TRAFFIC SAFETY ON RURAL EXPRESSWAYS

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ABSTRACT

This report analyses a database created from 644 two-way, stop-controlled intersections on rural Iowa expressway highways. Expressways are divided multi-lane highways with a median. This database included five years of crash data and data relating to the approach traffic volumes and a few geometric features at the intersections. Since the data are from rural intersection, the traffic volumes at many of the intersections are very low and over the five-year period roughly half the intersections experienced no crashes. Our analysis showed that increasing minor roadway volume results in increasing crash rates and increasing crash severity. Increasing minor volumes also resulted in an increasing involvement of right angle crashes. Although we know that major roadway volumes increase the frequency of crashes, increases in minor roadway volume appear to be more highly related to crash rate increases and increased crash severity. When crash experience at rural expressway intersections is compared to crash experience on all rural intersections with a primary roadway (including expressways), the older drivers (drivers 65 years and older) are found to over-represented. When we made comparisons of the type of crashes, right angles crashes at expressway intersections are generally over-represented in most age groups but older drivers are more frequent involved in right angle crashes at all rural intersections but particularly over represented at expressway intersections.

INTRODUCTION

Over the past several years several states have developed expressway systems to improve the connectivity between cities, while promoting economic growth. A number of states have adopted policies for upgrading two lane facilities to four lanes. They are intended to provide a network of high speed/high capacity highways similar to Interstate Highways without the expense of improving all design features to Interstate standards. Overall, the assumption is that expressways provide most of the mobility and safety benefits of Interstate highways but at a lower cost than an interstate. This report plans to focus on a portions of personal research that demonstrate the safety of these facilities.

BACKGROUND

Although design standards will vary from state to state, expressways are defined for our purpose as four-lane, divided facilities with interchanges only at intersections with major highways and all other intersections are at-grade with some signalized intersections. The majority of the expressway intersections have only stop-sign controls on the minor crossing roadway. Access points to the expressway are generally limited and they may or may not have frontage roads, depending on the density of development and the availability of right of way. Although these are generally high-speed facilities, the speed limit is generally set based on local conditions instead of a system-wide standard.

Little literature exists on this topic, however a study conducted in West Virginia looked at older driver's ability to negotiate a stop-controlled intersection at a four lane divided highway. Surprisingly 13.2 percent of the respondents admitted to having made a mistake when turning from the minor roadway on to the expressway and ended up going the wrong way down an expressway lane.

Another project conducted in Nebraska points out six factors that may contribute to crashes at these types of intersections. Five of these factors involve the inability to judge an adequate gap before turning on to the expressway. In addition this study also found that 30 out of 42 responding states were building or have built this type of facility. This report also found that two states have designed new rural expressways that bypass cities as full-access control facilities or that they have built interchanges at all major intersections along the bypass. These policies were adopted because of high crash rates found at high-volume, at grade intersections on expressways already in use.

RURAL EXPRESSWAY CRASH ANALYSIS

After researching this topic it was decided that further research should be completed in this area. Specifically we decided to examine the state of Iowa and its stop-through controlled intersections. The following analysis will clearly demonstrate the procedures completed and the conclusions the data and statistical modeling has lead us to. This initial section outlines the development of a intersection database in which these expressways could be best analyzed.

Database Development

A GIS based intersection database is created to assist in the research of rural expressway intersection safety. Specifically records from five databases were integrated to produce our expressway intersection database, which include:

- Iowa Department of Transportation Roadway Inventory database
- Iowa Department of Transportation Accident Location and Analysis System
- Iowa Video log Imagery
- Iowa Department of Natural Resources Color Infrared Imagery
- Iowa Department of Transportation Crash Record Database

The Iowa Expressway crash database includes 644 rural stop – through intersections that are selected using the following characteristics:

- Intersection is located on a multi-lane, non-interstate divided facility
- Intersection is not access controlled
- Intersection is two-way stop controlled
- Intersection is outside of an incorporated city limit

The Iowa Department of Transportation 2003 Roadway inventory is used to select the roadway segments of interest. These segments are used to insert attributes including traffic volume, median width, and the presents and length of turning bays. Next the Iowa Department of Transportation Accident Location and Analysis System is used to add historic intersection location points. The intersection selection is completed following a visual inspection of the 2002 - 2003 Iowa Video log imagery and the 2002 Iowa Department of Natural Resources Color Infrared imagery to verify intersection locations. Once the intersections of interest are identified the Iowa Department of Transportation Crash Record Database is added to examine collision attributes. Due to the accuracy of the cartography, crashes were selected using a fifty meter buffer area around each intersection. These crashes were then visually inspected using the attributes found inside each crash record to add or remove inaccurate queries (e.g. Crash location = intersection). Overall the database includes over one hundred different attributes for the use of the investigator.

Overall five years of data was used to minimize the impacts random spikes in crash activity or inactivity that occur during a single years. The most recent data available to us through the Iowa DOT was for the year 2000 and therefore the first year of our analysis period is 1996.

Descriptive Analysis of Crash Rate of Rural Expressway Intersections

Past research has observed that crash rates on expressways increase with increasing volumes. Therefore, as a first step in the analysis of the crashes at expressway intersection crash rates were calculated per million entering vehicles for increasing volumes. Since the majority of these intersections are rural intersections with very low volumes, many experienced very, very low crash frequencies. The mean crash rate is 0.16 crashes per million entering vehicles (MEV) for all 644 intersections and the median crash rate is 0.068 crashes per MEV. If we took into account all rural and urban two-way stop-controlled intersections, we would find a crash rate closer to 0.4 crashes per MEV as observed in a study of Minnesota expressways. The low median crash rate in Iowa's rural expressway intersection database indicates the skew of the data towards low volume intersections.

In Figure 1 we have graphed average crash rate, crash severity rate (a system where the crash severity index for the intersection is divided by the Millions of Entering Vehicles per year), and fatal crash rates for all intersections and summarized by increasing minor roadway volume. To rank severity a fairly simple system was used - fatal crashes have a weight of 5, major injury crash have a weight of 4, minor injury crash have a weight of 3, possible injury / unknown crashes have a weight of 2, and property damage only crashes have a weight of 1.

