Effect of Quantitative and Qualitative Factors on Elder Driver Intersection Crashes

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ABSTRACT

Past research has shown that intersections are particularly difficult for older drivers to negotiate. To investigate potential contributing factors, standard database elements were paired with visual inspections of video log images to evaluate factors such as visual clutter, approach sight distances, and the condition and visibility of pavement markings. For comparative purposes, the paper also examines the effect of the same factors on crashes in which non-elderly drivers were found to be at fault. The study set includes all intersections on state roads in Florida that had undergone at least one fatal traffic crash in the year 2000, primarily because of information available from a companion study. Thirty-two independent variables were selected to describe the roadway geometrics, traffic characteristics, pavement, signage, and control devices. A variety of regression models were investigated, and best-fit measures, including Akaike and Bayesian Information Criteria, favored negative binomial models reduced by forward stepwise selection for both elder and non-elder crashes.

Fourteen variables were found to have significant effect on crash likelihood. Major operation and design aspects, such as high traffic counts and absence of signalization and medians, appear to be much more significant measures of crash likelihood for both older and younger drivers than other features or enhancements. Older drivers had more crashes when pavements were not marked with advanced lane assignment marking and when skid resistance was lower. However, younger drivers were more prone to traffic crashes at intersections with lower sign reflectivity and hanging signals, factors which did not impact older drivers. Further, several qualitative safety features, including advanced warning signs recommended by the Florida Elder Road User Program, had greater impacts on non-elderly drivers. Potentially counter-intuitive results, such as decreased crash likelihoods with higher speed limits, decreased turning sight distances, and presence of raised pavement markings, might be caused by self-limiting behavior among drivers when presented with safety concerns; however, additional research is recommended.

KEYWORDS: Elder Drivers, Intersections, Crashes, Visual Assessment

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1. INTRODUCTION

Florida has a unique population with 18 percent of its population age 65 and older. It is also projected that by the year 2020, one in four Florida residents will be 65 and older (*Florida,* 1999). Mobility needs are very crucial for senior citizens and for many, the automobile is the primary means to fulfill these needs. Therefore, it is vital to explore age as a factor in traffic crashes. Research has shown differences in driver performance among different age groups. Advanced driver age can cause impairment in sensory capacity, motor and psychomotor capacity, as well as cognitive capacity (Staplin, 1999). As a result, driver age can affect many aspects of the driving task, including perception-reaction time, responses to movement of other vehicles, responses to traffic devices, handling of hazards in the roadway, and control movement time (Staplin, 1997).

Ideas to minimize traffic crashes involving older drivers include larger street signs, advanced signage, and intersection design and signalization that decreases reliance on judgment in making left turns (e.g. protected left turns, roundabouts, etc.). Many of these design and operational guidelines were included the Florida Elder Road User Program (FERUP), a Florida Department of Transportation sponsored program designed to help seniors maintain their mobility and provide a safer system in which they can travel (*Florida*, 1999). Several countermeasures recommended by this program have been implemented to various degrees throughout Florida. Other design details and operational characteristics, such as type and alignment of signal heads, use of medians and/or turn lanes, and number of informational and warning signs may have either a positive or negative effect on elder driver safety.

It is important to explore these factors, some of which are quantifiable and some of which are more subjective in nature, and their effects on intersection safety and the number of elder driver crashes. In addition to the standard data elements available from databases such as the Florida Department of Transportation's (FDOT's) Roadway Characteristics Inventory (RCI) database, video log images and other data sources were used to conduct visual inspections of intersections in the study set to evaluate factors such as visual clutter, approach sight distances, and the condition and visibility of pavement markings. The goal of this study was to determine which factors have the largest impact on elder driver intersection crashes and consider which intersection improvements might be the most effective countermeasures in reducing crash rates among older drivers. For comparative purposes, the paper also examines the effect of the same factors on crashes in which non-elderly drivers were found to be at fault.

1.1. Related Research

Older drivers have low crash rates per capita. However, when exposure is taken into account, they have among the highest crash rates per mile (Owsley, 2004). Intersections are particularly difficult for older drivers to negotiate. About half of fatal crashes involving drivers 80 years and older occur at intersections and involve more than one vehicle. This compares with 23 percent among drivers up to age 50 (Isler, 1997). Because of the high crash rates involving older drivers, and because of the high fatality rates of older drivers involved in traffic crashes, these crashes have been the focus of important research efforts, several of which are detailed here.

At-grade intersections have the highest probability of conflict between vehicles. A number of related studies have shown that sight distance problems at intersections usually result in a higher crash rate (David and Norman, 1979). This is especially true of the left turn maneuver from minor road onto a major road at a stop-controlled intersection. A study by Skyving, Berg, and Laflamme (2009) reinforced previous studies (Richardson and Marottoli, 2003; Lyman et al, 2002) indicating that negotiating intersections can be problematic for older drivers, even when traffic is not that fast moving. This Swedish study found that two of four major crash classes responsible for elder driver fatalities involved large numbers of left-turn crashes at intersections and driveways on low- and moderate-speed roadways.

The angle at which intersecting roads meet is an important consideration in the design of roadway facilities. Intersections at an angle other than 90 degrees may require greater head movement to provide the necessary sight distance. This motion is particularly troublesome for older drivers, many of whom experience a decline in head and neck mobility (Isler et al, 1997). Federal Highway Administration guidelines for highway designs accommodating older drivers recommend that skew at intersections be limited to angles no greater than 75 degrees, and that skew should be eliminated if right-of-way is not a concern (Staplin, 2001).

Improper or faded roadway markings can result in crashes because older drivers can be confused about the markings. Improved delineation can be accomplished through higher standards for retro-reflective pavements markings, more frequent repainting of edges and center lines, and the use of raised pavements markers (RPM's) and other marking treatments, especially in areas of alignment changes or lane drops. Staplin, et al (1997) found that older drivers need pavement markings that are anywhere from 30 to 300 percent more retro-reflective than younger drivers.

Some researchers have suggested that sign conspicuity and comprehensibility can be difficult for older drivers. Internal contrast is the difference between the luminance of the sign copy and its background. Sturr, Kline, and Taub (1990) studied the static acuity of younger (ages 18 to 25) and older (ages 60 to 87) persons under varying luminance levels ranging from day to night vision. Their findings showed there is very little differentiation between age groups at the highest level of illumination, but at lower illumination levels, older persons were at a disadvantage. Scialfa et al (2008) found that healthy older adults were generally good at sign comprehension but had difficulty with way-finding signs, while older adults with cognitive impairment had poorer sign comprehension overall and particular difficulty with way-finding icons and signs that had icons only.

