AN ANALYSIS OF OLDER-DRIVER INVOLVEMENT IN CRASHES AND INJURY SEVERITY IN KANSAS

by

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Abstract

The older population (>65 years) numbered 36.8 million in the United States in 2005. By 2030, the number is estimated to be 71.5 million, almost twice as many. An increase in the older population means an increase in older drivers as well. As a result of the natural aging process, the possibility of older drivers being involved in crashes and sustaining severe injuries increases, according to past findings. The objective of this study was to identify characteristics of older drivers involved in crashes in Kansas as well as associated safety issues, which can be used to suggest potential countermeasures for improving safety.

A detailed characteristic analysis was carried out for older, middle-aged, and younger drivers involved in crashes, using crash data obtained from the Kansas Department of Transportation, and comparisons were made among the groups. However, the characteristic analysis had no basis with regard to injury severity and hence, univariate statistical analysis was carried out to highlight these severities. In addition, a survey was conducted focusing on identifying older-driver behaviors, potential problems, and level of exposure to various conditions. From the severity analysis, it was found that injury severity of older drivers in crashes occurring on rural roads was significantly higher compared to those on urban roads. Therefore, a detailed analysis was carried out using the decomposition method and ordered probit modeling to identify contributing factors leading to the situation.

According to the findings, the number of older male drivers involved in crashes was higher compared to older female drivers, even though older driver licensees' data indicate the opposite. Most of the older-driver-involved crashes occurred under good environmental conditions and at intersections. A majority of older drivers had difficulties associated with left-turn maneuvering and preferred to avoid high-traffic roads and other demanding conditions. Exposure to inclement weather conditions and difficulties associated with merging, diverging, and identifying speeds and distance of oncoming traffic have lead to higher crash propensity. In rural areas, driving in the wrong direction, failing to comply with traffic signs and signals, and speeding were identified as frequent contributing factors in high severe crashes.

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Finally, I would like to thank all my colleagues, friends, and family members for their continuous encouragement and support.

Dedication

I would like to dedicate my thesis to my parents, H.N.G. Perera and U.R.K. Menike, who gave me a tremendous support to make everything in my life a success. Also I would like to dedicate this to my teachers from the school, and the university, who gave me the courage and support to rise in my academic career so far.

CHAPTER 1 - Introduction

1.1 Background

More than 2.2 million persons celebrated their 65th birthday in 2006 in the United States, while about 1.8 million persons 65 years or older died. Census estimates show an annual net increase of about 500,000 in the number of persons 65 years and over. The older population (persons 65 years or older) numbered 37.3 million in 2006 and represented 12.4% of the total U.S. population, or about one in every eight Americans *(1)*. The older population is expected to further increase in the future; by 2030 there will be an estimated 71.5 million older people in the United States, which is more than twice the older population in 2000. Kansas also indicated a similar trend as the U.S., showing 357,709 older people in 2006, which represents 12.9% of the total population in Kansas *(2)*.

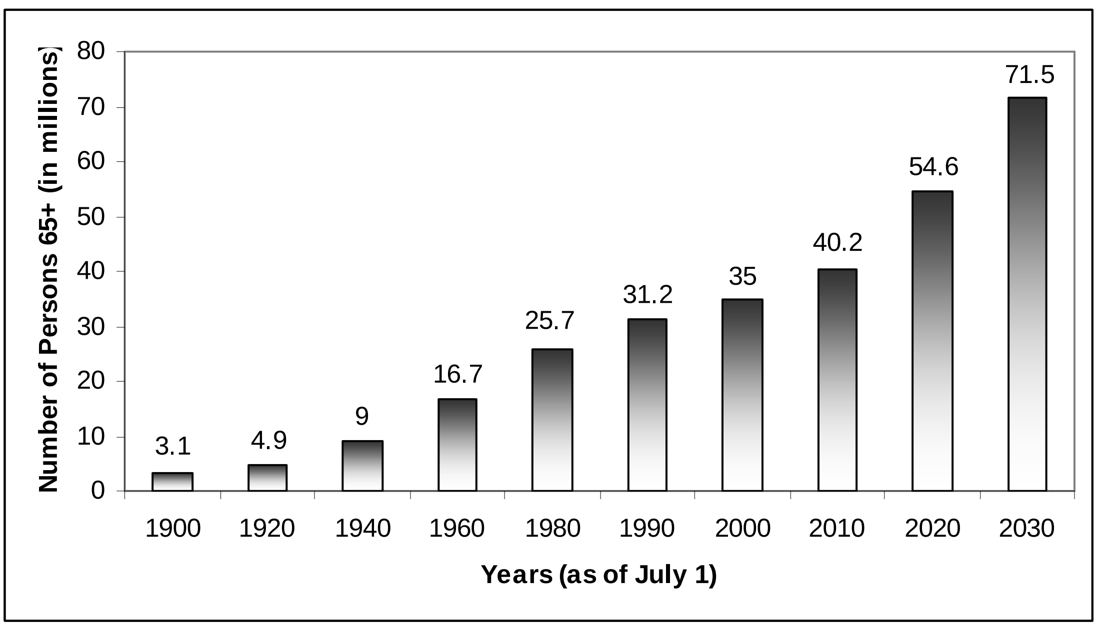

Figure 1.1 Number of Persons 65+ years in U.S., 1900-2030

Note: Increments in years are uneven.

(Source: A Profile of Older Americans: 2007) (1)

The population 65 years and over in the United Sates is estimated to increase from 35 million in 2000 to 40 million in 2010, and then to 55 million in 2020. This is a 15% and 40% increase for that decade, respectively. Moreover, the 85 years and over population is projected to increase from 4.2 million in 2000 to 6.1 million in 2010, and then to 7.3 million in 2020. As a percentage, this is a 40% and 44% increase for that decade, respectively.

When analyzing crash data in Kansas for the past 10 years, a decreasing trend in all people involved in crashes can be observed. Figure 1.2 depicts the comparison between older people to all ages involved in crashes; it is important to note that older people represent older drivers, older occupants, and older pedestrians in this chart. However, a majority of older people involved in crashes are drivers. Details of these numbers are presented in Appendix-A.

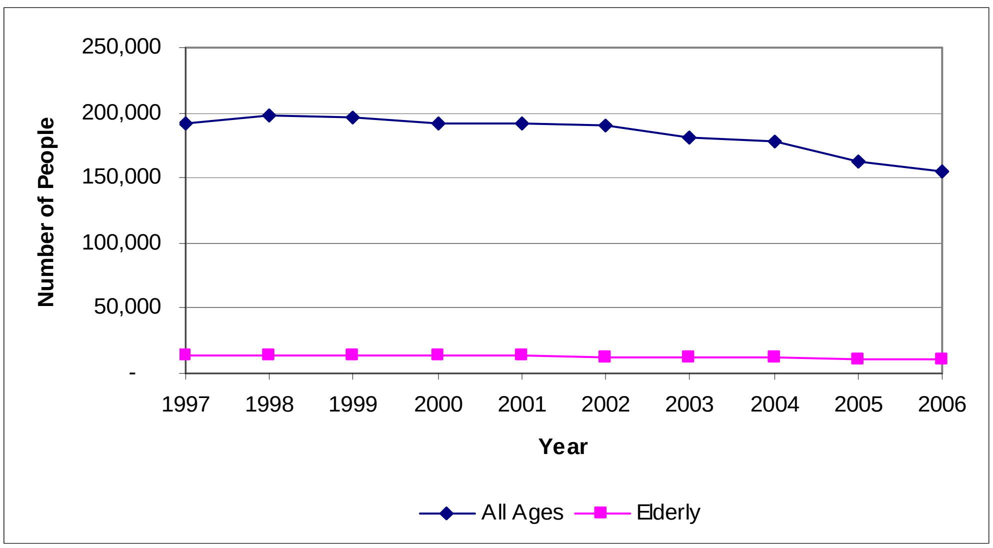

Figure 1.2 Comparison of Number of People Involved in Crashes Based on Age: Older People vs. All Ages

Over the last decade, a decrease in the total number of people involved in crashes can be observed, whereas there is no such clear variation among the elderly population. This could be mainly due to two reasons. Either, there was no improvement in the elderly population with respect to involvement in crashes and as a result the same number of crashes seemed to occur each year, or there was an improvement among the elderly population and there was a reduction in involvement in crashes, but it has been compensated by an increased number of the elderly population so no differences can be observed. The latter assumption is more appropriate, which can logically explain the situation with regard to higher elderly population growth rates over the last decade.