It was expected the average crash rate and crash rate severity to increase as the minor roadway volume increases. In other words, as crossing traffic volumes increase the crash rate increases and crashes become more sever. The fatality rate is calculated using Hundred Million Entering Vehicles (HMEV) and the fatality rate also increases as minor roadway volume increases. Because each of these rates increases across increasing minor roadway volumes, the safety performance of the intersection declines as traffic volumes increase. Our pattern of increasing crash severity and decreasing crash fatality rates is similar to what was found in a companion analysis of Minnesota rural, stop through intersections. In Minnesota they also found higher volume intersections had more severe crashes.

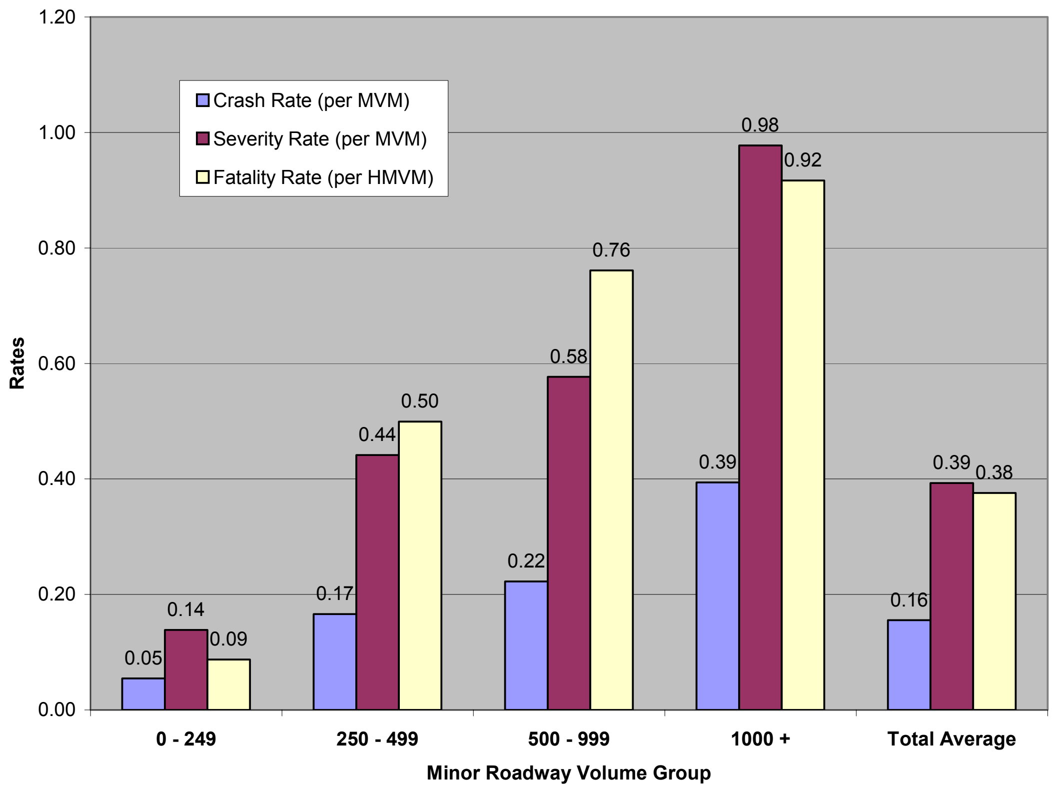

Figure 1 Crash, Severity, and Fatality Rates of Rural Expressways by Minor Roadway Volume

* Data represents averages for the five-year period from 1996-2000. Minor Roadway volume represents the average ADT volume of all entering minor routes.

Crash Type

In the Iowa crash reports used by reporting officers during the period of our data collection provide 16 different types of intersection crash types to choice from plus the officer could decide to not to check a crash type and the type became unknown. For our purposes desegregating crash types to 16 types was too fine and we wished to reduce this to a few (four) crash types. The following bullets demonstrate how these types were combined into four crash types, head on, right angle, rear end, and sideswipe.

Original Crash Type	**Aggregated Crash Type**
Head On	Head On
Sideswipe/Right Turn	Right Angle
Sideswipe Left Turn	Right Angle
Sideswipe/Dual Left Turn	Right Angle
Sideswipe/Dual Right Turn	Right Angle
Broadside/Right Angle	Right Angle
Broadside/Right Entering	Right Angle
Broadside/Left Entering	Right Angle
Broadside/Left Turn	Right Angle
Sideswipe/Both Left Turning	Right Angle
Rear End	Rear End
Rear End/Right Turn	Rear End
Rear End/Left Turn	Rear End
Sideswipe/Opposite Direction	Rear End
Sideswipe/Same Direction	Rear End
Other	Other

Figure 2 and 3 present graphs of the frequency of crash types grouped by increasing minor and major roadway volumes. Figure 2 divides the intersection by their minor roadway volume and Figure 3 divides crashes by major roadway volume. We had expected that as volumes increase we would see increasing right angle crashes. Right angle crashes are generally as a result of a driver failing to select an appropriate gap. In Figure 2 we can observe that right angle crashes increase at minor roadway volumes increase. In Figure 3 we observe no increase in right angle crashes with increasing major roadway traffic volumes. Because right angle crashes are likely to be more sever, we believe that increasing minor roadway volumes results increasing crash severity, as seen in Figure 1.

We believe that we are observing two phenomena that are causing right angle crashes. One is that there is more opportunity to have more right angle crashes when the minor volume higher and the second reason is that drivers are more frequently accepting unsafe gaps when there is more traffic (and maybe even congestion) on minor roadway approaches. In earlier research we see that increasing major road volumes result in increased crash frequency. The analysis here shows (Figure 1 and 2) that minor roadway volumes result in increasing crash severity and increasing crash rates. More specifically, increasing crash frequency seems to be related to major roadway volumes and increasing crash rate and crash severity seems to be related to minor roadway volume.