External contrast is the difference between the luminance of the sign and that of the area immediately surrounding the sign. As the sign's external contrast ratio increases, so does the sign's conspicuity. External contrast may be negatively affected by visual clutter in the scene. Ho et al (2001) found that the ability to locate traffic signs embedded in digitized images of driving scenes declined with increased clutter and with aging. However, the effect of increased clutter had less effect on older drivers relative to the young.

Other studies have found that older drivers do not have increasing difficult in detecting and understanding road signs, possibly because they are able to compensate for age-related vision decline. Kline et al (1999) found that older observers were better than younger ones in identifying defocused (optically blurred) text in both daytime and nighttime conditions. Schnell, Aktan, and Li (2004) also found no significant differences in the ability of older and younger drivers to recognize various negative contrast symbol signs (black on yellow) under low adaptation luminance conditions, regardless of background complexity.

1.2. Florida Elder Road User Program

In 1989, in response to the needs of Florida's growing elderly population, Florida participated in a federal pilot program studying the effect of certain roadway improvements on the driving skills of the elderly in those areas. During the pilot program, the suggested roadway improvements were implemented within 22 counties that had a high senior population (*Florida*, 1999). In 1992, FDOT introduced Florida's Elder Road User Program (FERUP) state-wide, adopting the recommendations of various federal studies (*TRB*, 1988; *TRB*, 1989). Goals of the program, which was renamed the Safe Mobility for Life Program in 2007, were to aid seniors in maintaining their mobility and to provide a safer system in which they could travel. To combat the loss of driving skills due to the natural affects of aging, especially those skills affecting visual capability and decision-making, implementation of these improvements began state-wide. These improvements were aimed at providing better guidance along roadways, more legible signs and increased advance warning of upcoming traffic and roadway conditions (*Florida*, 1999).

The implementation plan included a number of short- and long-term improvements. Various aspects of the FERUP and other roadway improvements were installed on the State Highway System (FDOT jurisdiction) within two years of the pilot study (1991); however, not all intersections on state or local roads are currently 100% compliant. The roadway and traffic operations goals of the program were:

- Increased visibility
  - Increased lane and edge line pavement marking widths to 6 inches
  - Use of raised pavement markers (RPMs)
  - Use of larger lettering on guide signs
- Improved pedestrian features at intersections
  - Use of refuge islands
  - Use of high emphasis crosswalks
  - Use of slower walk speeds in signal timing
- Provide advance notification
  - Use of advanced street name signs
  - Use of advanced warning signs (stop, yield, and signal ahead)

In 2002, FDOT evaluated the effectiveness of the FERUP by setting up a driving course with differing aspects of the program for drivers ages 55 and older and allowing them to complete a questionnaire detailing their driving experience. The goal of the study was to determine whether older drivers could distinguish between previous design standards and the most recent design standards. It was found that there were definite advantages to larger lettering on signage. Furthermore, wider pavement markings and raised pavement markers were found to be beneficial. Offset turn lanes were found to have no real significant benefit to the older drivers (Guerrier and Fu, 2002). This study established that older drivers can distinguish and benefit from these improvements, but did not explore the effect that the various improvements have on crash occurrence.

1.3. Crash Prediction Models

Previous research has revealed that Poisson and negative binomial distributions are often appropriate for modeling discrete counts of events such as crashes, which are likely to be rare or non-existent during a given time period. In many crash modeling situations, the data generally exhibits high variation, resulting in the variance being greater than the mean, a phenomenon known as overdispersion. A negative binomial model is better suited for this case (Cameron and Trivedi, 1998); the distribution is as follows:

$$\Pr(y) = \frac{\Gamma(y+\alpha^{-1})}{y!\Gamma(\alpha^{-1})}\left[\frac{\alpha^{-1}}{\alpha^{-1}+\mu}\right]^{\alpha^{-1}}\left[\frac{\mu}{\alpha^{-1}+\mu}\right]^{y}, \quad y = 0, 1, 2...$$

where y = response variable of interest
α = shape factor
Γ = gamma function
μ = mean parameter

If $\alpha = 0$, the mean is concentrated in the point, and the equation reduces to the Poisson distribution. The appropriateness of the negative binomial model relative to the Poisson model is determined by the statistical significance of the estimated coefficient α, and by the dispersion parameter, σ_d.

$$\sigma_d = \frac{Pearson\chi^2}{n-p}$$

where $Pearson\chi^2$ = Pearson chi-squared statistic
n = the number of observations
p = the number of model parameters

Pearson χ^2 is defined as:

$$Pearson\chi^2 = \sum_{i=1}^{n}\frac{[y_i - \hat{E}(y_i)]^2}{Var(y_i)}$$

where y_i = observed number of accidents at intersection *i*
$\hat{E}(y_i)$ = predicted accident frequency for intersection *i*
$Var(y_i)$ = variance of accident frequency for intersection *i*

If σ_d turns out to be significantly greater than 1.0, then the data has greater dispersion than is explained by Poisson distribution, and the negative binomial regression model is fitted to the data.

A zero-inflated distribution may be used in cases where there are excessive zero counts. Again, this situation often occurs with crashes because of the high number of segments or intersections with no crashes during the study period. The zero-inflated negative binomial (ZINB) regression model has the following formulation:

$$Pr(y) = \begin{cases} \varphi_i + (1-\varphi_i)\left[\dfrac{\frac{1}{\alpha}}{\frac{1}{\alpha}+\mu_i}\right]^{\frac{1}{\alpha}}, y = 0 \\ (1-\varphi_i)\left[\dfrac{\Gamma\left(\frac{1}{\alpha}+r\right)\lambda_i^{\alpha}(1-\lambda_i)^{y}}{\Gamma\left(\frac{1}{\alpha}\right)y!}\right]^{\frac{1}{\alpha}}, y > 0 \end{cases}$$

where $\lambda_i = \dfrac{\frac{1}{\alpha}}{\frac{1}{\alpha}+\mu_i}$

Maximum likelihood methods are used to estimate the parameters of Poisson and negative binomial regression models.

