkins, and Burchett (2004) concluded that factors other than roadway volume contribute to the safety performance of a rural expressway intersection. Using a limited dataset (10 intersections) they speculated that design features at intersection approaches, including horizontal curves, vertical curves, intersection skew, and land use intensity, increase crash frequency and crash severity. These features will be referred to as intersection features of interest.

To further examine intersection features of interest, a database of expressway intersections was created. This database includes 644 at-grade intersections. From this set of intersections, the 100 intersections with the best safety performance and the 100 intersections with the poorest safety performance were identified for a comparative statistical analysis. After completing the analyses of these 200 intersections, the 30 worst performing intersections were examined in greater depth. Through the intersection analyses, common characteristics were identified that contribute to the safety performance of rural expressway intersections and the authors were able to make recommendations based on the findings.

This paper is organized into four sections. The first section is this introduction. The next section outlines a descriptive and statistical analysis of 200 intersections with an examination of common trends in crash rates and types. Both intersection alignment and land use are examined. The third section includes an analysis of the 30 intersections with the poorest safety performance. More thorough data collection was performed to provide more resolution to the analysis of these 30 intersections. The final section of this paper includes a summary of characteristics that significantly contribute to the reduction in safety performance of expressway intersections. This paper also includes recommendations for the improvement of expressway intersection design and suggestions for future expressway research.

RURAL EXPRESSWAY CRASH ANALYSIS

This section of the paper performs descriptive graphical analysis of the intersection crash database and uses the results of the graphical analysis to support the specification of a statistical model of intersection safety performance.

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

After the intersection 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 five-year period was selected to ensure consistency with other expressway intersection research completed in Iowa by Maze, Hawkins, and Burchett (2004).

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.

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 us to create an intersection severity index for each intersection. The simple severity index below was used:

- 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 crash severity rate was created. From this crash severity rate, the 100 highest and 100 lowest severity intersections were selected from the 327 intersections that had experienced a crash during the study period. This set of 200 rural expressway intersections is the subject of all analyses completed in this section.

**Descriptive Analysis of 200 Rural Expressway Intersections**

Maze, Hawkins, and Burchett observed that crash rates on rural expressways increase with increasing mainline volumes (2004). 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 1 million entering vehicles for crash rate and severity rate, while 100 million entering vehicles was used for the fatality rate.

Figure 1 compares the high- and low-severity intersections to the average Iowa expressway intersection rates. It is assumed that a comparison of the attributes of the good and poor performing intersections will allow the isolation of characteristics that result in good and bad safety performance. The overwhelming difference in crash rate also exhibits the need to better understand the hazards associated with rural expressway intersections to improve the safety of these intersections.
Geometric Features Descriptive Analysis

By using the database, the impacts of geometric features of interest on expressway intersection safety performance were examined. 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, and a dummy variable was added to indicate the presence of a feature: if the intersection was located on a curve or the intersection was not perpendicular to the expressway route, the dummy variable representing each feature was set equal to one, and if the feature was not present, the dummy variable was set to zero. This method allowed an analysis of the intersection safety performance with respect to a feature of interest.

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 2 includes a total larger than the number of intersections in the dataset. Figure 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, whereas a majority of the high-severity intersections have one or more geometric feature(s) of interest.

Figure 3 shows the 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 non-perpendicular intersections have a higher fatality rate than intersections on vertical curves, and intersections on horizontal curves have a fatal crash rate 50% greater than intersections on tangent sections.
Figure 2. Intersection type distribution

Figure 3. High-severity geometric location crash, severity, and fatality rates
The results of an identical analysis for the low-severity index locations are presented in Figure 4. Again, observe that skewed intersections tend to have more severe crashes than intersections with other features.

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 the severity or fatality rates shown in Figures 2 and 3. To remain consistent with previous research, the crash types were grouped into four categories: head-on, right-angle, rear-end, and sideswipe.