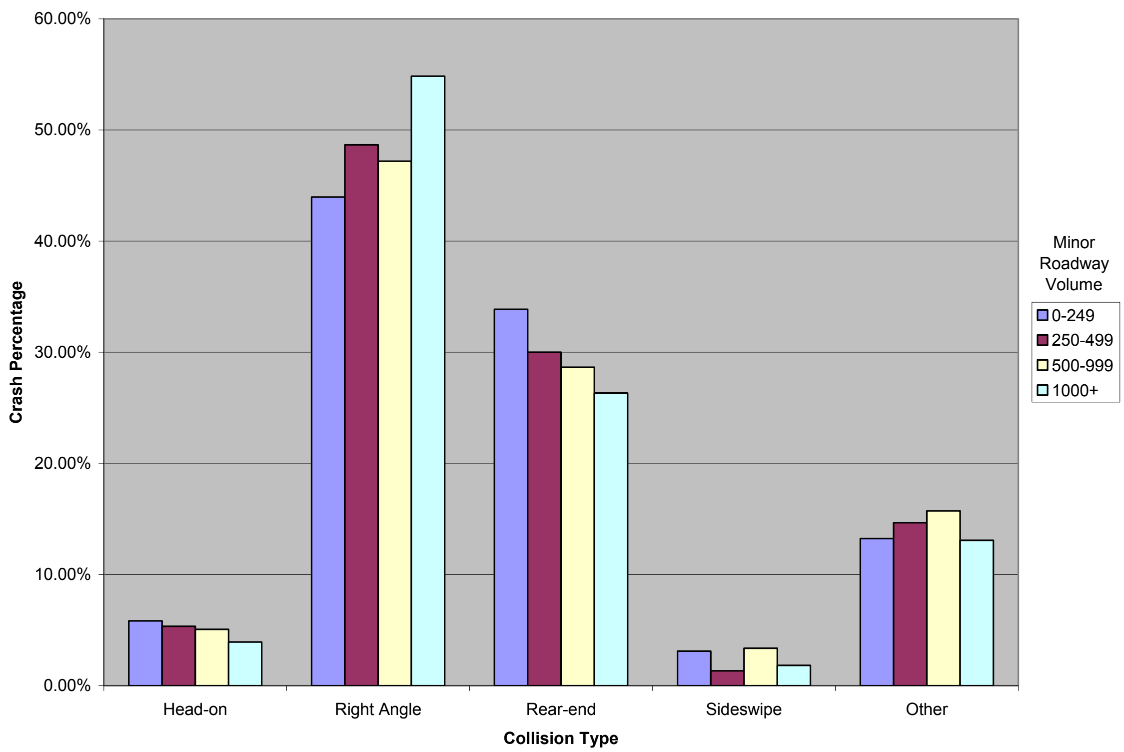

Figure 2 Crash Type by Minor Roadway Volume

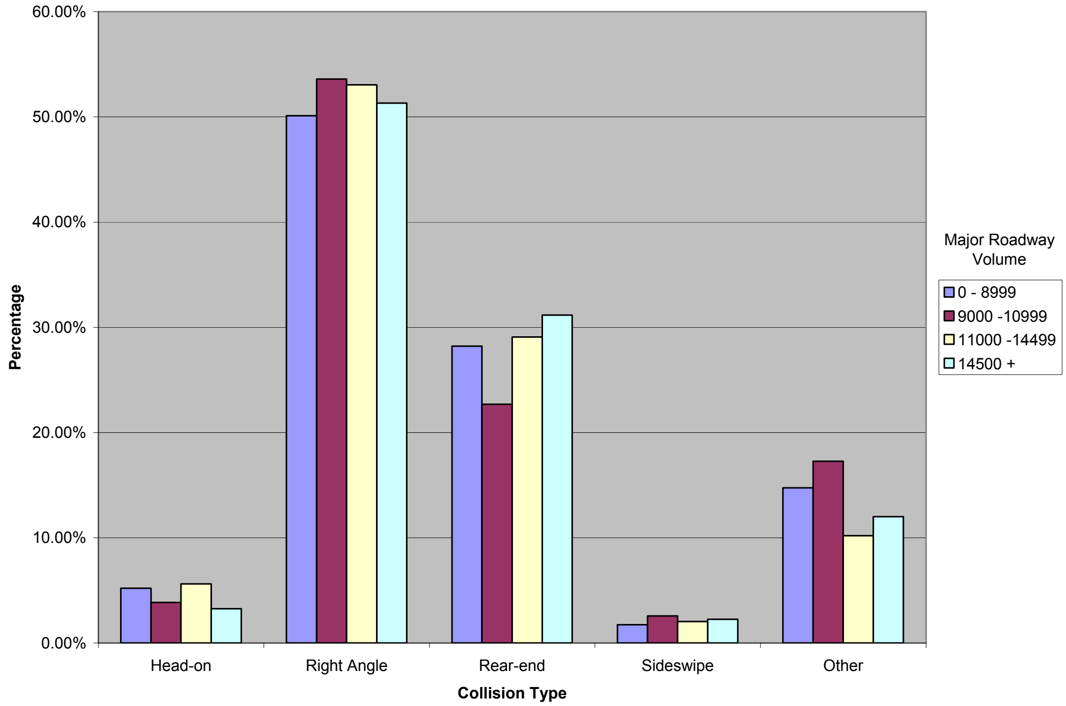

Figure 3 Crash Type by Major Roadway Volume

Intersection Crash Type Distribution

Figure 4 examines the same rural expressway intersections in comparison to all rural through stop-controlled intersections on rural primary highways (all primary roads including expressways). These data are derived from five years of crash records (1996 through 2000) and are summarized by five types of collisions. Notice that the distribution of collision types is basically the same on expressway and on rural primary highways. On all types of highways, right angle crashes are the most common crash type and right angle crashes are only slightly more common at expressway intersections than at other two-way stop controlled intersections.