2. METHODOLOGY

The goal of this study was to examine a number of qualitative and quantitative factors and determine which factors have the largest impact on elder driver intersection crashes. Sources including Florida Department of Transportation video logs and still photographs, as well as Roadway Characteristics Inventory (RCI) data, were used to evaluate parameters such as type and condition of signage, type and alignment of signal heads, visibility of signs and signals, and evidence of visual clutter. Although many of these factors are measurable in a more quantitative sense, with units of length or candelas, for example, such specific data is frequently unavailable. Therefore, to supplement the quantitative data on the intersections, each intersection was assessed qualitatively from the point of view of an older driver approaching the intersection at a normal driving speed. This procedure is described in more detail in Section 2.2.

2.1. Study Data Set

The study set includes all intersections on state roads in Florida that had undergone at least one fatal traffic crash in the year 2000. Severe crashes at these intersections might be indicative of a roadway design or traffic operation issue. Moreover, a good deal of information on these intersections was available because of data collected in a companion study (Spainhour et al, 2005). Commercial driveways with significant traffic control and other features typical of standard at-grade intersections were included if they fit other study criteria. Intersections that underwent significant changes (widening, installation of traffic signals, etc.) during the study period were discarded from the study. Also, sufficient data had to be available to assess the features of the intersection. A total of 597 intersections met the criteria in the study.

Once the intersections were identified, the roadway segment and milepost were used to obtain the number of crashes at each location during the study period. The primary source of quantitative crash data was the FDOT Crash Analysis Reporting (CAR) database. Crashes were identified as intersection crashes using the Site Location field. However, if there was a question as to whether or not a crash occurred at an intersection, verification was performed by viewing video logs of the area of interest. To include a larger number of crashes in the study, three years worth of crash data (2000-2002) were examined. All crashes at the selected intersections were included, regardless of injury severity. A total of 6,746 crashes occurred at the selected intersections during the study period, of which 1,021 and 5,725 were designated as having older or younger at-fault drivers, respectively. For simplicity, these crashes are often called elder driver crashes and non-elder driver crashes herein, referring to the age of the driver who was found to be at fault in the crash. While all 597 intersections had at least one crash during the study period, 216 of the selected intersections had no crashes in which elder drivers were found to be at fault, and 50 had no crashes in which non-elder drivers were found to be at fault. For the purpose of this research, an older driver is defined as one aged 65 or above.

After careful consideration of crash modeling studies and other literature on the subject, as well as the available data, a total of 32 independent variables were selected to describe the roadway geometrics, traffic characteristics, pavement, signage, and control devices. The variables and their allowable values are listed in Table 1. In general, the variable characteristics become less benign as the values increase. Cases where the variable was not applicable (e.g. super-elevation where there was no curvature, or signal visibility where there were no signals) were included with the benign cases. This decision was made because regression models cannot be run with missing values, but separate variables already measured the effect of the original condition (presence of curvature or signalization). The response variables in the models were the number of crashes in which elderly (*elder_crash_freq*) or non-elderly (*nonelder_crash_freq*) drivers were found to be at fault, respectively.

Table 1 Independent Variables Used in Model

Variable name	Meaning	Data Type
Rural_Urban	Geographical area of roadway	00=Rural; 01=Urban
Max_Posted_Speed	Maximum posted speed limit	01=<35 mph; 02=35-54 mph; 03=55-64 mph; 04=65 mph and above
AADT	Average daily traffic count	01=0-19634; 02=19635-43500; 03=43501 and above
Avg_T_Factor	Average truck factor	01=0-13.94; 02=13.95-27.94; 03=27.95 and above
Divided_Undivided	Presence of median	00=Divided; 01=Undivided
Median_Width	Width of median	01=0-20 ft; 02=21-54 ft; 03=55 ft and above
Surface_Width	Width of road surface	01=0-12 ft; 02=13-24 ft; 03=24 ft and above
Number_of_Lanes	Number of through lanes	01=1-2; 02=3-4; 03=4 or more
Left/Right Lane[a]	Left and right turn lanes present, as appropriate	00=Present; 01=Not Present
Left/Right_Turn_Sight[a]	Left/right turn sight distance sufficient	00=Sufficient or N/A; 01=Not Sufficient
Curvature	Degree of curvature	01=None; 02=Mild; 03=Sharp
Superelevation	Super-elevation of roadway	01=Proper or N/A 02=None
Level_Not_Level	Presence of roadway grade	00=Level; 01=Not Level
No_Skew_Skew	Presence of intersection skewed	00=No Skew; 01=Skew
Shoulder_Type	Type of shoulder	01=Paved; 02=Unpaved; 03=Curb or Other
Blacktop_Not	Type of pavement	01=Blacktop; 02=Other
Skid_Test_Results	Skid test result	01=41 and above or N/A; 02=31-40; 03=30 and below
Delineation[a]	Pavement markings clearly visible	00=Good; 01=Faded
Advanced_Lane_ Assignment[a]	Advance lane assignment pavement markings present	00=Present; 01=Not Present
Raised_Pavement_ Markers[a]	Raised pavement markers present	00=Present; 01=Not Present
Signalized_Unsig	Signalization of intersection	00=Signalized; 01=Unsignalized
Signal_Head_Type	Type of signal head used	01=Hanging or N/A 02=Mast Arm

Signals_Lanes[a]	Number of signals = number of lanes	00=Yes or N/A; 01=No
Signals_Line_Up[a]	Signals line up with lanes	00=Yes or N/A; 01=No
Signal_Visibility[a]	Visibility of signals	00=Visible or N/A; 01=Poorly Visible
Advanced_Signage[a]	Presence of advance warning signs	00=Present; 01=Not Present
Signs_Visible[a]	All signs visible upon approach	00=Yes; 01=No
Sign_Placement[a]	All signs properly placed	00=Proper; 01=Improper
Internal_Contrast	All signs legible	00=Legible or N/A; 01=Illegible
External_Contrast[a]	All signs can be detected	00=Can Be Detected; 01=Hard To Detect
Retro_Reflective_ Signage	Retro-reflective sheeting present on signs	00=Present; 01=Not Present
Visual_Clutter[a]	Visual clutter/noise present	00=Not Present; 01=Present

[a]Obtained through Visual Inspection

2.2. Visual Inspection Procedure and Examples

Because of the subjective nature of the visual assessment procedure, it is discussed in more detail here, and examples of several intersections are provided to illustrate how different features were categorized. The video log images provided by the Florida Department of Transportation served as the key source of information for the visual inspections. The video logs are still photographs taken in both directions at regular interval from the right most lanes of the state maintained roads. The video log images used in this study were taken at various times during the year 2000. Figure 1 shows a snapshot of the video log viewer. Note the acute skew angle of the intersection being displayed.