Similarly, the people involved in crashes presented in Figure 1.2 can be classified into five different categories based on the severity of injuries caused as a result.

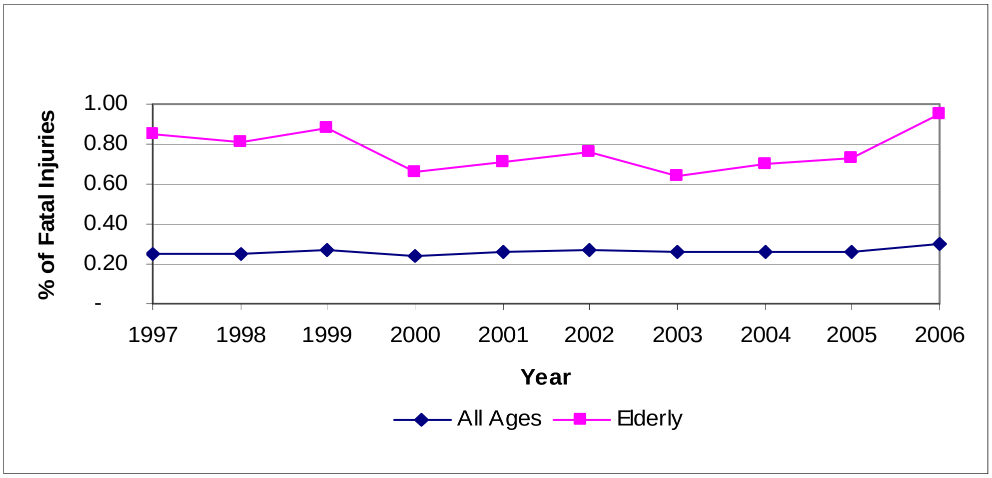

Figure 1.3 Comparison of Fatal Injuries to People Involved in Crashes Based on Age: Older People vs. All Ages

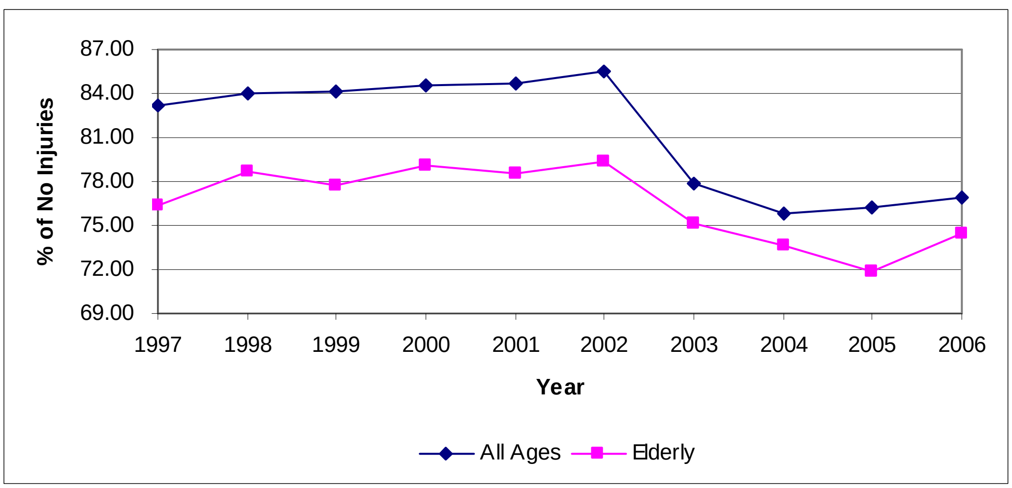

Figure 1.4 Comparison of No Injuries to People Involved in Crashes Based on Age: Older People vs. All Ages

Figures 1.3 and 1.4 depict the highest and lowest injury severity levels as a result of crashes. Figures depicting intermediate injury severity are presented in Appendix-B. By considering the figures, it is evident that older people experience higher injury severity when they are involved in crashes as compared to others, and the number of older people remaining uninjured as a result of crashes is lower compared to all ages.

1.2 Problem Statement

Since older drivers are a subgroup of the older population, an increase in the older population means an increase of older drivers as well *(3)*. This is more accurate for a state like Kansas where dependence upon vehicles is quite high. According to past research studies, older drivers tend to be involved in more severe crashes as compared to middle-aged drivers *(4, 5, and 6)*. On the other hand, advancement in technology and many other factors have led to an increase in life expectancy of an average person. According to the U.S. Administration on Aging, in 2004, persons reaching age 65 had an average life expectancy of an additional 18.7 years (20 years for females and 17.1 years for males as compared to 1900) *(1)*. But, as a result of natural aging, older drivers experience physical difficulties such as loss of vision, slower perception reaction times, decrement in depth perception and peripheral vision, and deterioration of physical strength and concentration. These may directly affect older drivers' driving capabilities and skills, which may increase the possibility of this group being victims of motor vehicle crashes. From a safety point of view, this has a direct impact on safety aspects for all road users.

When considering these facts, improving older-driver safety is important and as the first step, it is key to identify characteristics and factors related to older-driver safety in Kansas. This study is expected to serve that purpose.

1.3 Objectives

The objective of this study was to identify characteristics and factors related to older drivers and their involvement in crashes in order to improve their safety on the road in the future. Improvement could be accomplished in two ways. First, reduce the risk of older drivers from being involved in crashes and second, reduce their injury severity when crashes occur. Therefore, identifying factors related to various aspects of older drivers and diversified conditions contributing to older-driver safety was given priority in this study. Identification of possible strategies to improve the safety of older drivers and other road users was also considered.

Improvements were not limited to driver-related factors, but covered geometric arrangements and traffic operations as well.

1.4 Outline of the Thesis

This thesis consists of five chapters, covering the background, problem statement, and objectives in the first. The second chapter consists of a review of prior research related to the study area. In the third chapter, methodologies used in the analysis are presented along with descriptions of data used in the study. The fourth chapter covers the results from both preliminary and statistical analysis, and a detailed discussion is presented, relating results to past findings. In the final chapter summary and conclusions are presented and recommendations are also given suggesting possible countermeasures to improve the safety of older drivers.

CHAPTER 2 - Literature Review

Older-driver safety-related research studies have an extended history in addressing different safety aspects using a variety of databases and surveys. Past researchers have used various statistical modeling techniques to predict or explain the nature of older-driver crashes or injuries, and there are many findings listed under this area. Furthermore, different types of crashes have been examined by these researchers, narrowing down the study to identify more specific factors related to selected states. In this chapter an extensive discussion of past findings are presented under the following subsections: age and gender comparisons, rates and trends, injury severity and crash risk, crash types and related maneuvering difficulties, intersection-related crashes, effect of passengers on older drivers' safety, risk to self and risk to others, countermeasure evaluations, medication and risk of injuries, decision to stop driving, vehicle design, and statistical methodologies.

2.1 Age and Gender Comparisons, Rates, and Trends

McGwin and Brown *(4)* carried out a study comparing characteristics among young, middle-aged, and older drivers in the state of Alabama. Crash rates were calculated using two main approaches: per licensed driver and per person-mile of travel. Following the crash rates, the study was extended to analysis of more characteristics such as responsibility, driver conditions, temporal characteristics, roadway characteristics, environmental and geographic characteristics, crash characteristics, driver actions, and alcohol involvement. Significant differences between category frequencies were determined using the chi-square test. According to the results, young and older drivers are more often at fault in crashes as compared to middle-aged drivers. Characteristics results were similar to past findings such as older drivers are overrepresented in intersection-related crashes, failure to yield right of way, failure to heed stop signs and signals, crashes occurring at daylight in good weather conditions, and at lower speeds on straight roads, etc. The study concluded that younger drivers are risk takers but also lack in driver skills. On the other hand, older drivers are risk averse and have excellent driving skills. But with age, perceptual problems and difficulty judging and responding to traffic have counterbalanced this attribute among older drivers.