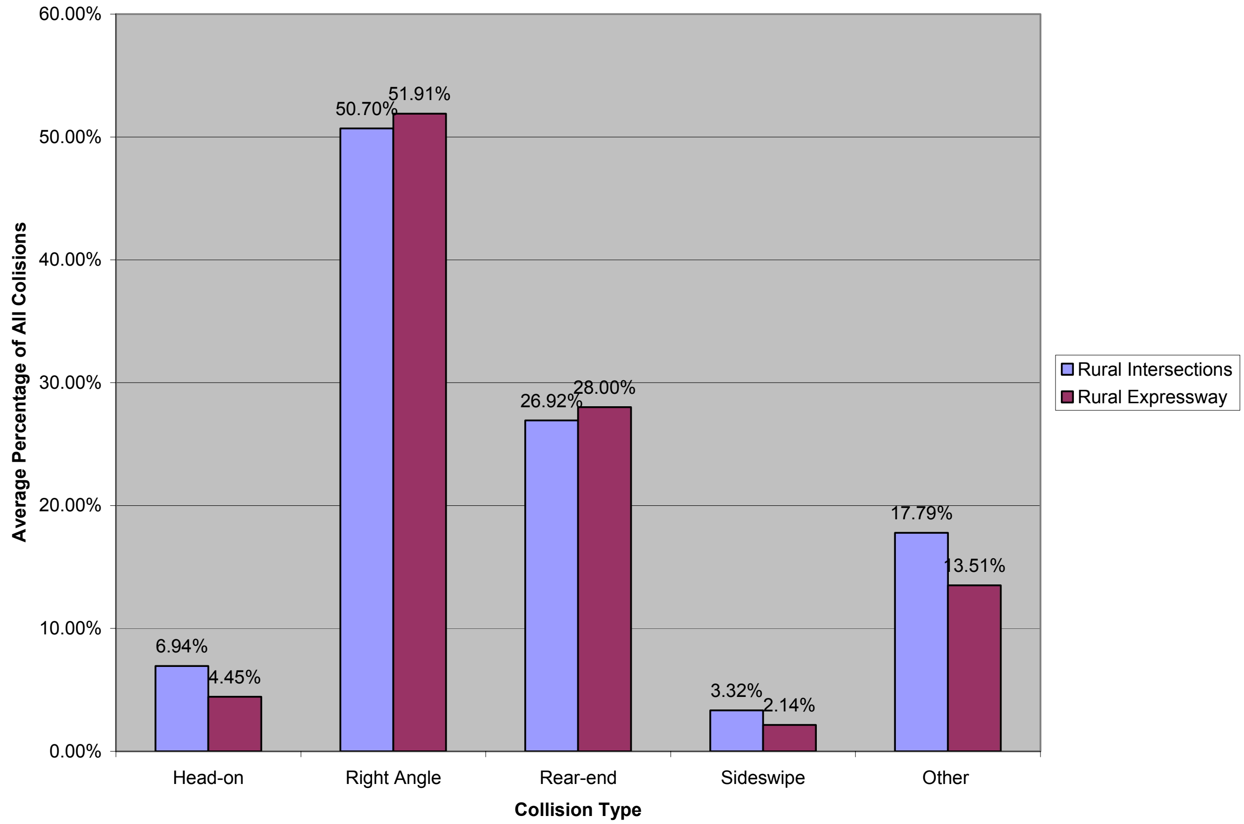

Figure 4 Comparison of Crash Type at Rural Expressway Intersections to All Intersections on Primary Roadways

Crash Severity of Rural Expressways

An analysis was completed involving the crash severity of rural expressways versus the statewide averages for rural intersections. For this analysis a directory was created to look at the most severe injury occurring in each of the crashes. This directory was then used to compare five years of data from 1996 – 2000 of rural expressways to the statewide average for stop – through intersections. These data are queried using the following assumptions: 2000 data includes crashes within fifty meters of an intersection and enhanced with visual inspection while 1996-1999 data used intersection nodes to query crashes within fifty meters of the intersection.

Figure 5 demonstrates that injuries on rural expressways are marginally more severe than injury crashes at rural intersections and the fatality percentage are about the same. This result is both positive and negative information. One the positive side we were afraid that crashes at expressway intersections would tend to be more severe because of higher speeds and they are not. Crashes at expressway intersections tend to have about the same severity as all rural intersections. The negative information is that even though at-grade expressway intersections have significantly higher design standards, crash experience is approximately the same as at stop-controlled rural intersections.

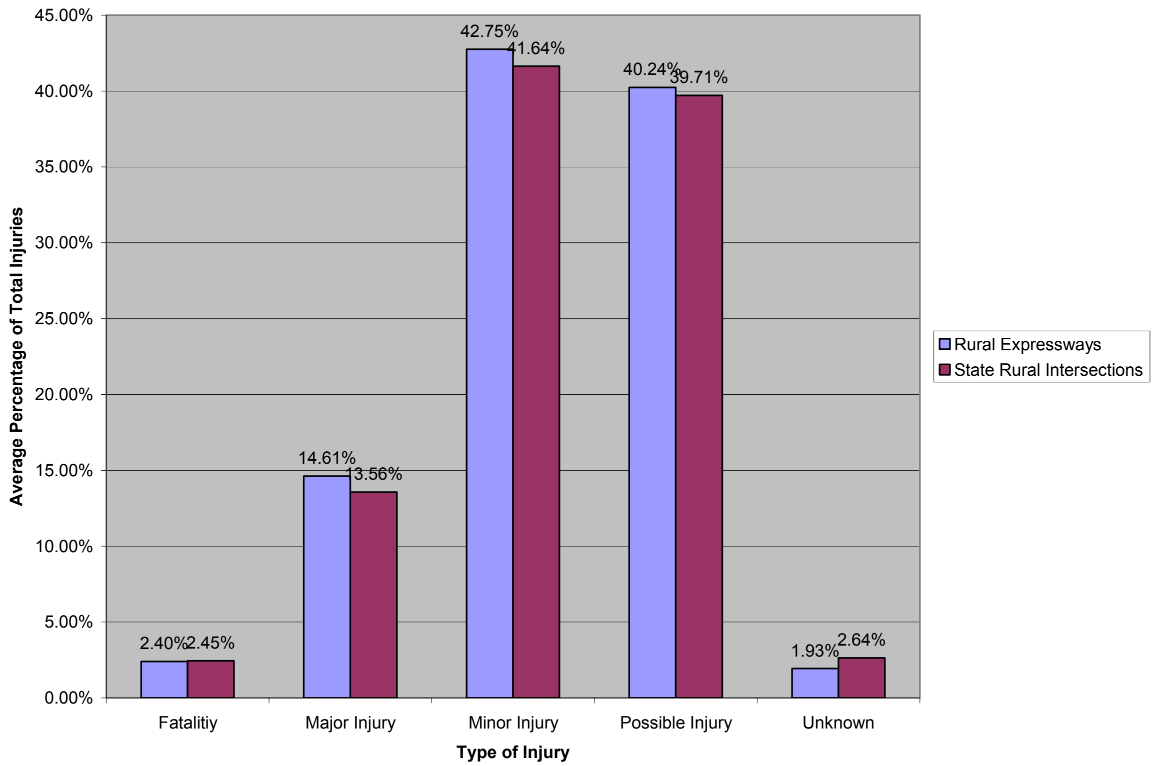

Figure 5 Comparison of Crash Severity at Rural Expressway Intersections to those at All Intersections on Rural Primary Highways

Crash Frequency Statistical Model

Next an analysis using the intersection database using maximum likelihood to estimate parameters for a Negative Binomial model. The following regression was performed using the software package *LIMDEP Version 7.0* . Given that we are modeling count data (crash frequency), both Poison and Negative Binomial models are considered for our analysis. Generally, crash data suffer from over dispersion that is a problem for the Poison model but not for the Negative Binomial model and, therefore, we chose to use the Negative Binomial model.