Figures 5 and 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 index intersections are right-angle when a geometric feature of interest is present. These right-angled crashes are generally the most severe crashes and account for the increased severity rate observed in Figures 3 and 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 crash types (single vehicle–fixed-object crashes).
Figure 5. High-severity intersection crash type

Figure 6. Low-severity intersection crash type
To complete the descriptive analysis of the geometric features, the type of injury accident associated with each type of intersection was examined. Figure 7 shows the proportion of crashes by severity type for each geometric feature of interest at high-severity intersections. A similar analysis for low-severity intersections was not done because the small number of crashes at these intersections does not provide meaningful information. At high-severity index locations, rather than at the tangent locations, more minor and major injury crashes occur where geometric features of interest are present.

![Figure 7. High-severity intersection injury distribution](image)

Both the increased number of right-angle crashes and higher crash severity indicate the reduced safety performance created by geometric features. It would appear from this descriptive analysis that intersection skew and vertical and horizontal curvature reduce the intersection safety performance when compared to intersections tangent to the expressway.

**Land Use Descriptive Analysis**

In this section, the presence of land use type in relation to expressway intersection safety is examined. Specifically, three types of land use adjacent to the intersection are examined: agricultural, commercial, and residential. To determine the land use adjacent to intersections, aerial photographs of the intersection were used and the percentage of the land cover for each land use within one mile of the intersection was determined. The predominant land use was then indicated as the intersection land use type. Most intersections were surrounded by one type of land use, so discriminating among different land use types was generally not difficult.

Figure 8 shows the distribution of land use types among the intersections. This figure is a raw count. 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.
The crash rate, severity rate, and fatality rate for the high-severity index locations, with respect to land use, are plotted in Figure 9. Because of the low number of crashes, the same graph is not shown for the low severity intersections.
Intersections located adjacent to residential land use have a much higher fatality rate than those adjacent to agricultural land use. The fatality rates for commercial land use and residential land use are 50% and 75% greater than the fatality rates for agricultural land use. This is probably in part due to higher minor roadway volumes in developed areas, but it is speculated that the very high fatality crash rates from residential areas are partly due to the peaking into and out of residential developments as commuters travel to and from work.

**Geometric Features and Land Use Statistical Analysis**

The estimation of safety performance functions (SPF) was completed using the software package *LIMDEP* version 7.0. This program allowed the authors to run a negative binomial model that allows for over-dispersion within the dataset. Over-dispersion is generally evident in crash data. The crash severity index was tested to determine the best model. Each model represents the five-year total crash severity observed at each intersection. The SPF modeling statistically determines the interaction between intersection crash frequency and independent variables (i.e., approach volumes, land uses, and geometric features of interest).

As determined in previous research, both major and minor roadway volumes significantly affect crash frequency and severity. Therefore, the analysis includes both major and minor roadway volumes as independent variables of the SPF. A Rho-squared value was calculated to determine the goodness-of-fit value 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, which can be observed in parentheses below each variable.

Several models with different combinations of the land use and geometric features of interest were estimated, but the best model specification is shown in Equation 1. Horizontal curve and mainline volume were dropped as independent variables due to lack of statistical significance in their parameter estimates. The authors were surprised that horizontal curvature dropped out of the analysis. It is speculated that mainline volume tended to be collinear with intensity of land use and including the land use variable resulted in the mainline volume becoming statistically significant. Remaining in the model are skewed intersections, vertical curvature, and commercial and residential land use. Each of these variables’ parameter estimates are very statistically significant. Also, the high Rho-squared value of 0.558 demonstrates that this model is extremely high for a model of this type.

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

\[
(0.00001)(0.6217)\quad (0.00001)\quad (0.0001)\quad (0.0001)\quad (0.0001)\quad (0.0001)
\]

Rho-Squared Value = 0.558

where
- Minor roadway volume = M2
- Intersection skew = S
- Vertical curve = V
- Commercial land use = C
- Residential land use = R
RURAL EXPRESSWAY ANALYSIS OF 30 WORST PERFORMING INTERSECTIONS

Through observations made in the descriptive and statistical analysis, it was evident that additional research was needed to increase the resolution of this examination of the effects of both geometric features of interest and land use variables on expressway intersection safety performance. A sample set of the 30 intersections with the poorest safety performance was selected and additional information on crash, volume, and intersection geometric features of interest was collected. This involved inspecting each of the 30 intersections to collect specific information on land use and geometric features of interest. These data were then used in a crash analysis to determine impact of these variables on safety performance.