Insert Fig. 1 approximately at this location

Figure 1 Example Video Log Image

Additional data sources were available for a number of crashes in the study, including TIFF images of crash reports, Traffic Homicide Investigation (THI) reports, and crash scene photographs. A limited number of site visits were conducted to verify details and validate the process. As described in Spainhour et al (2005), the additional data sources were used to complete and correct any errors and omissions discovered in the initial crash report data from the CAR database. In addition, the supplemental photographs were often taken from different viewpoints, which were most helpful when the secondary roadway was not state-maintained. While the crash scene photographs may have provided some insight into the nighttime visibility of an intersection, the video log images were collected during daytime conditions; therefore, the qualitative assessments of intersection factors represent daytime conditions.

Case studies of both signalized and unsignalized intersections are provided below. Figure 2 illustrates two typical signalized intersections. The intersection in Figure 2(a) is lacking sight distance: there are several objects such as trees and signs blocking the sight distance on the right-hand side. Therefore, the *left/right_turn_sight* variable would have the value “01=Not Sufficient.” The pavement markings are worn, so the variable *delineation* would equal “01=Faded.” Also, the wire configuration with numerous signal heads makes signal visibility poor, so the value of *signal_visibility* would be deemed “01=Poorly Visible.” The signal head type would be “00=Hanging.” On the other hand, the intersection in Figure 2(b) meets FERUP standards and has fewer undesirable characteristics. Figure 2(b) shows separate right and left turn lanes with advance lane assignment markings on the pavement. Moreover, the pavement is in good condition with high quality pavement markings. The sight distance is also proper because there are no obstructed views. Lastly, the signs have appropriate font, configuration, and placement. The signal head type is mast arm; however, there are fewer heads than lanes. All variable values would be assigned accordingly.

Insert Fig. 2 approximately at this location

Figure 2 Examples of Typical Signalized Intersections

Figure 3 depicts two typical unsignalized intersections. Figure 3(a) shows an intersection where pavement markings are distinguishable and properly maintained. The pavement is in good condition. There are also warning signs to alert the driver of changes in the roadway. Consequently, the variable representing *advanced_signage* would be set to “00=Present.” The signs are properly placed making the s*ign_placement* variable equal to “00=Proper.” Alternatively, Figure 3(b) shows worn, cracked pavement and faded pavement markings; this pertains to the *delineation* variable, which would take on a value of “00=Faded.” Nevertheless, the intersection has left and right turn lanes; therefore, the *left/right_lane* variable would take the value “00=Present.” Both intersections have raised pavement markers, making that variable “00=Present.”

Insert Fig. 3 approximately at this location

Figure 3 Examples of Typical Unsignalized Intersections

Another item of interest in the study is visual clutter. Figure 4 below depicts two different intersections with differing levels of visual clutter. Both intersections are located in urban areas; however, the intersection in Figure 4(b) has a larger amount of visual clutter than the one in Figure 4(a). There are a large number of business signs that may make it difficult for a driver to locate road signs; this is exacerbated to an extent by the curvature, which places the commercial signs in the driver’s line of sight as he or she approaches the intersection. As a result, the *visual_clutter* variable for this intersection would have the value of “00=Present.” Note, however that in Figure 4(a), one directional sign almost completely obscures another on approach, leading to a value of 01=No for the *signs_visible* variable.

Insert Fig. 4 approximately at this location

Figure 4 Examples of Visual Clutter

3. RESULTS AND DISCUSSION

A rating system was developed to provide a general assessment measure of the condition of the 597 intersections in the study set. The rating system basically assigns one point to each of the 32 variables in the study and awards that point to intersections having benign conditions for that variable. The highest rated intersection met all 32 criteria, and the lowest rated intersection met only 15 of the criteria. As shown in the Table 2, approximately four percent of the intersections are in excellent condition, defined as benign values for at least 29 of the 32 variables. Forty-eight, forty-three, and five percent of the intersections were in good, fair, and poor condition, respectively, as defined in Table 2.

Table 2 Condition of Selected Intersections

Intersection Condition	Number of Intersections	Vehicle Exposure per Year	Elderly Crashes		Non-Elderly Crashes	
			No.	No. per 10^8 vehicles	No.	No. per 10^8 vehicles
Excellent (29-32)	24	226,833,995	44	6.47	216	31.74
Good (25-28)	288	2,957,815,460	521	5.87	2762	31.13
Fair (21-24)	257	2,948,066,675	429	4.85	2587	29.25
Poor (15-20)	28	239,952,825	27	3.75	160	22.23
Total	597	6,372,668,955	1021	5.34	5725	29.95

Table 2 also shows the total number of elder and non-elder crashes at the intersections, categorized according to condition. To account for exposure, the total number of vehicles per year on the main leg of all intersections in each category is shown, and the crashes are normalized by that value. Note that crashes caused by both elder and non-elder drivers appear to occur more frequently at the higher quality intersections, even when normalized for exposure. Obviously, this is a very rough measure of "quality," where each factor is given equal weight. However, it leads to the question of what factors most heavily influence crash occurrence at intersections, which is further explored below.

All statistical analysis was done using Stata/SE 8.1 for Windows. Prior to running any models, a correlation analysis was conducted to evaluate the degree of correlation among the variables. Of the 496 variable-variable correlation coefficients, only seven were found to be greater than 0.5; they are listed below. The first two can be explained by traffic operations and roadway design principles, and the rest seem to imply that intersection upgrades tend to address more than one factor at the same time, e.g. additions of advanced signage and pavement markings at the same time. To address the effect of correlated variables on goodness of fit, models were run with and without the associated variables with no significant difference in fit or coefficient values. The results presented below include all 32 dependent variables.

- Annual average daily traffic (AADT) & number of lanes (0.5554)
- Super-elevation & curvature (0.6029)
- Advanced signage & advanced pavement markings (0.5751)
- Signal head type & retro-reflective signage (0.6915)
- Sign placement & internal contrast (0.5548) & external contrast (0.5676)
- Internal contrast & external contrast (0.7768)

Table 3 provides summary statistics for the raw measures of all numeric input variables, as well the two dependent variables in the study. While numerical variables are presented here for illustrative purposes, categorical variables were used in the regression models, as described previously.