Major and Minor volume

Our regression analysis included all 644 rural expressway intersections and crash frequencies for a five year period (1996-2000). The dataset includes the minor and major roadway volumes at 644 expressway intersections. The traffic volumes form our independent variable and the crash frequency is our dependent variable.

Next we performed several regressions using a negative binomial model. Our work with the model is done to help us to obtain a general understanding of the relationships between the volumes and crashes. For the following model we will use a Rho-Squared value to demonstrate the goodness of fit of the model. Like R-Squared, the Rho-squared value varies from 0.0 to 1.0 and measures the model's ability to account for variance in the dependent variable. The closer this value is to one the better the model represents the data set. (Similar to an R^2) The numbers in parenthesis below each equation represents the statistical significance of that parameter estimates.

$$\text{Roadway Crash Frequency} = e^{(0.02278 + (0.00005 * \text{Minor ADT}) + (0.00042 * \text{Major ADT}))} \quad (1)$$

(0.881) (0.0001) (0.00001)

Rho-Squared Value = 0.381

As we expected, crash frequency increases with both minor and major roadway volume. There is a strong statistical relationship between independent variables and the dependent variable. The relatively low Rho-Squared Value does indicate that there are important unaccounted for variables, but the Rho-Squared Value is very good for this type of analysis. We also estimated a model were we included the product of minor and major roadway volumes to test the importance of the interaction between minor and major roadways but the interaction variable did not improve the model and an interaction term was dropped from further analysis.

Younger and Older Drivers

Next an analysis of older and younger driver involvement is conducted to help understand problems that these groups may be having on rural expressways. Table 1 and Table 2 below represent a comparison of the total number of crashes occurring on each of the 644 expressway intersections (Table 1) versus the total number of crashes occurring at all rural Iowa intersections (Table 2) over a five-year period. The crash column represents the percentage of fatal and injury crashes that include at least one driver in each age category. Also the fatality and injury totals represent any person involved in a crash that included a driver of that age group. Notice that the involvement of drivers over 65 years of age and above is about 45 percent higher on rural expressways in comparison to the statewide averages.

Table 1
Average Rural Expressway Intersection Injury and Fatal Crash Involvement By Age Group 1996-2000

		Frequency	
Age	**% Crashes**	**Fatalities**	**Injuries**
All	100.00%	22	894
0-15	0.59%	3	1
16-24	41.81%	4	230
25-34	32.35%	9	189
35-44	30.57%	3	178
45-54	27.61%	3	218
55-64	17.95%	1	114
65+	23.08%	2	118
70+	17.75%	2	88

* 1996 and 1999 data derived from node intersection-related definition.
** 2000 data derived from crashes w/in 50 meters.
*** % Crashes calculated from total crashes at all (statewide) rural intersections.

Note: Age ranges are inclusive.

Note: Percentages were calculated by dividing the number of crashes of a certain collision type involving a driver of that age group by the total number of crashes. E.g., 8.40% of the crashes at rural intersections were Head -on crashes involving 70+ drivers.

Table 2
Average Statewide Rural Intersection Injury and Fatal Crash Involvement By Age Group 1996-2000

		Frequency	
Age	**% Crashes**	**Fatalities**	**Injuries**
All	100.00%	492	17970
0-15	1.94%	8	398
16-24	41.77%	191	8268
25-34	27.46%	156	5433
35-44	29.02%	143	5631
45-54	21.48%	105	4069
55-64	15.77%	97	3060
65+	15.94%	153	3327
70+	11.27%	117	2443

* 1996 and 1999 data derived from node intersection-related definition.
** 2000 data derived from crashes w/in 50 meters.
*** % Crashes calculated from total crashes at all (statewide) rural

Note: Age ranges are inclusive.

Note: Percentages were calculated by dividing the number of crashes of a certain age group by the total number of crashes. E.g., 11.27% of the crashes at rural intersections involved a driver 70+ of age.

Table 3 and Table 4 break down the type of fatal and injury collision for each age group. These outputs include the involvement of our aggregated four types of collisions for each age. This was done to better demonstrate which specific collision types these age groups are having the most difficulty conducting. Drivers of most ages (with the exception are the 25-34 and 35-44 age groups) appear to significantly more difficulty with right-angle crashes at expressway intersections. The involvement in right angle crashes is 34 percent higher, 16 percent, 36 percent, 35 percent, 18 percent, and 28 percent higher involvement in right angle crash at expressway intersections for the 16-24, 45-54, 55-64, 65+ and 70+ age groups. However, overall, right angle crash involvement only increases by 8 percent from all rural intersections to rural expressway intersections. All thought the young drivers and older drivers are clearly over represented in right angle crashes this seems to be a trend for all intersections and expressway intersections tend to emphasize this trend.

Table 3

Distribution of Rural Expressway Intersection Injury

and Fatal Crashes By Type and Age 1998-2000

Age Group	Collision Type				
	Head-on	Right Angle	Rear-end	Sideswipe	Other
All	4.64%	49.82%	29.22%	2.23%	14.10%
0-15	0.00%	66.67%	0.00%	0.00%	33.33%
16-24	2.04%	59.18%	30.10%	1.02%	7.65%
25-34	2.80%	39.16%	37.76%	4.20%	16.08%
35-44	3.60%	45.32%	28.78%	2.88%	19.42%
45-54	0.00%	54.62%	24.37%	4.20%	16.81%
55-64	1.43%	64.29%	21.43%	2.86%	10.00%
65+	0.00%	63.46%	17.31%	5.77%	13.46%
70+	0.00%	70.51%	11.54%	6.41%	11.54%

* 1996 and 1999 data derived from node intersection-related definition.
** 2000 data derived from crashes w/in 50 meters.
*** % Crashes calculated from total crashes at all (statewide) rural intersections.

Note: Age ranges are inclusive.

Note: Percentages were calculated by dividing the number of crashes of a certain collision type involving a driver of that age group by the total number of crashes. E.g., 8.40% of the crashes at rural intersections were Head -on crashes involving 70+ drivers.