Abdel-Aty et al. *(7)* used conditional probabilities to explore the potential relationships between driver age and factors related to crash involvement including crash location, manner of collision, roadway character, speed of vehicles prior to crash, roadway surface conditions, and light conditions. It was found that the elderly (≥65 years) are overrepresented in crashes that occur at intersections. Irrespective of the location, older drivers are overrepresented in right-turn and left-turn related crashes and angle collisions. Older drivers tend to avoid bad weather or poor driving conditions, and therefore, their crashes tend to occur under clear weather conditions and during daylight times. In general, the analysis indicated that both young and old drivers are usually over involved in crashes. The younger group tends to drive in situations or conditions where there are higher risks, but elderly drivers tend to avoid adverse conditions as an attempt to compensate for the decline in their driving capabilities.

Cook et al. *(8)* calculated the odds of different characteristics exhibited by older drivers and odds of older drivers being killed or hospitalized compared to those of younger counterparts. Results showed that older drivers are less likely to have crashes at high speeds, involving right-turns, and involving drug or alcohol use. But they were more than twice as likely to have crashes involving left-turns and also more likely to be killed or hospitalized than young drivers. Among belted drivers, an older driver was nearly seven times more likely to be killed or hospitalized than a young driver.

Li et al. *(9)* estimated the susceptibility to injury versus excessive crash involvement in the increased fatality risk of older drivers per vehicle-mile of travel (VMT). Elderly drivers older than 75 years and younger drivers had much higher driver death rates per VMT compared with drivers aged 30-59 years. The highest death rates per mile driven and the highest death rates per crash were found among drivers 80 years or older. Further results showed that the fragility began to increase starting at the age of 60 years and increased steadily with advancing age.

Lyman et al. *(5)* calculated driver-involvement rates for all police-reported crashes per capita, per licensed driver, and per vehicle-mile traveled for 1990 and 1995. Also driver-involvement rates for fatal crashes were calculated, and based on these, projections were made for years 2010, 2020, and 2030. Using projections of population growth, it was estimated that for all ages there would be a 34 percent increase in the number of drivers involved in police-reported crashes and a 39 percent increase in the number of drivers involved in fatal crashes between 1999 and 2030. In contrast, among older drivers, police-reported crash involvements are expected to increase by 178 percent and fatal involvements are expected to increase by 155 percent by 2030.

Baker et al. *(3)* studied the special characteristics of fatal crashes involving females older than 70 years and found that senior women are overrepresented in crashes that occur under what is generally considered as the "safest" conditions in daylight, when traffic is low, when the weather is good, and when the road is dry.

2.2 Injury Severity and Crash Risk

Dissanayake and Lu *(10)* carried out a study to identify factors influencing injury severity of older drivers involved in fixed-object passenger car crashes. Crash data in the state of Florida was used for this study from years 1994 to 1996. Two models were developed using binary logistic regression modeling for crash severity and injury severity. The explanatory variables were selected from four categories: driver related, vehicle related, roadway related, and environment related. Since the respondent variable had different levels of severity as marked in police crash reports, several sets of sequential binary logistic regression models were developed. It was found that from the model for most severe to less severe had better predictive capability than the others. Further, they found that the injury-severity model had better predictive capability than the crash-severity model. Travel speed was found as an important parameter capable of generating different levels of injury severity. Similarly, use of restraint devices was found as important in making a difference in injury severity. The variable representing the point of impact in the crash was also found to be important, and the odds of front impact causing severity were high. Use of alcohol and drugs, personal condition, gender, whether the driver was at fault, urban/ rural nature, and grade/ curve existence at the crash location were also found as important parameters in predicting injury severity. Among their findings, older males had a higher probability of generating less severe injuries when involved in crashes compared to others and conversely, rural locations and locations with curves or grades had a higher probability of generating more severe injuries to older drivers.

Abdel-Aty *(11)* analyzed driver injury-severity levels using the ordered probit modeling methodology. Three different models were developed for roadway sections, signalized intersections, and toll plazas in central Florida. Results showed that several factors were common in all three models such as driver age, gender, seat belt use, vehicle type, point of impact, and speed ratio. Further results revealed that wherever a crash occurred, older drivers, male drivers, and those not wearing seat belts had a higher chance for severe injuries. Results from the roadway section model showed crashes at curves and those in rural areas were more likely to cause injuries. In the signalized intersection model, it was found that driver violation was significant and in toll plazas, vehicles equipped with electronic toll-collection devices had a propensity for higher injury severity.

Boufous et al. *(12)* carried out a study based on a past finding that “older people are more likely to be seriously injured or to die as a result of a traffic crash.” Multivariate analysis was carried out and various factors were found to be independent predictors for injury severity among older people. In addition, they found that intersection configuration could explain over half of the observed variation in injury severity and concluded that intersection treatments might help to reduce injury severity in crashes.

Khattak et al. *(13)* carried out a study to identify factors contributing to severe injuries among older drivers involved in traffic crashes. Crash data from 1990-1999 in the state of Iowa were used for this study where an older driver was injured. According to their study, older male drivers experienced more severe injuries when compared to older female drivers, and unprotected older drivers incurred more severe injuries irrespective of gender. Further, the model revealed that crashes occurring on horizontal curves on level terrain were more injurious as compared with crashes occurring at other locations. The model also showed that older drivers under the influence of alcohol experienced more severe injuries when compared with older drivers who were not under such influence. Injury levels were found to be more severe at higher-speed-limit roadways and older drivers tended to be more severely injured if the crash occurred on a rural road.

2.3 Crash Types and Related Maneuvering Difficulties

Older drivers’ maneuvering difficulties compared with younger drivers were studied by Chandraratna and Stamatiadis *(14)*. Kentucky crash data were used and through the literature survey three main types of maneuverings were identified as more common among elderly drivers: left turns against oncoming traffic, gap acceptance for crossing non-limited-access highways, and high-speed lane changes on limited-access highways.

It was found that the risk of an older driver being involved in a left-turn crash increased after the age of 65, with higher tendencies in rural areas. Light conditions were also a contributing factor for left-turn crashes and females had a higher chance of being involved in left-turn crashes compared to males. However, younger females also had a higher propensity to be involved in left-turn-related crashes but not as high as elderly females. Similar results were obtained for gap acceptance and again, older females were at a greater risk, but light conditions were found to be insignificant. Lane changing was also found to be a difficulty among older drivers. Presence of a passenger in the vehicle was found to lower the crash involvement risk, especially in the case of left-turn crashes.

Mercier et al. *(15)* studied broadside and angle vehicular collisions and found age and gender as predictors for injury severity on rural highway crashes. Injury severity along with point of impact, were considered both in angle and broadside crashes. Hierarchical logistic regression and principal components logistic regression were used in different cases based on the impact point. Their findings varied depending on the point of impact and examination of the gender of the vehicle occupant. Age was found as a significant predictor of injury severity and was slightly greater for females than males. Use of seat belts proved to reduce injury severity, but results were less certain for females.

McKelvey and Stamatiadis *(16)* studied highway accident patterns in Michigan and found that older drivers were more likely to be involved in multi-vehicle crashes and head-on, angle crashes on non-interstate highways than other drivers. Cited violations among older drivers were found to be failing to yield right of way, illegal turns, and improper lane use. Fatality rates for older drivers were found to be considerably greater compared to other drivers, and trends in the licensing of drivers showed that younger drivers had been replaced by older drivers in the population, virtually in a one-to-one ratio.

Mercier et al. *(6)* studied the influence of age and gender on injury severity as a result of head-on crashes on rural highways. The initial hypothesis was that due to a variety of reasons, older drivers and passengers would suffer more severe injuries when involved in head-on collisions. Logistic regression analysis methodology was used and variables included age of both the driver and passenger, position in the vehicle, and form of protection used. Age was identified as an important factor predicting injury severity for both men and women, and use of seat belts appeared to be more beneficial for men than for women. Deployed air bags were more beneficial for women than for men.