Table 3 Summary Statistics for Numerical Variables

Variable	Min	Max	Mean	Median	St Dev	Variance
Number of Lanes	1	12	4.23	4	1.49	2.21
AADT	1100	197000	29245	27500	18683	3.49E+08
Surface Width (ft)	10	51	27.14	24	6.98	48.72
Median Width (ft)	6	197	28.90	24	18.94	358.69
Posted Speed Limit (mph)	30	70	47.45	45	7.89	62.21
Average T Factor	0.68	41.84	7.83	5.68	6.28	39.42
Skid Test Number	24	61	39.18	38	6.54	42.77
Radius of Curvature (ft)	1078	11459	3184	2142	2741	7514400
Super-elevation	0	7	1.89	1.7	1.75	3.07
Elder Crashes	0	12	1.71	1	2.16	4.66
Non-Elder Crashes	0	112	9.59	5	13.04	170.01

Frequency and box plots for elder and non-elder intersection crashes are shown in Figure 5; the box plots display the 25^{th} and 75^{th} percentiles within the boxes, and the adjacent values (1.5 times the respective percentile) as whiskers. As shown in Table 3, the variance is great than the mean for crashes caused by both elderly and non-elderly drivers. This implies that data violates the Poisson distribution assumption, and the binomial distribution should be the most appropriate. Figures 6 and 7 show observed distributions for the elder and non-elder crash data in comparison to both the Poisson and negative binomial models. Again, the negative binomial distribution fits better with the observed data, especially for elder driver crashes. Therefore, the negative binomial model was tested first; however, several additional models including zero-inflated and zero-truncated models were also tested to explore goodness of fit.

Insert Fig. 5 approximately at this location

Figure 5 Distribution of Elder and Non-Elder Crashes

Insert Fig. 6 approximately at this location

Figure 6 Comparison of Poisson and Negative Binomial Models with Elder Crash Distribution

Insert Fig. 7 approximately at this location

Figure 7 Comparison of Poisson and Negative Binomial Models with Non-Elder Crash Distribution

Table 4 shows the results of the negative binomial model of elder driver intersection crashes. A positive coefficient indicates that increasing the value of the independent variable in question results in a higher probability of elder crashes occurring at an intersection. The *p*-value (P>|z| column) indicates the significance of the result; p=0.05 corresponds to 95% confidence in the result. A number of goodness of fit statistics are included as footnotes to the table. The likelihood ratio chi-squared test statistic for the model is 123.76, with p=0.000, indicating that the overall model is statistically significant. The model has an α value of 0.62656, also with *p*=0.000, which confirms that the negative binomial model is favored over the Poisson's.

Table 4 Results of Negative Binomial Model of Elder Driver Crashes

Variables	Coef.	Std. Err	Z	P>|z|	95% CI Min	95% CI Max
Rural_Urban	-.04861	.10756	-0.45	0.651	-.2594	.16221
Max_Posted_Speed	-.36082	.18878	-1.91	0.056	-.7308	.00919
AADT	.19548	.09487	2.06	0.039	.0095	.38143
Avg_T_Factor	.10743	.14279	0.75	0.452	-.1724	.38730
Divided_Undivided	-.52358	.13087	-4.00	0.000	-.7801	-.26709
Median_Width	-.02251	.06314	-0.36	0.721	-.14627	.10124
Surface_Width	-.12516	.11820	-1.06	0.290	-.35680	.10650
Number_of_Lanes	-.00892	.10462	-0.09	0.932	-.21397	.19612
Left/Right Lane	.02740	.11473	0.24	0.811	-.19746	.25226
Left/Right_Turn_Sight	-.30396	.11307	-2.69	0.007	-.52558	-.08235
Curvature	-.06853	.26464	-0.26	0.796	-.58721	.45015
Superelevation	-.38206	.44256	-0.86	0.388	-1.2494	.48533
Level_Not_Level	.11257	.18633	0.60	0.546	-.25263	.477779
No_Skew_Skew	-.02564	.14515	-0.18	0.860	-.31014	.25886
Shoulder_Type	.06030	.06180	0.98	0.329	-.06074	.18150
Blacktop_Not	.16360	.26889	0.61	0.543	-.3634	.69060
Skid_Test_Results	.24237	.13573	1.79	0.074	-.02369	.50835
Delineation	-.16662	.23639	-0.70	0.481	-.62994	.29670
Advanced_Lane_Assignment	.23598	.19546	1.21	0.227	-.14713	.61908
Raised_Pavement_Markers	-.42168	.14108	-2.99	0.003	-.69819	-.14517
Signalized_Unsig	-.43688	.24774	-1.76	0.078	-.92246	.04869
Signal_Head_Type	-.06170	.14273	-0.43	0.665	-.34143	.21802
Signals_Lanes	-.01703	.1542	-0.11	0.912	-.31930	.28523
Signals_Line_Up	.06902	.34523	0.20	0.842	-.60761	.74565
Signal_Visibility	-.01963	.38009	-0.05	0.959	-.76451	.72532
Advanced_Signage	.04882	.12990	0.38	0.707	-.20579	.30342
Signs_Visible	-.28536	.23899	-1.19	0.233	-.75373	.18308
Sign_Placement	.16665	.34251	0.49	0.627	-.50467	.83796
Internal_Contrast	.15916	.26277	0.61	0.545	-.35587	.67419
External_Contrast	-.39705	.30019	-1.32	0.186	-.98540	.19131
Retro_Reflective_Signage	.36291	.26040	1.39	0.163	-.14747	.87329
Visual_Clutter	.06810	.15975	0.43	0.670	-.24501	.38120
Constant	.91119	.65956	1.38	0.167	-.38151	2.2039

Likelihood-Ratio test of NB model: $chi^2(32)=123.76$, Prob > $chi^2=0.0000$ ∴ whole model significant
Log likelihood=-1003.3992 (full), LL=-1065.277 (intercept only) ∴ full model favored over constant only
α=0.62656 LR test of α: $chi^2(01)=191.68$, Prob > $chi^2=0.0000$ ∴ α≠0, NB favored over Poisson
Akaike Information Criterion (AIC)=3.475
Bayesian Information Criterion (BIC)=-1591.851, BIC'=80.786

Four variables were found to be significant at the 95% confidence level in the standard negative binomial model. Of these, *AADT* had a positive coefficient, indicating that an increase in traffic correlated with an increase in elder driver crashes. *Divided_undivided* had a negative coefficient, meaning that undivided highways, the higher valued category, correlated to a decrease in elder driver crashes, with respect to divided highways, the lower valued category. Finally, *left/right_turn_sight* and *raised_pavement_markers* had negative coefficients, implying that decreased sight distances and lack of RPM's correlate to decreases in elder driver crashes, both unexpected results. *Max_posted_speed*, *skid_test_results*, and *signalized_unsig* were all significant at the 90% confidence level, with higher speed limits, increased pavement friction, and unsignalized intersections correlating to decreases in elder driver crashes.