Table 4

Distribution of Rural Intersection Injury and Fatal Crashes

By Type and Age 1998-2000

Age Group	Collision Type				
	Head-on	Right Angle	Rear-end	Sideswipe	Other
All	6.82%	46.03%	26.43%	3.26%	17.46%
0-15	6.46%	46.01%	25.86%	2.28%	19.39%
16-24	7.34%	44.07%	29.16%	3.48%	15.95%
25-34	6.65%	46.42%	27.57%	3.49%	15.87%
35-44	6.41%	45.80%	27.22%	3.05%	17.52%
45-54	6.42%	46.99%	26.43%	3.46%	16.70%
55-64	6.76%	47.34%	24.39%	3.36%	18.15%
65+	7.12%	53.67%	21.47%	2.51%	15.23%
70+	7.14%	55.14%	20.51%	2.20%	15.01%

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CONCLUSIONS

To conclude, several states are developing four-lane, divided expressway systems with partial access control. These facilities tend to have speeds at or near that of Interstate highways but without the expense of grade separating every intersection. Although access control limits the number of at-grade intersections, most intersections on expressways are at-grade and cross streets are stop sign controlled. Minnesota and Iowa have observed similar crash trends. This analysis showed that increasing minor roadway volume results in increasing crash rates and increasing crash severity. Increasing minor volumes also resulted in an increasing involvement of right angle crashes. Although we know that major roadway volumes increase the frequency of crashes, increases in minor roadway volume appear to be more highly related to crash rate increases and increased crash severity.

When crash experience at rural expressway intersections is compared to crash experience on all rural intersections with a primary roadway (including expressways), the older drivers (drivers 65 years and older) are found to over-represented. When we made comparisons of the type of crashes, right angles crashes at expressway intersections are generally over-represented in most age groups but older drivers are more frequently involved in right angle crashes at all rural intersections but particularly over represented at expressway intersections.

Obviously we can see from the data that turning is a major contributing factor to increasing crashes. It was suggested in most of the reports that it would be reasonable to look for safer designs at even low volume intersections, as well as high volume intersections. After reading the material it is clear that eventually grade separation or a full conversion to an Interstate type facility will be needed on some of the higher volume routes. Many States have experimented with low cost methods including intersection lighting, improved marking and signing, low technology methods to help drivers judge gaps in the traffic, reducing speed limits at intersections, and educational measures for high risk groups on crossing and turning at expressway intersections. It may be appropriate for states to begin to close off median cross-overs and allowing only right turns to and from crossing roadways or the complete closing of an intersection. Hopefully reducing the exposure of vehicles to these types of problems. It is clear that these facilities do not offer the safety benefits that was once perceived, as well it is clear that improvements and alternative intersection designs will be needed to help alleviate this problem.

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FIGURES

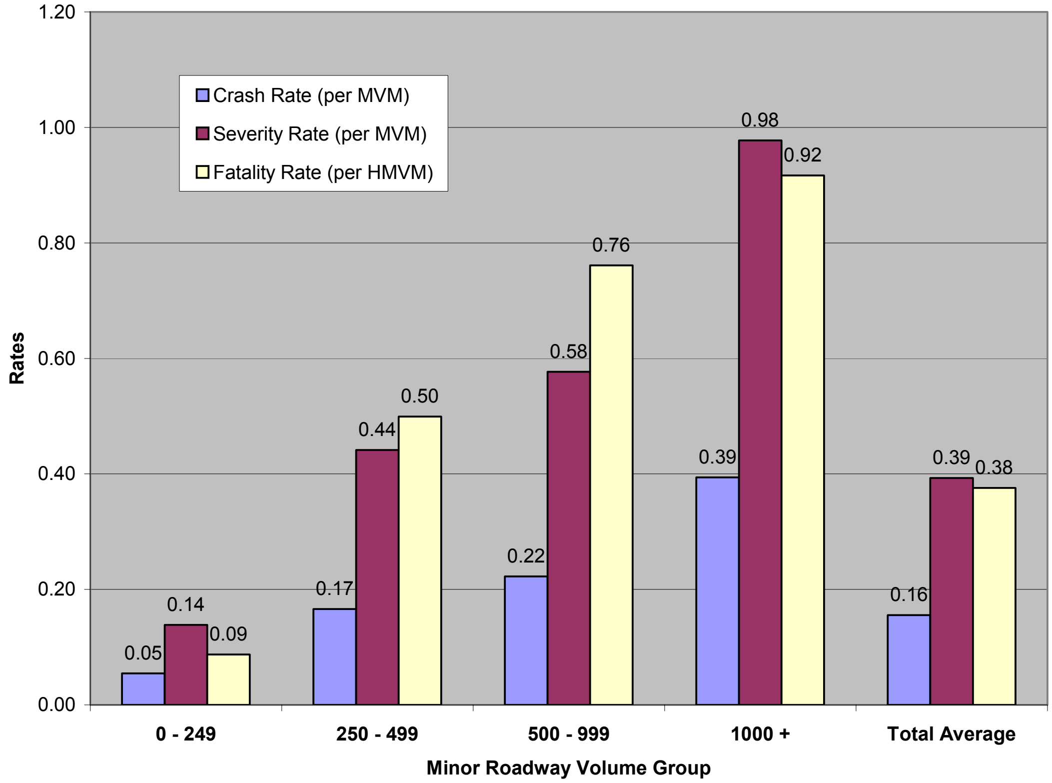

Figure 4 Crash, Severity, and Fatality Rates of Rural Expressways by Minor Roadway Volume