2.4 Intersection-Related Crashes

Stamatiadis et al. *(17)* studied intersection crashes involving older drivers in the state of Michigan to examine the contributing factors. Apart from the percentage-wise analysis, relative accident involvement ratio (RAIR) was used to quantify the relative exposure. Drivers were divided into different age groups and comparisons were made. Drivers in the age group 60-69 years did not show a large difference in RAIR compared to average drivers, but drivers older than 69 years showed higher degrees of difficulties. Among those, maneuvering turns, especially left turns, and being involved in rear-end and right-angle crashes were common. Failing to yield right of way, following too close, and improper lane changing were found to be the most commonly cited violations for elderly drivers. Elderly female drivers were found to cause more crashes than their male counterparts. Further, it was found that elderly drivers were more susceptible to head-on crashes while turning left and in angle and rear-end crashes than middle-aged drivers. Interestingly, they found elderly drivers' crash involvement as non-correlated to the presence of traffic signals.

Braitman et al. *(18)* identified factors leading to older-driver crashes at intersections. Police crash reports, telephone interviews with at-fault drivers, and photographs of intersections were used in this study. Three driver groups were defined: 35-54 years, 70-79 years, and above 80 years. Results showed that drivers above 80 years old had fewer rear-end crashes than other age groups. Both older-driver groups had fewer ran-off-road type crashes compared to the middle-aged group. It was found that failure to yield the right of way increased with age and occurred mostly at stop-controlled intersections, generally where drivers were turning left. The age group from 70-79 years made more evaluation errors after seeing the vehicle and were unable to judge the available gaps, while drivers above 80 years old failed to see or detect the other vehicle.

Preusser et al. *(19)* calculated fatal crash involvement risk for older drivers relative to drivers aged 40-49 years in the United States during the years 1994-1995. Results indicated that drivers aged 65-69 years were 2.26 times more at risk for multiple-vehicle crashes at intersections and 1.29 times more at risk in all other situations. Comparable figures for drivers aged 85 and older were 10.62 for multiple-vehicle crashes at intersections and 3.74 for all other situations. Also, the relative crash risk was particularly high for older drivers at uncontrolled and stop-controlled locations.

Stamatiadis et al. *(20)* examined the relationship between accidents of elderly drivers and intersection traffic control devices. The relative accident involvement ratio (RAIR) was used to quantify the involvement to exposure ratio for different age categories of drivers who met with crashes in the state of Michigan during 1983-1985. According to the results, elderly drivers experienced more difficulties at all intersection areas and indicated a higher RAIR than middle-aged drivers. They also experienced more significant problems at multi-phase signalized intersections. The elderly showed higher RAIR in crashes involving turning maneuvers, in multiphase signals, multi-lane roads, and at rural roads during night conditions. Older drivers were overrepresented in head-on crashes while turning left. The predominant violations were found to be failing to yield the right of way, following too closely, and improper turns. The leading types of crashes were found to be head-on while turning left, and right-angle and rear-end collisions.

Synthesizing their research findings, the authors recommended that changes to licensing techniques would be appropriate in improving the safety of older drivers, and driver education and training programs would also help elderly drivers to identify their limitations.

2.5 Effect of Passengers on Older Drivers' Safety

Hing et al. *(21)* carried out a study to evaluate the impact of passengers on the safety of older drivers. In social psychology, it is accepted that people behave differently in the presence of spectators and similarly, researchers used the same philosophy to see whether drivers perform differently in the presence of passengers. Four years of crash data involving older drivers in the state of Kentucky were used in this analysis. Binary logistic regression and quasi-induced exposure analysis methods were used to calculate the relative accident involvement rates (RAIR). Two age groups were considered: 65-74 years as younger and over 75 years as older. Single-vehicle crashes and multi-vehicle crashes were disaggregated according to the number of passengers: no passenger, one passenger, and two or more passengers. Sub categories were made based on driver's gender, occupant's gender mix, time of crash, road curvature, road grade, and number of lanes.

According to their findings, the presence of two or more passengers had a negative impact on the probability for drivers 75 years of age or older who were at fault in crashes during daytime. The trend was different when traveling at night, and researchers suggested that it could be due to passengers who are active during such adverse conditions and provide additional support for the driver. Males and females had no difference in their propensity to cause a single-vehicle crash, but females were more likely to cause multi-vehicle crashes. Interestingly, they found that presence or absence of passengers had no effect on the 65-74 year age group, and groups of male vehicle occupants with an over 75-years-old male driver had higher propensity for single-vehicle crashes.

2.6 Risk to Self and Risk to Others

Several papers were found in regard to the risk involved with older drivers to themselves and to other road users. Findings are discussed in this section.

Dellinger et al. *(22)* carried out a study to assess the risk of death or non-fatal injury drivers older than 65 years posed to themselves and to other road users as compared with drivers in younger age groups. In their study, they categorized crash-related deaths and injuries into two groups: those occurring among the drivers themselves, and among others, such as passengers, bicyclists, or pedestrians. According to the findings, they suggested that older drivers make relatively low contributions to crash-related injuries or deaths, but their contributions are generally a result of injuries to self rather than to others.

Evans *(23)* carried out a similar study using 1994-1996 U.S. crash data. According to the author, older drivers pose less of a threat to others due to driving a lesser number of miles. For the same distance traveled, the 70-year-old driver poses a higher threat than the 40-year-old driver. But in terms of renewing the license of a 70-year-old driver for another year, this poses a 40% less threat to other road users than renewing the license of a 40-year-old male driver for another year.

Lafont et al. *(24)* studied the same issue but used a different methodology which considered the lost-life years of all road users. According to Lafont, previous studies in this area had not considered the age of other road users and it is quite possible that age-related frailty is an important factor for other road users as it is for drivers. Findings were similar to past studies and older-driver responsibility for lost-life years of other road users was the lowest.

Dulisse, B. *(25)* examined the degree to which older drivers impose an excess risk of death or injury serious enough to require hospitalization of other road users. Results showed that drivers aged 65-74 years did not appear to impose excess risk of either death or injuries requiring hospitalization in either the aggregate or individual-level analyses. But drivers over 75 years were found to impose excess risk of injuries to other road users.

2.7 Countermeasure Evaluation

McCoy et al. *(26)* carried out a study to identify problems associated with older drivers and to provide countermeasures for improving older-driver safety. The second phase of this study was to evaluate the countermeasures developed in their earlier phase. Based on results of the first phase, identified countermeasures were physical therapy, perceptual therapy, driver education, and traffic engineering improvements. Both therapies dealt with self-administered, home-based exercises which can improve physical movements and visual perception. All four methods were found to improve older drivers' performance significantly. The combined effect of driver education and physical or perceptual therapy was found to improve older-driver performance, but none of these increases were statistically significant. Based on the points assigned for each improvement, an average improvement of 7.9 percent was found among all four countermeasures. Further, they evaluated the cost effectiveness of each of these improvements and found that physical therapy was the most cost-effective method of improving driver performance, followed by driver education. Traffic engineering improvement cost was not assigned to individuals and therefore remained as a lump sum. They suggested that traffic engineering improvements would be the most cost-effective method on high volume roadways and other countermeasures would be more suitable for low-volume roadways.

2.8 Medication and Risk of Injury

Older drivers are more likely to consume medicine and several medications are known to impair driving abilities. Leveille et al. *(27)* studied psychoactive medications and injurious motor vehicle collisions involving older drivers using a population-based, matched-case control study of older drivers involved in injury crashes during 1997 and 1998. According to their findings, use of antidepressants and opioid analgesics by older drivers was associated with increased risk for injurious motor vehicle collisions; the relative risk compared to non-users was 2.3 and 1.8, respectively. Current use of benzodiazepines or sedating antihistamines had little association with increased risk for injurious collisions.