Whenever there are large numbers of zeros in the count data, the Poisson or negative binomial distribution may not satisfactorily fit the data, and a zero-inflated count model might be preferred. In essence, zero-inflated regression models are characterized by a dual-state process, where the observed count can either be located in a perfect state (zero elder driver crashes) or in an imperfect state (one or more elder driver crashes). First, the model estimates the effects of the independent variables on the crash frequency; these coefficients are interpreted just like standard negative binomial coefficients. For these variables, a positive coefficient indicates that increasing the value of the independent variable in question results in a higher probability of zero crashes occurring at an intersection.

The Vuong test was used to investigate fit of the zero-inflated model. The Vuong test statistic (V) has an asymptotic normal distribution; if V is more positive than 1.96, the zero-inflated model has a better fit with the observed data, with 95% confidence. However, if V has a large negative value, then the normal Poisson or negative binomial is preferred. Because 216 of the 597 intersections had zero elder-driver crashes, a zero-inflated negative binomial (ZINB) model was run to investigate its fit. Initially the model failed to converge, and convergence had to be forced artificially. Table 5 shows the results of the ZINB model, including goodness of fit statistics. In addition to the low Vuong's statistic of 0.28 (p=0.3887), which fails to favor the zero-inflated model, note the high p-values for almost every coefficient in the non-inflated portion of the model. Because this model had such poor fit with the data, its results are not discussed any further.

Table 5 Results of Zero Inflated Negative Binomial Model of Elder Driver Crashes

Variables	Coef.	Std. Err	Z	P>|z|	95% CI Min	95% CI Max
Rural_Urban	.00208	.11054	.020	.985	-.2146	.21874
Max_Posted_Speed	-.01552	.20836	-.070	.941	-.4239	.39286
AADT	.01888	.09917	.190	.849	-.1755	.21324
Avg_T_Factor	.01644	.15780	.100	.917	-.2928	.32573
Divided_Undivided	-.01994	.14260	-.140	.889	-.2994	.25954
Median_Width	-.00182	.06570	-.030	.978	-.1306	.12695
Surface_Width	-.00913	.12116	-.080	.940	-.2466	.22834
Number_of_Lanes	.00129	.10830	.010	.991	-.2110	.21355
Left/Right Lane	.00521	.11986	.040	.965	-.2297	.24013
Left/Right_Turn_Sight	-.00921	.11779	-.080	.938	-.2401	.22166
Curvature	.00562	.28217	.020	.984	-.5474	.55867
Superelevation	-.04963	.45925	-.110	.914	-.9497	.85048
Level_Not_Level	-.00134	.19040	-.010	.994	-.3745	.37184
No_Skew_Skew	-.00320	.15089	-.020	.983	-.2990	.29254

Shoulder_Type	.00034	.06414	.010	.996	-.1254	.12606
Blacktop_Not	.01927	.28917	.070	.947	-.5475	.58604
Skid_Test_Results	.01638	.14077	.120	.907	-.2595	.29229
Delineation	-.00911	.24575	-.040	.970	-.4908	.47255
Advanced_Lane_Assignment	.00925	.20417	.050	.964	-.3909	.40943
Raised_Pavement_Markers	-.02621	.14822	-.180	.860	-.3167	.26430
Signalized_Unsig	-.02309	.25977	-.090	.929	-.5322	.48606
Signal_Head_Type	-.00645	.14366	-.040	.964	-.2880	.27512
Signals_Lanes	-.00287	.15507	-.020	.985	-.3068	.30105
Signals_Line_Up	-.00017	.34844	.000	1.000	-.6831	.68276
Signal_Visibility	.01035	.40743	.030	.980	-.7882	.80889
Advanced_Signage	.00114	.13223	.010	.993	-.2580	.26031
Signs_Visible	.00018	.26134	.000	.999	-.5120	.51241
Sign_Placement	.01658	.34638	.050	.962	-.6623	.69548
Internal_Contrast	.01496	.26232	.060	.955	-.4992	.52909
External_Contrast	-.03706	.30711	-.120	.904	-.6390	.56487
Retro_Reflective_Signage	.02519	.27105	.090	.926	-.5061	.55644
Visual_Clutter	-.00006	.16049	.000	1.000	-.3146	.31450
Constant	.60991	.69867	.870	.383	-.7595	1.97929
Inflated Model						
Rural_Urban	99.65832	6.57686	1.650	.100	-19.070	218.387
Max_Posted_Speed	5.02518	34.07831	1.470	.142	-16.767	116.817
AADT	55.38322	42.05830	1.320	.188	-27.049	137.816
Avg_T_Factor	66.54515	38.91239	1.710	.087	-9.7217	142.812
Divided_Undivided	156.3271	89.99377	1.740	.082	-2.057	332.712
Median_Width	1.09974	17.61634	.060	.950	-33.428	35.6271
Surface_Width	-11.2873	59.34587	-.190	.849	-127.60	105.028
Number_of_Lanes	19.75070	28.80556	.690	.493	-36.707	76.2086
Left/Right Lane	12.01746	16.17989	.740	.458	-19.694	43.7295
Left/Right_Turn_Sight	136.7313	86.50034	1.580	.114	-32.806	306.269
Curvature	84.56425	5.79315	1.660	.096	-14.989	184.117
Superelevation	-15.614	95.59581	-1.580	.115	-337.98	36.7500
Level_Not_Level	-8.6892	8.29738	-1.000	.315	-238.07	76.6908
No_Skew_Skew	-26.0747	19.19403	-1.360	.174	-63.694	11.5449
Shoulder_Type	-65.8878	38.87370	-1.690	.090	-142.08	1.3032
Blacktop_Not	91.04876	54.50525	1.670	.095	-15.780	197.877
Skid_Test_Results	-14.6106	47.55292	-.310	.759	-107.81	78.5914
Delineation	-2.95583	149.88150	-.020	.984	-296.72	29.807
Advanced_Lane_Assignment	-95.5158	96.35718	-.990	.322	-284.37	93.3408
Raised_Pavement_Markers	18.91258	31.62997	.600	.550	-43.081	8.9062
Signalized_Unsig	8.07769	56.15628	1.430	.154	-29.987	19.142
Signal_Head_Type	5.66935	69.45532	.080	.935	-13.46	141.799
Signals_Lanes	-137.107	107.80690	-1.270	.203	-348.40	74.1901
Signals_Line_Up	-.46180	.00000	-	-	-.4619	-.4618
Signal_Visibility	91.21616	375.76540	.240	.808	-645.27	827.703
Advanced_Signage	-27.8642	65.88325	-.420	.672	-156.99	101.265
Signs_Visible	136.5794	117.76200	1.160	.246	-94.230	367.389
Sign_Placement	-14.4961	23.37350	-.060	.950	-466.02	437.028
Internal_Contrast	61.88449	363.22430	.170	.865	-65.02	773.791