Hourly Volume Analysis

Although residential development serves as proxy for peak volumes, more detailed analysis of hourly volumes was needed to determine the actual impact of peaking on safety performance. With the assistance of the Iowa DOT, hourly volumes were obtained for all 30 intersections. An hourly count was obtained for each of the 30 expressway intersections with a count 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 6 a.m. and 9 a.m., while the evening peak volumes occur between 4 p.m. and 7 p.m. Once the peak hours were determined for each intersection, crash information was extracted from the expressway intersection database. The crashes at each intersection were then calculated for a peak hour crash percentage versus off-peak hour crash percentage. It was determined that 51.75% of the accidents at the sample set intersections occurred during the peak hours. These peak hour volumes averaged 45.20% of the total daily traffic volume, which indicates that average peak morning and afternoon hours experienced more than 20% of the daily traffic. Typical hourly peaking is in the range of 8% to 12% of daily traffic (Texas Transportation Institute). Therefore, the highest crash rate intersections experience extremely high hourly peaking. Although the sample size is limited, this does seem to indicate that peaking is an important variable.

Near-side vs. Far-side Crashes

Through the INTERSECTION MAGIC version 6.60 software package, each intersection in the 30-intersection set was analyzed to determine whether each crash occurred on the near lanes of the expressway to the minor approach or the far lanes 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, four years of data should be sufficient to minimize the impact of random spikes in crash activity.

Figure 10 shows the distribution of near- and far-side crashes for all 30 intersection. Note that almost 50% of the crashes that occurred at the 30 intersections were far-side crashes. The ratio of near-side to far-side crashes is 62% to 38%. A far-side crash indicates the crossing driver misjudged the gap in the far-side lanes.
As discussed earlier in the paper, intersections on horizontal curves seem to perform differently than intersections on vertical curves or skewed intersections, and an analysis of these intersections was completed to determine possible differences within the data. Of the 30 intersections researched, 7 were located on a horizontal curve. All seven intersections were not located near major commercial or residential development, but were typically part of a bypass. These horizontal curves were determined to have 3% of curvature or more per 100 feet of expressway. In each case, the intersections were four-legged, but observed a higher volume on one of the minor legs than on the other. An analysis of these seven intersections was completed to view the possible difference in the intersections. Figure 11 shows that horizontal curves do not observe a roughly equal distribution of far-side or near-side crashes. Also note that when horizontal curve locations are removed from the remaining intersections, the far-side crash percentage increases. This is interpreted to mean that drivers crossing the expressway have difficulty even judging gaps in the near-side lanes. Pulling out in front of vehicles in the near-side lanes may in part explain the elevated fatal crash rate seen in Figure 3.

Further examination of the horizontal curve locations found that over 60% of the crashes occurred nearest to the minor leg intersection approach with the highest volume. The lower volume minor roadway approach observed 25% of the volume typically observed on the remaining minor leg. Each of the seven horizontal curve locations was similar in design and surrounding land use. From these observations, it is clear that horizontal curves create a unique hazard for drivers. These curves are located throughout the state and are typically found on bypasses around cites. 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 demonstrates that added influences of geometric features and land use on safety performance of expressway intersections. Although a small sample, 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.

CONCLUSIONS AND RECOMMENDATIONS

Through this research it was observed that safety performance of expressway intersection varies greatly. Much of the variation in safety performance is explained by minor roadway volumes, but some of the variation can be attributed to the expressway curvature at the intersection, skew of the intersection, and land use surrounding the intersection. These features impact both the crash rate and crash severity. Although only a small set of intersections was examined, it appears that judging gaps in the far lanes is most problematic for drivers, except on horizontal curves, where drivers have equal difficulty judging gaps in both the far-side and near-side lanes.

It is recommended that research to address these issues cover detailed analysis of more intersections at locations in the United States other than Iowa. Although we believe that some intersection attributes elevate crash rates, more research is needed to quantify these relationships. With a better understanding of the most problematic design features of expressway intersections, these conditions can be avoided during corridor planning. For existing expressways, safety engineers can begin to address proactively the intersections with features that tend to make them problematic.
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