Hemmelgarn et al. *(28)* studied the risk of motor vehicle injuries among elderly and the association with use of benzodiazepine. It was found that brief or extended periods of exposure to long-half-life benzodiazepines were associated with an increased risk of motor vehicle crash involvement in the elderly population. The first seven days of long-half-life benzodiazepine exposure was associated with a 45 percent increase of the rate of involvement in injurious crashes, which reduced as time passed. However, there was no such elevated risk for short-half-life benzodiazepines.

McGwin et al. *(29)* carried out a population-based, case-control study to identify medical conditions and medications associated with the risk of at-fault crashes among older drivers. Older drivers with heart disease or stroke were found to be more likely to be involved in at-fault motor vehicle crashes, and arthritis was found to be an increasing risk factor for females. Use of some drugs, including benzodiazepine, was found to be associated with increased risk of being an at-fault driver.

2.9 Decision to Stop Driving

D'Ambrosio et al. *(30)* studied factors contributing to the decision of limiting or stopping the driving task by elderly drivers. A survey was carried out in Massachusetts, Florida, and Illinois to collect data, which showed the majority of survey respondents were engaged in voluntary self-regulative patterns to some degree. The elderly generally preferred to be approached by individual family members, as opposed to those outside the family, when having conversations about their driving. Based on household status, differences emerged on who should speak with the older driver, and most older adults preferred to hear from their spouse first, doctors and adult children were also preferred choices for conversation.

Johnson *(31)* conducted a study to see what factors were involved in rural older adults' decision to stop driving. The study was carried out in the western part of the United States. A questionnaire and semi-structured interviews were used in order to gather information related to their pre-stopped and post-stopped driving situations. Interesting comments were made by older drivers who had forfeited their driver's licenses. The study found that the majority of the participants had been involved in some sort of an accident while driving and for most of them this experience influenced the decision to stop driving. Health problems were also identified as a key factor in the decision to stop driving. Feelings of insecurity about driving made some participants give up driving and more importantly, the study found that influence from family and friends was a significant factor, though this was not in line with past findings.

Marottoli et al. *(32)* assessed the factors associated with driving cessation, number of miles driven, and changes in mileage with the elderly population. A multiple logistic regression model was developed and individual predictors for driving cessation were found to be: higher age, lower income, not working, neurological disease, cataracts, lower physical activity level, and functional disability. Combined effects of these factors were found in relation to the percentage of drivers who stopped driving.

2.10 Vehicle Design

Similar to other factors, vehicle design is also important for older driver safety and Herriotts *(33)* studied existing car designs in relation to older-driver needs. The study found that the mainstream motor vehicle industry has largely ignored many of the issues relating to the older driver, with many current car designs being unsuitable for drivers with age-related disabilities. Herriotts study was based on survey data with the main design-related issues as follows:

- Finding a comfortable driving position,
- Getting in and out of the car,
- Using the radio,
- Ease of reversing and parking,
- Using the boot or hatch, and
- Ease of wheel changing.

Among the main difficulties, turning around to look out of the rear window, getting in and out of the car, and using the seat belt were common responses. It was suggested that considering these findings for fundamental architecture of vehicle design would help cater to older drivers.

2.11 Statistical Methodologies

To understand the risk factors that increase the probability of injury severity in crashes, various disaggregated analysis techniques have been used by past researchers. These techniques include logistic regression, ordered logit and probit models, multinomial logit models, and nested logit models *(34)*.

Indike Ratnayake *(35)* carried out an analysis using Kansas crash data considering all ages who met with a crash during 1999 to 2002. Ordered probit modeling was used to investigate the critical factors contributing towards higher crash severity in rural/urban highway crashes. According to the author, most of the contributing factors towards high severity crashes were common for both rural and urban areas. Among the research findings, alcohol involvement, excessive speed, driver ejection, curved and graded roads, etc. was contributory factors for high-severity crashes.

Khattak et al. *(13)* also conducted a study using ordered probit modeling to isolate factors that contribute to more severe injuries to older drivers involved in traffic crashes. Factors related to vehicle, roadway, driver, crash, and environmental conditions were considered. They found that alcohol-related crashes and crashes involving farm vehicles were more likely to cause serious injuries to older drivers.

Duncan et al. *(36)* analyzed injury severity in truck-passenger car rear-end collisions using ordered probit modeling. Based on their model, they concluded that darkness, high speeds, grades, alcohol, and being a female were factors which increase passenger vehicle occupant severity. Many other researchers have used ordered probit modeling for severity analysis in the past such as Kockelman and Ma *(37)*, Renski et al. *(38)*, Kockelman and Kweon *(39)*, O'Donnell and Connor *(40)*, and Khattak et al. *(34)*.

CHAPTER 3 - Methodology

3.1 Data

3.1.1 Crash Data

Crash data obtained from the Kansas Department of Transportation were used in this study. This data set, Kansas Accident Reporting System (KARS), comprises all police-reported crashes in the state of Kansas. For the analysis in this study, crash data from years 1997 to 2006 were considered. Different age categories were defined for the analysis as follows. Age greater than or equal to 65 years was considered as older population, and age between 64 to 25 years was considered as middle aged. Age below 25 years was considered as younger population but in the case of younger drivers, age below 15 years was not considered in the data set since they were not a position to hold valid drivers license and therefore their behavior could be different from other young drivers.

The first part of this study focused mainly on identifying critical factors and issues where older drivers were at risk based on past crash data. Therefore, crash data were analyzed based on various aspects such as driver, crash, roadway, and environment-related factors. For the latter part of the study, the entire data set was used including young and middle-aged drivers involved in crashes.

Both in decomposition ratio analysis and ordered probit analysis, KARS data for the five-year period from 2002-2006 were used, primarily under the rural/ urban classification. The classification was done based on the type of road on which the crash occurred and if such data was not available, that particular data line was disregarded for these analyses. Every older driver involved in a crash/ crashes during the considered period was taken into account with respective injury severity and other related information. This included single-vehicle crashes as well as multi-vehicle crashes. Accordingly, there were about 45,741 older drivers involved in crashes during the five-year period, where 14,594 crashes occurred in rural areas and 31,146 occurred in urban areas.

For the ordered probit analysis, some data lines were deleted where data were missing in at least in one variable. After doing that, about 11,636 crashes involving older drivers on rural roads and 27,480 on urban roads remained for analysis.

3.1.2 Survey Data

It may not be advisable to arrive at conclusions about older drivers solely depending on crash data, since those characteristics are linked only with a special segment of older drivers who met with crashes. In other words, there are many older drivers who haven't met with crashes during the last few years and their representation is unobserved in such analysis. However, their characteristics should also be taken into consideration to make fair conclusions about older-driver characteristics in Kansas. A questionnaire was prepared with the intention of addressing issues and difficulties highlighted in the basic crash data analysis. Thus the survey was carried out to understand different behavioral changes in older drivers with respect to driving under various circumstances. The survey form consisted of five main areas: general, demographic, exposure-related, challenging situation, and difficulty level-related questions. The objective of this survey was to obtain information from older drivers irrespective of being involved in a crash, in order to get a general idea about their behavior, exposure, and different types of difficulties associated with them.

As the first step, a pilot survey was conducted with Area Transportation Agency (ATA) bus drivers in Manhattan, Kansas. This pilot survey was carried out to make sure that these questions were answered as meant to be answered because there was a chance to misunderstand some questions due to traffic terminologies the general public may not be familiar with. According to the feedback, few changes were made and the survey questionnaire was finalized. (The finalized survey form is given in Appendix-C.)