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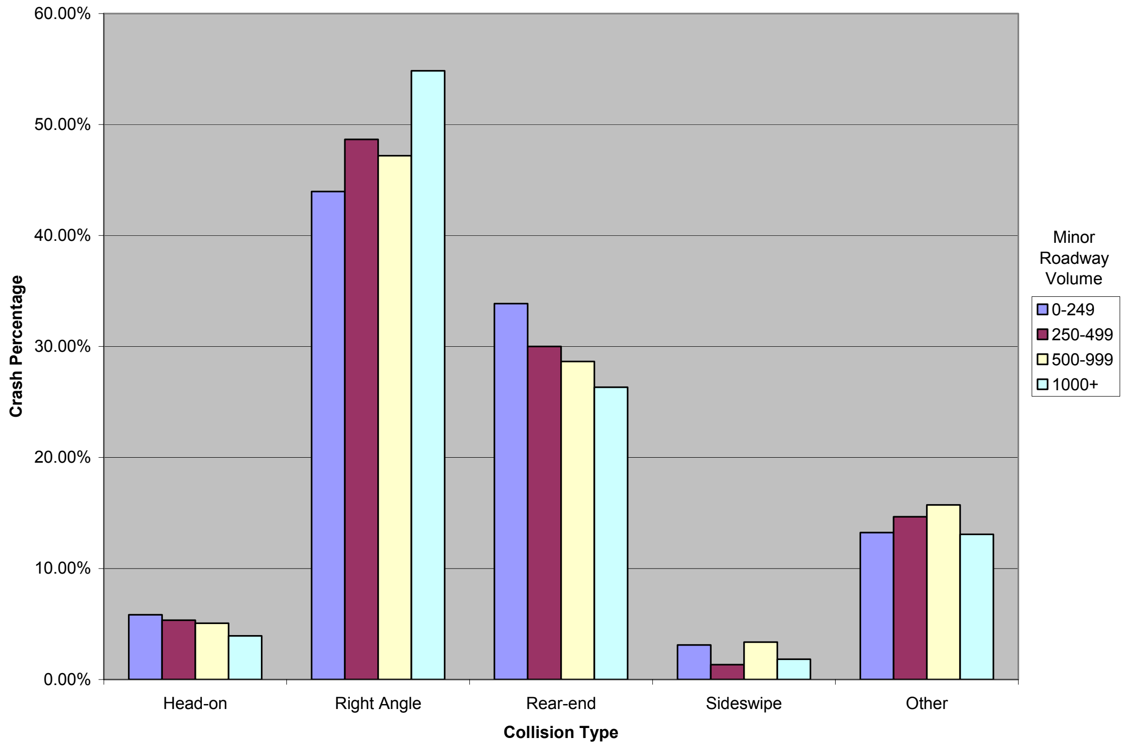


Figure 5 Crash Type by Minor Roadway Volume

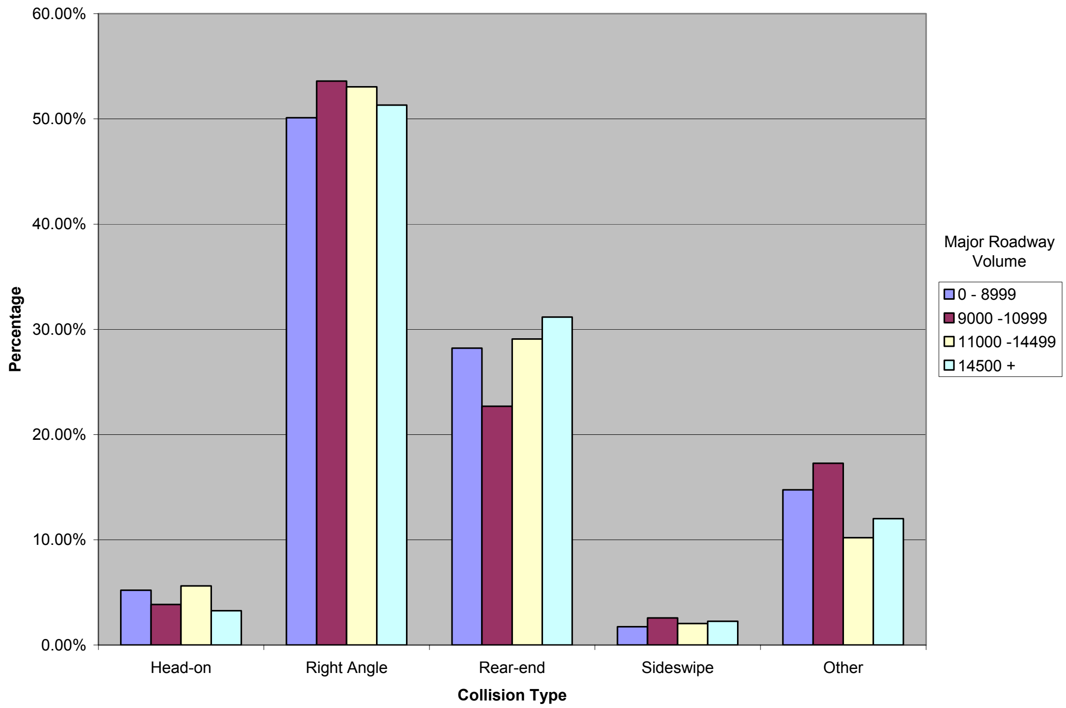
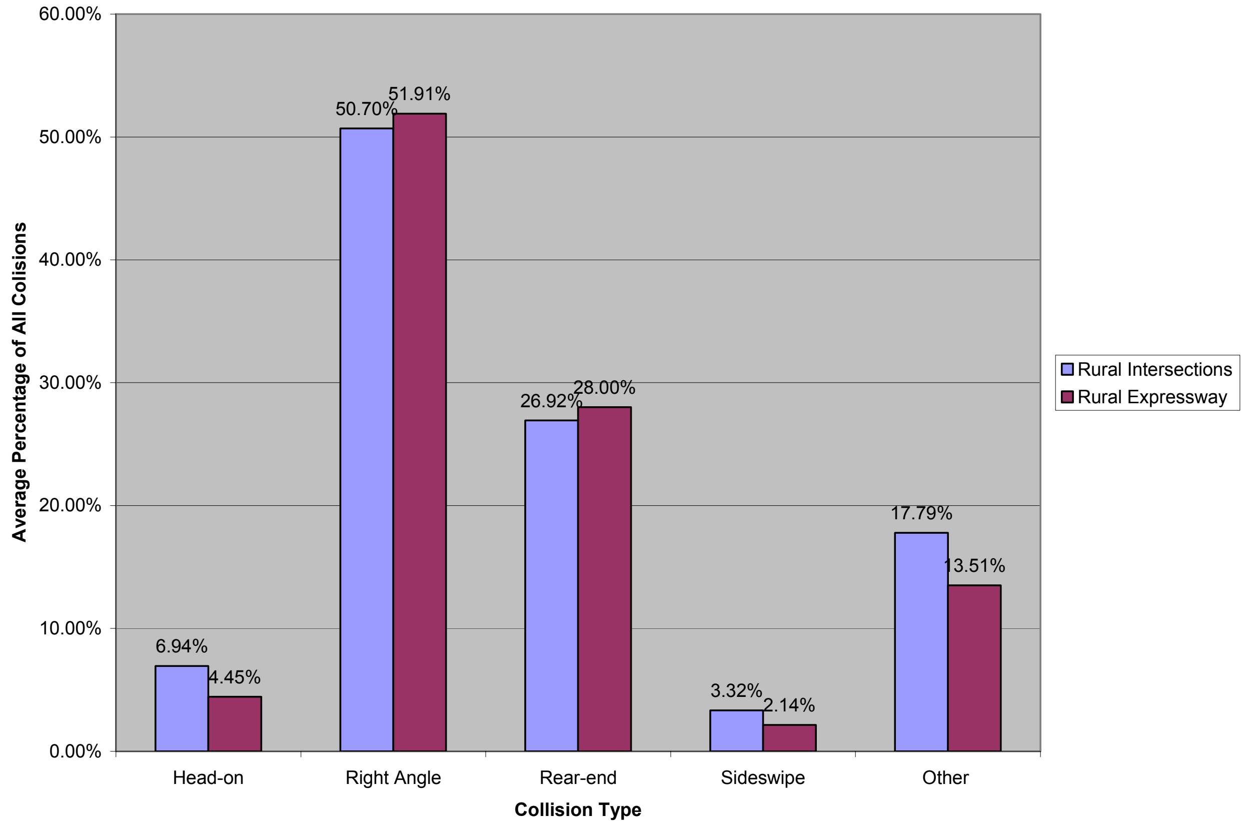