External_Contrast	-126.666	417.42140	-.300	.762	-944.78	691.465
Retro_Reflective_Signage	-65.7344	69.56497	-.940	.345	-202.08	7.6104
Visual_Clutter	-128.851	139.84660	-.920	.357	-402.94	145.243
Constant	-463.603	267.68650	-1.730	.083	-988.26	61.053

Likelihood-Ratio test of NB model: $chi^2(64)=10.88$, Prob > $chi^2=1.0000$ ∴ whole model not significant
Log likelihood=-1005.93 (full), LL=-1000.49 (intercept only) ∴ full model favored over constant only
$\alpha=0.71329$, Prob > $chi^2=1.0000$ ∴ $\alpha \neq 0$, NB favored over Poisson
AIC=3.576, BIC=-1386.74, BIC'=285.894

Numerous other models, including Poisson, zero-inflated Poisson, and several stepwise selection and zero-truncated models, were tested to ensure that the model with the best fit parameters was chosen. The best fit statistics, as measured by the smallest Akaike Information Criterion (AIC) and the most negative Bayesian Information Criterion (BIC), favored a compact model generated by a forward stepwise selection based on the standard binomial regression model. Stepwise regression removes the potential biasing effect of manual variable selection with its preconceptions on which factors should be included in the model. A forward stepwise selection process starts with an empty model and then incrementally adds and removes variables while optimizing model fitness values. The process terminates if no further variable can be added to the model or if the variable just entered into the model was the only variable removed in the previous elimination step. A *p*-value of 0.15 was chosen as a cutoff for adding variables to the model, implying that variables with greater than 85% confidence were added, and a *p*-value of 0.30 was chosen as a cutoff for removing variables.

The selection process resulted in a model with nine variables, summarized in Table 6. The AIC of 3.414 and BIC of -1729.38 were the smallest and most negative, respectively, of all models tested in the study. The likelihood ratio chi-squared of 101.81 indicated that the data had good overall fit with the data (*p*=0.000).

Table 6 Results of Negative Binomial Model with Stepwise Selection for Elder Driver Crashes

Variables	**Coef.**	**Std. Err**	**Z**	**P>|z|**	**95% CI Min**	**95% CI Max**
Signalized_Unsig	-.70229	.09998	-7.02	0.000	-.89825	-.50633
Divided_Undivided	-.50707	.12207	-4.15	0.000	-.74632	-.26783
Raised_Pavement_Markers	-.45880	.12924	-3.55	0.000	-.71211	-.20549
Left/Right_Turn_Sight	-.29016	.10775	-2.69	0.007	-.50135	-.0790
Max_Posted_Speed	-.32436	.17136	-1.89	0.058	-.66022	.01149
Advanced_Lane_Assignment	.33577	.15063	2.23	0.026	.04053	.63101
AADT	.14649	.07491	1.96	0.051	-.00034	.29332
Skid_Test_Results	.23734	.13271	1.79	0.074	-.02276	.49745
Signs_Visible	-.31926	.21612	-1.48	0.140	-.74284	.10432
Constant	.97834	.44664	2.19	0.028	.10294	1.8538

Likelihood-Ratio test of NB model: $chi^2(9)=114.274$, Prob > $chi^2=0.0000$ ∴ whole model significant
Log likelihood=-1065.277 (full), LL=-1008.140 (intercept only) ∴ full model favored over constant only
$\alpha=0.6480677$, LR test of α: $chi^2(01)=202.35$, Prob > $chi^2=0.0000$ ∴ $\alpha \neq 0$, NB favored over Poisson
AIC=3.414, BIC=-1729.383, BIC'=-56.746

The results of this model are very similar to the negative binomial model based on all 32 variables (see Table 4). Five variables were found to be significant at the 95% confidence level in the compact negative binomial model. Of these, *signalized_unsig* and *divided_undivided* had negative coefficients, meaning that unsignalized and undivided intersections were associated with fewer elder-driver crashes than signalized and divided intersections, respectively. Again, *left/right_turn_sight* and *raised_pavement_markers* had negative coefficients, implying that decreased sight distances and lack of RPM's correlate to a decrease in elder driver crashes. *Advanced_lane_assignment*, which previously was not significant, is significant at the 95% confidence level in this model; the positive coefficient implies that lack of lane assignment markers (the higher valued category) increases crash risk for older drivers. *Max_posted_speed*, *AADT*, and *skid_test_results* were all significant at the 90% confidence level, with higher speed limits, increased traffic counts, and increased pavement friction correlating to decreases in elder driver crashes.

To provide comparison data, similar models were run on the crashes where a non-elder driver was found to be at fault. The analogous models showed comparable results to those found with the elder crash data, except that the ZINB was significant and preferred over the standard NB model (p=0.000). Again, however, the model had to be forced artificially into convergence, and no variables in the inflated model were significant at a confidence above one percent; therefore, the model was discarded as not fitting the data. Despite the presence of fewer zero-crash intersections than might be predicted by a standard negative binomial model (as evident in Figure 7), a zero-truncated model (ran against only the intersections with at least one crash) did not have better fit with the data. Again, the model with best fit with the non-elder crash data, as measured by the smallest Akaike Information Criterion (AIC) and the most negative Bayesian Information Criterion (BIC), was a compact model generated by a forward stepwise selection based on the standard binomial regression model. Results of this model are presented in Table 7; note that the AIC and BIC values were superior compared to the other models of non-elder crashes, and cannot be directly compared to those listed previously for elder driver crashes.