Conducting a survey among the older population was a challenging task because they were scattered and their expectations and attitudes towards participating in an older-driver safety survey was unknown. Identifying elderly people who currently drive made the situation harder. From the pilot survey, it was found that an average older driver would take 15 to 20 minutes to fill out a survey form, which might also be a concern. A good study of this nature requires a reasonable number of survey responses distributed throughout the state to overcome any sort of biases or misrepresentations. After studying a few alternative methods, it was found that senior centers and apartments in retirement communities would be the best place to conduct the survey. Most of these residents are older than 65 years, making it possible to complete a sufficient number of surveys in an effective manner. Further, it was not that difficult to identify a good number of elderly who still drive as well. The method of conducting the survey was by personally visiting such places and getting help from property managers for distribution. The survey forms were kept in a mail-back envelope to make it easier for participants to return them. Initially, the survey was carried out in Manhattan and Lawrence, covering most of the retirement centers, assisted-living apartments, and senior centers. After doing this, it was realized that those living in these communities may not represent a good blend of the entire older-driver population and therefore, two more alternatives were considered to eliminate possible biases. The first method was to distribute them in churches and the next option was to distribute them in gas stations. These two methods were initially tried at Manhattan and Lawrence. It was found that using churches worked well and the response rate was high, but there was a difficulty associated with targeting people older than 65 years. Survey forms distributed in gas stations didn't turn out as expected and the response rate was much less. Finally, it was decided to go ahead with both senior centers and churches in various parts of Kansas, and the survey was carried out in Manhattan, Lawrence, Topeka, Sabetha, Marysville, Dodge City, Garden City, and Wichita. Figure 3.1 depicts the geographical distribution of the places where the survey was conducted.

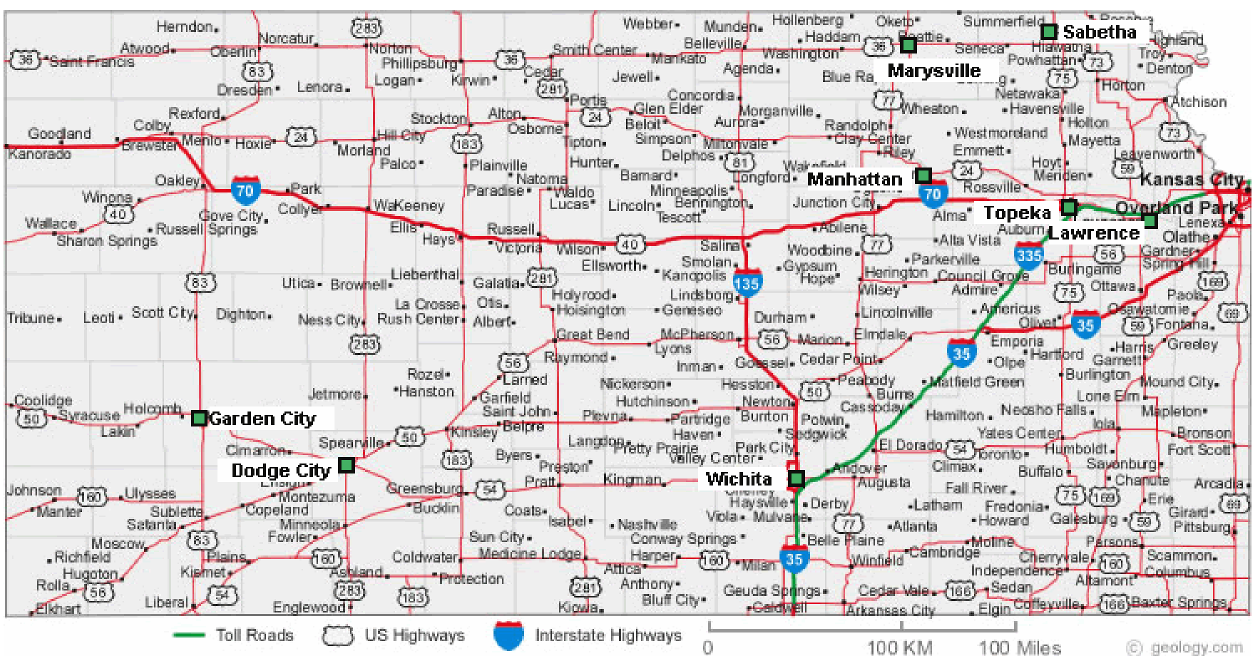

Figure 3.1 Cities in Kansas Where the Older-Driver Survey Was Conducted

From all locations, a total of 311 completed survey forms was received and the response rate for this survey was around 32 percent. Out of 311 survey forms received, 27 respondents were younger than 65 years and therefore ignored. As a result, 284 survey responses were retained for the analysis.

3.1.3 Exposure Data

National Household Travel Survey (NHTS) data from 2001 was used *(41)* as the source of exposure since this was the latest and most reliable information available for this purpose., Annual miles driven by older drivers under urban/ rural classification were extracted for Kansas using NHTS data, which was then subcategorized under different age groups and gender. In this case, the sample size became too small for acceptance. As the next best alternative, the entire U.S. data and Midwest data were considered under the same classifications. After a close examination, it was found that Midwest data better represented the Kansas conditions due to the similar nature of urban/ rural miles traveled. The Midwest consisted of 12 states, namely Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. However, there was no travel data available in NHTS for three of the states: Nebraska, North Dakota, and South Dakota, and therefore only nine states' data were combined in this study. When obtaining exposure data, the sample was subdivided based on age and gender, and miles driven by a single person in each category was estimated by dividing the total number of miles driven by sample size (Appendix-D).

Kansas driver's license data were also obtained from the Federal Highway Administration's (FHWA) highway statistics database *(42)* for years 2002-2006. Older drivers were subcategorized under different age groups considered in this study and also based on gender. Furthermore, they were considered in urban and rural categories based on population-distribution percentages extracted from the Kansas Statistical Abstract 2007 *(43)*. The reasoning behind the population-based subdivision was that NHTS data were based on location of the household, assuming that most of their travel miles were around their neighborhood and therefore the same approach was taken to identify number of drivers that live in urban and rural areas. Then, number of drivers in each category was multiplied by the corresponding number of miles driven by a single person in that category, as calculated earlier, to arrive at total miles driven for each category (Appendix-E).

3.2 Data Analysis

Even though older-driver-related crashes were emphasized and their categorical distributions presented, it is not advisable to make decisions or develop conclusions about over involvement solely based on older-driver information. These significant numbers, after all, may show a common problem pertaining to all drivers that may not be specific to older drivers. In that regard, a comparison between other age groups would be more appropriate in identifying problems and issues limited to older drivers. Therefore, similar characteristics were identified for young and middle-aged drivers. In order to see whether there was a relationship between age groups and other categories under driver, crash, roadway, and environment-related factors, statistical tests of independence were carried out.

These tests were carried out based on number of crashes occurring under different categories with no consideration given to injury severity. However, from a safety perspective, injury severity also plays a vital role in addition to the number of crashes. For example, more crashes with less severity may not be that critical as compared to fewer crashes with higher injury severity. As a result, following the test-of-independence study, a univariate analysis was also carried out by assigning different weights for different severity levels.

For the analysis of the survey responses, simple percentage calculations followed by weighted frequency calculations were completed. In addition, for more specific analysis, the odds-ratio method was used, which is an output from the binary logistic regression. The method is presented in detail in Section 3.2.3.

Based on these preliminary analyses mentioned, it was found that rural crashes involving older drivers were more severe than urban crashes. Therefore, the next step focused on rural road crashes in comparison with urban road crashes with the objective to identify contributing factors leading to increase injury severity. First, the decomposition method was selected, which is discussed in detail in Section 3.2.4. This is a fairly new methodology which has recently been introduced into transportation studies. It has been used by many health economists in the past to assess the relative importance of many risk factors leading to health expenses *(44)*. Recent transportation studies have used this methodology to decompose values into different rates to identify different contribution factors *(44, 45)*.

The decomposition method was selected for this part of the study because it decomposes the rates into contributing factors, which fits exactly with the study objectives. Additionally, both severity and crashes were taken into consideration in this method, which enriched the study objective by addressing different trends associated with severity levels and crashes. Past findings have revealed many factors contributing to older-driver crashes and severities but not specifically related to rural areas or the state of Kansas. Therefore, factors for detailed study were carefully selected by looking at preliminary crash data analysis, survey results, and past studies.

Following the decomposition method, the ordered probit methodology was utilized as explained in Section 3.2.5. In the analysis conducted using decomposition ratios as described in Section 4.3.1, the contributing factors were considered alone and their effect towards the crash/ injury severity was determined. In other words, one variable at a time was considered to see the relationship or how much it affects crash/ injury severity. However, in the analysis using ordered probit modeling, the objective was to incorporate all variables into a single formula to see the multiple or combined effects of such variables toward injury severity. Variables were developed under four different categories: driver, crash, roadway, and environment related.