Figure 6 Crash Type by Major Roadway Volume



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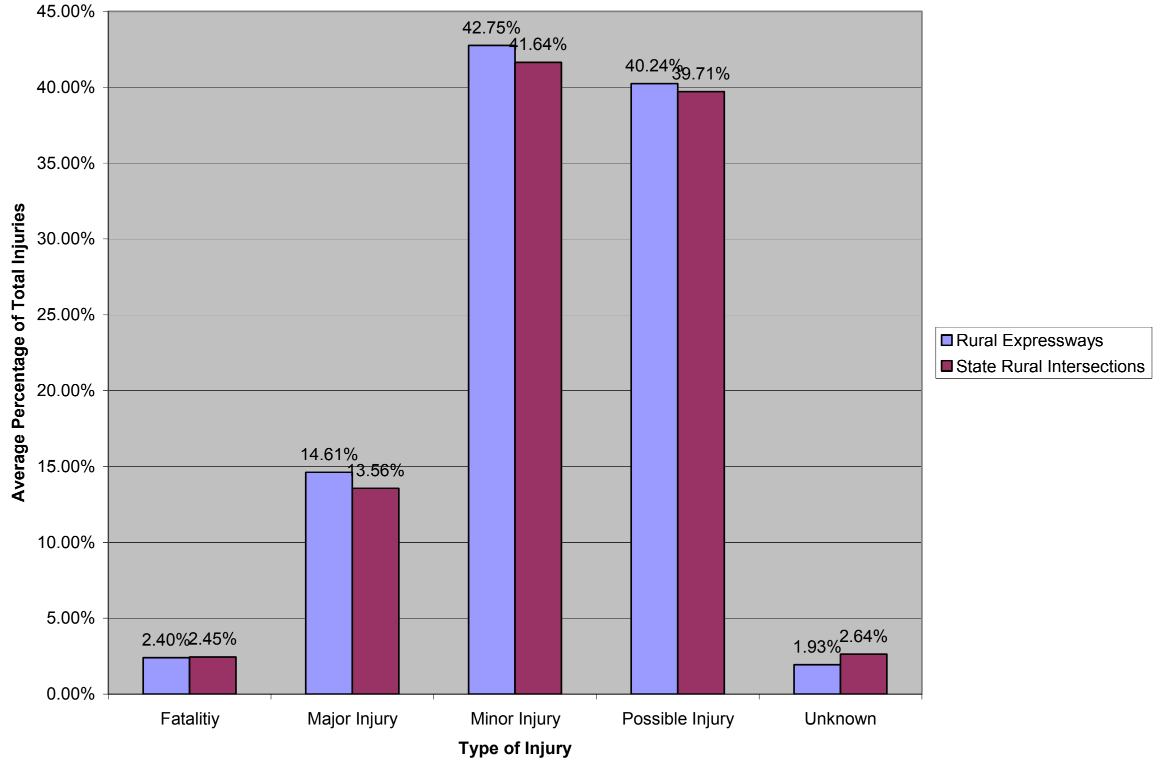

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*** % Crashes calculated from total crashes at all (statewide) rural intersections.

Note: Age ranges are inclusive.

Note: Percentages were calculated by dividing the number of crashes of a certain collision type involving a driver of that age group by the total number of crashes. E.g., 8.40% of the crashes at rural intersections were Head -on crashes involving 70+ drivers.

Table 4

Distribution of Rural Intersection Injury and Fatal Crashes

By Type and Age 1998-2000

Age Group	**Collision Type**				
	Head-on	Right Angle	Rear-end	Sideswipe	Other
All	6.82%	46.03%	26.43%	3.26%	17.46%
0-15	6.46%	46.01%	25.86%	2.28%	19.39%
16-24	7.34%	44.07%	29.16%	3.48%	15.95%
25-34	6.65%	46.42%	27.57%	3.49%	15.87%
35-44	6.41%	45.80%	27.22%	3.05%	17.52%
45-54	6.42%	46.99%	26.43%	3.46%	16.70%
55-64	6.76%	47.34%	24.39%	3.36%	18.15%
65+	7.12%	53.67%	21.47%	2.51%	15.23%
70+	7.14%	55.14%	20.51%	2.20%	15.01%

* 1996 and 1999 data derived from node intersection-related definition.
** 2000 data derived from crashes w/in 50 meters.
*** % Crashes calculated from total crashes at all (statewide) rural intersections.

Note: Age ranges are inclusive.

Note: Percentages were calculated by dividing the number of crashes of a certain collision type involving a driver of that age group by the total number of crashes. E.g., 8.40% of the crashes at rural intersections were Head -on crashes involving 70+ drivers.

EQUATION

$$\text{Roadway Crash Frequency} = e^{(0.02278 + (0.00005 \cdot \text{Minor ADT}) + (0.00042 \cdot \text{Major ADT}))} \quad (1)$$

(0.881) (0.0001) (0.00001)

Rho-Squared Value = 0.381