Table 7 Results of Negative Binomial Model with Stepwise Selection for Non-Elder Driver Crashes

Variables	Coef.	Std. Err	Z	P>|z|	95% CI Min	95% CI Max
Signalized_Unsig	-.92411	.18316	-5.05	0.000	-1.283	-.56513
AADT	.36346	.06870	5.29	0.000	.22879	.49813
Curvature	-.58609	.18879	-3.10	0.002	-.95611	-.21607
Signals_Line_Up	-.91592	.31408	-2.92	0.004	-1.5315	-.30033
Retro_Reflective_Signage	.39527	.18433	2.14	0.032	.03400	.75654
Signal_Head_Type	-.31456	.12334	-2.55	0.011	-.55629	-.07282
Advanced_Signage	.23820	.09946	2.39	0.017	.04327	.43314
Surface_Width	.15413	.08604	1.79	0.073	-.01450	.32277
Raised_Pavement_Markers	-.17438	.10314	-1.69	0.091	-.37654	.02778
Constant	1.8866	.32346	5.83	0.000	1.2527	2.5206

Likelihood-Ratio test of NB model: $chi^2(9)$=259.026, Prob > chi^2=0.0000 ∴ whole model significant
Log likelihood=-1966.439 (full), LL=-1836.925 (intercept only) ∴ full model favored over constant only
α=0.8292397, LR test of α: $chi^2(01)$=3143.55, Prob > chi^2=0.0000 ∴ $\alpha \neq 0$, NB favored over Poisson
AIC=6.191, BIC=-71.812, BIC'=-201.499

As with the elder crash model, the compact model for the non-elder crashes had nine variables. However, many of the significant variables are different. The three variables that were common to both models, *signalized_unsig*, *AADT*, and *raised_pavement_markers*, had the same coefficient signs, and therefore can be interpreted similarly. The remaining six variables were not significant in any elder driver model. The *signal_head_type* and *signals_line_up* variables both have negative values, indicating that mast arm signals and signals offset from the travel lanes are both associated with decreased likelihood of crashes. Positive coefficients on the *retro_reflective_signage* and *advanced_signage* variables indicate that lack of these safety features correlated with increased crash probabilities, as would be expected. However, a negative coefficient on the *curvature* variable implies that increasing curvature is associated with decreased probability of crashes where non-elder drivers were at fault.

4. CONCLUSIONS

This study sought to evaluate the factors affecting elder driver intersection crashes by building a crash prediction model that examines older driver crash frequency using variables obtained from quantitative variables such as maximum posted speed limit and subjective variables such as sign visibility. A similar model for non-elderly driver crashes was developed for comparison. For this study, statistical tests revealed the crash data were overdispersed, favoring the negative binomial over the Poisson distribution. Despite the presence of many zero-crash intersections in the older driver data set, and somewhat fewer zero-crash intersections in the non-older driver data set, neither zero-inflated nor zero-truncated models were preferred over the standard negative binomial model. Best-fit models, as measured by Akaike and Bayesian Information Criteria, were chosen; the favored models for both elder and non-elder crashes were standard negative binomial models reduced using forward stepwise regression. Table 8 provides a summary of factors that were found significant at the 90 percent confidence level, and a statement of how each variable affects elder and/or non-elder crashes.

Table 8 Summary of Contributing Factors in Crashes with Elder and Non-Elder At-Fault Drivers

	Significant Variables and Preferred States	
Independent Variable	**Elder Driver Crashes**	**Non-Elder Driver Crashes**
Signalized_Unsig	Unsignalized better	Unsignalized better
AADT	Lower traffic count better	Lower traffic count better
Raised_Pavement_Markers	No RPM's better	No RPM's better
Divided_Undivided	Undivided better	No significant effect
Left/Right_Turn_Sight	Less sight distance better	No significant effect
Max_Posted_Speed	Higher speed limit better	No significant effect
Advanced Lane Assignment	Advanced markings better	No significant effect
Skid_Test_Results	Increased friction better	No significant effect
Curvature	No significant effect	Increased curvature better
Signals_Line_Up	No significant effect	Signals offset from lanes better
Retro_Reflective_Signage	No significant effect	Retro-reflective signage better
Signal_Head_Type	No significant effect	Mast arm signals better
Advanced_Signage	No significant effect	Advanced signage better
Surface_Width	No significant effect	Wider roads better

Examining the conclusions in Table 8, major operation and design aspects, such as high traffic counts and absence of signalization and medians, appear to be much more significant measures of crash likelihood than other features or safety enhancements. Undivided highways and unsignalized intersections with low traffic counts were likely associated with decreased crash probability because they are simpler, easier to visually inspect and easier to navigate. Many other variables in the study, including geographical location, grade, presence of truck traffic, and type of pavement and shoulder, had little to no effect on intersection safety. This list includes several factors examined by other researchers, including delineation quality, skew angles, and sign contrast and visibility (Staplin et al, 1997; Isler et al, 1997; Scialfa et al, 2008). Results are consistent with those of other researchers that appear to indicate that older drivers either do not have increased difficulty with sign detection under various environments, or are able to effectively compensate for age-related vision decreases (Sturr et al, 1990; Ho et al, 2001; Kline et al, 1999; Schnell et al, 2004).

Several qualitative safety features, including advanced warning signs that might have initially been installed as part of the Florida Elder Road User Program, had greater impacts on non-elderly drivers. Younger drivers were also more prone to traffic crashes at intersections with lower sign reflectivity and hanging signals, factors which did not impact older drivers. However, older drivers had more crashes when pavements were not marked with advanced lane assignment markers and when skid resistance was lower.

Several results of the study appear counter-intuitive, such as decreased crash likelihoods with higher speed limits, decreased turning sight distances, and curvature. These effects might be caused by self-limiting behavior among drivers (D'Ambrosio et al, 2007). For instance, drivers might avoid left-turning movements on segments with higher speed limits or poor sight distance. Higher crash rates also might be correlated with certain safety features, such as RPM's, because the safety features are so commonplace, or because the safety devices were placed at intersections which already had much higher than average crash rates. However, additional research should be directed toward each unexpected result. In addition, examining contributing factors by crash type and severity is also recommended.

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