3.2.1 Test of Independence

This method tests the independence of two variables using chi-square distribution. A table similar to 3.1 is referred to as a contingency table. As the test of independence uses the contingency table format, it is sometimes referred to as contingency table test. Let X and Y denote two categorical variables, X having *i* number of levels and Y having *j* number of levels. The *ij* possible combinations of outcomes could be displayed in a rectangular table having *i* rows for the categories of X and *j* columns for the categories of Y. As an example, in Table 3.1, the categorical variable X denotes the gender of a sample of drivers and Y denotes their vehicle preferences.

Table 3.1 Example Contingency Table for Gender and Vehicle Type

Gender (X)	***Vehicle Type (Y)***			***Total***
	Car	***Truck***	***SUV***	
Male	n_{11}=120	n_{12}=250	n_{13}=270	n_{1+}=640
Female	n_{21}=200	n_{22}=100	n_{23}=225	n_{2+}=525
Total	**n_{+1}=320**	**n_{+2}=350**	**n_{+3}=495**	**n=1,165**

The cells of the table represent the *ij* possible outcomes. Since *i*=2 and *j*=3 in this case, there are six possible outcomes.

The cell counts are denoted by n_{ij}, with $n= \Sigma_{ij} n_{ij}$ denoting the total sample size.

$n_{1+} = n_{11} + n_{12}$ and $n_{+1} = n_{11} + n_{21}$

The test of independence addresses the question of whether the vehicle type preference is independent of gender. The hypotheses for this test of independence are as follows:

H_o: Vehicle type preference is "independent" from his/her gender; and

H_a: Vehicle type preference is "not independent" from his/her gender

where H_o is the null hypothesis and H_a is the alternative hypothesis.

Expected frequencies for the cells of the contingency table are calculated based on the assumption that the null hypothesis is true. Let e_{ij} denote the expected frequency for the contingency table category in row *i* and column *j*.

Then, expected frequencies are calculated as

$$e_{ij} = \frac{(Row\ \ i\ total\ ) \times (Column\ \ \ j\ total\ )}{Sample\ \ size} \qquad (3.1)$$

$$= \frac{(n_{i+}) \times (n_{+j})}{(n)}$$

The test procedure for comparing observed frequencies and expected frequencies uses the following formula and a chi-square value is calculated.

$$\chi^2 = \sum_i \sum_j \frac{(n_{ij} - e_{ij})^2}{e_{ij}} \qquad (3.2)$$

With *i* rows and *j* columns in the contingency table, the test statistic has a chi-square distribution with (*i-1*)*(*j-1*) degrees of freedom. Once the chi-square value is calculated for the data, it can be compared with the tabular values at user-defined confidence levels.

For the example in Table 3.1, the value of the test statistic is χ^2= 77.783. At a 95% confidence level, the value shown in the table for two degrees of freedom is 5.991. Since the calculated χ^2 > the table value, the null hypothesis is rejected and it can be concluded that vehicle type preference is not independent from his/her gender.

According to this methodology, the test of independence was carried out for all categories of crashes and different driver groups. In Section 4.1.1, results of calculated chi-square values for different categories along with their respective degrees of freedom were presented.

3.2.2 Univariate Analysis

This test was carried out to compare different mean severity values obtained for different categories considered under the test of independence. Assigning weights to individual severity levels in order to calculate "equivalent property damage only" (EPDO) crashes was the most important and challenging step in this process. Various organizations use different sets of weights based mostly on economic impact of crash severity, which may vary depending on the purpose of its application. For this analysis, severity indices were obtained from KDOT, which were as follows *(46)*:

- Fatal injury (F), Incapacitating (Disabled-D), and Non-incapacitating (Injury-I) - 15
- Possible injury (P), No injury (N), and Unknown (U)- 1

$$\textit{Number of EPDO Crashes} = W_1 * (F + D + I) + W_2 * (P + N + U) \qquad (3.3)$$

where

W_1 = weight to convert fatal, incapacitating, and non-incapacitating crashes into EPDO crashes; and

W_2 = weight to convert possible injury, no injury, and unknown crashes into EPDO crashes.

After assigning injury-severity indexes for all crashes, a mean (μ_0) severity index and variance (σ_0) were calculated. Further, in each category under different conditions, the mean injury severity (μ_i) and variance (σ_i) were also calculated. The Z test *(47)* was used to calculate the difference between two means and following that, the calculated Z value was compared with the tabular value at a 95% significance level.

$$Z = \frac{\mu_i - \mu_0}{S_p \sqrt{\frac{1}{n_i} + \frac{1}{n_0}}} \qquad (3.4)$$

$$S_P = \sqrt{\frac{(n_i - 1)S_i^{\ 2} + (n_0 - 1)S_0^{\ 2}}{n_i + n_0 - 2}} \qquad (3.5)$$

where

n_i = number of crashes in selected category,

n_0 = total number crashes,

S_p = pooled standard deviation,

S_i = standard deviation for the selected category, and

S_0 = standard deviation for all crashes.

3.2.3 Odds Ratio

Logistic regression was used to calculate odds ratios (OR) and 95% confidence intervals (CI) to assess the strength of the association between independent variables and dependent variables.

The dependent variable considered here has two possible outcomes, 0 and 1, corresponding to “yes” if the event occurred and “no” if the event did not occurred. Therefore binary logistic regression is considered in this analysis. The odds in favor of an event occurring is defined as the probability that the event will occur divided by the probability that the event will not occur. In logistic regression, the event of interest is always y =1. Given a particular set of values for the independent variables, the odds in favor of y =1 can be calculated as follows *(48)*:

$$Odds = \frac{P\left(y = 1 \middle| x_1, x_2, \ldots, x_p\right)}{P\left(y = 0 \middle| x_1, x_2, \ldots, x_p\right)} \qquad (3.6)$$

where

$P\left(y = 1 \mid x_1, x_2, \ldots, x_n\right)$ = probability of event occurring, and

$P\left(y = 0 \mid x_1, x_2, \ldots, x_n\right)$ = probability of event not occurring.

The odds ratio measures the impact on the odds of a one-unit increase in only one of the independent variables. The odds ratio looks at the odds that y =1 given that one of the independent variables is increased by one unit ($odds_1$), divided by the odds that y =1 given no change in the value of the independent variables ($odds_0$).

$$odds\ \ ratio\ = \frac{odds_{\ 1}}{odds_{\ 0}} \tag{3.7}$$

This statistical method was used to analyze survey data mainly in relation to respondents who mentioned that they met with crashes during the last 10 years. Odds ratios and relevant confidence intervals at 95% were calculated for various conditions and are presented in the Section 4.2.3.

3.2.4 Decomposition Method

The decomposition ratio methodology is a fairly simple tool to identify the factors associated with fatal motor vehicle crashes. Equation 3.8 shows the fatal crash incidence density rate, which is a product of three factors: injury fatality rate, crash injury rate, and crash incidence density. Thus the risk of being involved in a fatal crash (A) is the product of the risk of dying when a crash involving injury occurs (B), the risk of injury given a crash (C), and the risk of crash per miles driven (D).

$$\begin{matrix} Fatal\ crash \\ incidence\ density\ (A) \end{matrix} = \begin{matrix} Injury\ \ fatality \\ rate\ (B) \end{matrix} \times \begin{matrix} Crash\ injury \\ rate\ (C) \end{matrix} \times \begin{matrix} Crash\ incidence \\ density\ (D) \end{matrix} \tag{3.8}$$

where

$$\text{Fatal crash incidence density (A)} = \frac{\text{Number of fatal crashes}}{\text{Number of vehicle miles traveled (in 100 million miles)}}$$

$$\text{Injury fatality rate (B)} = \frac{\text{Number of fatal crashes}}{\text{Number of injury crashes (in 1000 injury crashes)}}$$

$$\text{Crash injury rate (C)} = \frac{\text{Number of injury crashes}}{\text{Number of all crashes (in 1000 crashes)}}$$

$$\text{Crash incidence density (D)} = \frac{\text{Number of all crashes}}{\text{Number of vehicle miles traveled (in million miles)}}$$

Rural-to-urban fatal crash incidence densities were compared as a ratio given below.

$$\frac{A_{rural}}{A_{urban}} = \frac{B_{rural}}{B_{urban}} \times \frac{C_{rural}}{C_{urban}} \times \frac{D_{rural}}{D_{urban}} \quad (3.9)$$

3.2.5 Ordered Probit Modeling

The ordered probit model has the ability to recognize the indexed nature of various response variables *(39)*. A variable can be considered as ordinal when its categories can be ranked from low to high, where the distance between adjacent categories are unknown *(49)*. Injury severity in motor vehicle crashes can also be ordered as fatal injury, disabling or incapacitating injury, non-incapacitating injury, possible injury, or no injury ranging from the highest severity level to the lowest according to the severity of injuries caused to occupants. According to Long *(49)*, simply because the values of a variable can be ordered, does not imply that the variable should be analyzed as ordinal. But in this study, the response variable, injury severity, can be analyzed as ordinal because, in reality, injury severity follows the order when a crash occurs. Further, Long has discussed the applicability of ordered logit and probit models in detail in his publication *(49)*.

The ordered probit model can be derived from a measurement model in which a latent variable y* ranging from -∞ to ∞ is mapped to an observed ordinal variable y, injury severity in this case *(49)*. The latent variable y* is continuous, unobservable, and used to derive the measurement model as follows:

$$yi = m \qquad if\ \tau_{m-1} \le y^* < \tau_m \qquad for\ m = 1\ to\ J \quad (3.10)$$

The τ's are called thresholds or cutoff points. The extreme categories *1* and *J* are defined by open-ended intervals with τ_0 = -∞ and τ_J = ∞. The observed y is related to y*, according to the measurement model:

$$y_i = \begin{cases} 1 \rightarrow No\ injury & if\ \tau_0 = -\infty \le y^* < \tau_1 \\ 2 \rightarrow Possible & if\ \tau_1 \le y^* < \tau_2 \\ 3 \rightarrow Non-incapacitating & if\ \tau_2 \le y^* \tau_3 \\ 4 \rightarrow Incapacitating & if\ \tau_3 \le y^* < \tau_4 \\ 5 \rightarrow Fatal & if\ \tau_4 \le y^* < \tau_5 = \infty \end{cases} \quad (3.11)$$

The structural form for the ordered probit model with binary response can be considered as

$$y_i^* = x_i \beta + \varepsilon_i \quad (3.12)$$

x_i is a row vector with a 1 in the first column for the intercept and the i^{th} observation for x_k in column $k+1$. β is a column vector of structural coefficients with the first elements being the intercept β_0, and ε_i is the error term.

In order to estimate the regression of y* on x as in binary regression modeling, the maximum likelihood (ML) estimation can be used with an assumption. In ordered probit modeling, the error term ε_i is assumed to be distributed normally with a mean of 0 and variance of 1, and the respective probability density function (pdf) and cumulative distribution function (cdf) are as follows:

$$\phi(\varepsilon) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{\varepsilon^2}{2}\right) \tag{3.13}$$

$$\Phi(\varepsilon) = \int_{-\infty}^{\varepsilon} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{t^2}{2}\right) dt \tag{3.14}$$

Once the distribution of the error is specified, the probabilities of observing values of y given x can be computed. For example, if the injury severity of an older driver, whose victim of a motor vehicle crash is fatal, the y value is 5 and y* falls between τ_4 and $\tau_5 = \infty$. Accordingly, the probability formula will be

$$\Pr\left(y_i = 5 \mid x_i\right) = \Pr\left(\tau_0 \le y_i^* < \tau_1 \mid x_i\right) \tag{3.15}$$

By substituting equations 3.12 and 3.14, the expression becomes

$$\Pr\left(y_i = 5 \mid x_i\right) = \Phi(\tau_5 - x_i\beta) - \Phi(\tau_4 - x_i\beta) \tag{3.16}$$

By generalizing the equation to compute the probability of any observed outcome y = m given x, it becomes

$$\Pr\left(y_i = m \mid x_i\right) = \Phi(\tau_m - x_i\beta) - \Phi(\tau_{m-1} - x_i\beta) \tag{3.17}$$

Let β be the vector with parameters from the structural model, with the intercept βo in the first row, and let τ be the vector containing the threshold parameters. Either βo or τ_1 is constrained to 0 to identify the model. In this analysis, the SAS version of 9.1 was used, which considered the τ_1 value as equal to 0.

$$\Pr\left(y_i = m \mid x_i, \beta, \tau\right) = \Phi(\tau_m - x_i\beta) - \Phi(\tau_{m-1} - x_i\beta) \tag{3.18}$$

If the observations are independent, the likelihood equation is

$$L(\beta,\tau \mid y, X) = \prod_{i=1}^{N} p_i \tag{3.19}$$

By combining equations 3.18 and 3.19,

$$L(\beta,\tau \mid y, X) = \prod_{j=1}^{J} \prod_{yi=j} \left[\Phi(\tau_j - x_i\beta) - \Phi(\tau_{j-1} - x_i\beta)\right] \tag{3.20}$$

Π y_i=j indicates multiplying in each case where y is observed to equal j. Using logs, the log likelihood is

$$\ln L(\beta,\tau \mid y, X) = \sum_{j=1}^{J} \sum_{yi=j} \ln\left[\Phi(\tau_j - x_i\beta) - \Phi(\tau_{j-1} - x_i\beta)\right] \tag{3.21}$$

Using numerical methods, the equation can be maximized to find τ's and β's. The marginal effect from *x* factors can be considered by computing the partial changes in the equation in order to interpret the regression model. By taking the partial derivative with respect to x_k in equation 3.18, the result becomes

$$\begin{aligned} \frac{\partial \Pr(y = m|x)}{\partial x_k} &= \frac{\partial\Phi(\tau_m - x\beta)}{\partial x_k} - \frac{\partial\Phi(\tau_{m-1} - x\beta)}{\partial x_k} \\ &= \beta_k\left[\phi(\tau_m - x\beta) - \phi(\tau_{m-1} - x\beta)\right] \end{aligned} \tag{3.22}$$

The partial change or marginal effect is the slope of the curve relating x_k to Pr(y=m|x), holding all other variables constant, and is usually computed at the mean values of all variables.

According to the ordered regression model equation, explanatory variables are linearly related to the response variables and thus have an increasing effect on injury severity if the variable estimate has a positive value and vice versa for variable estimates with negative values. Model output under selected categories is as follows.

3.2.5.1 Goodness of Fit Measure

In linear regression models, the goodness of fit is usually measured by the R^2 value whereas there is no such straightforward measure to evaluate model fitness of ordered probit models. McFadden (1974) suggested using a likelihood ratio index (LRI) that is analogous to the R^2 in the linear regression model**.**

$$R^2{}_M = 1 - \left[\ln L / \left(\ln L_0\right)\right] \qquad (3.23)$$

where

L = the value of the maximum likelihood function, and

Lo = likelihood function when regression coefficients, except for the intercept term, are zero *(50)*.

The R^2_M value is bounded by zero and one, where one denotes perfect fit of the model. Similarly, a few other values are given in the SAS output such as Estrella, Adjusted Estrella, Veall-Zimmermann, and McKelvey-Zovoina, which can also be considered in evaluating goodness of fit of a model.

In regression modeling, significance of individual parameters towards the model is important and overall goodness of fit also plays a vital role in that aspect. In SAS output for an ordered probit model, number of goodness of fit measurements was given because unlike other regression modeling, there is no such single value which can determine the model fitness consistently. As a result, various values given in terms of probabilities were considered when selecting models, and out of that, McFadden's LRI was considered in this study. Similarly, the Estrella value is also desirable in discrete choice modeling.

CHAPTER 4 - Results and Discussion

4.1 Characteristics of Older Drivers Involved in Crashes and Comparison with Young and Middle-Aged Drivers

In this study, the objective was to identify the characteristics of older drivers involved in crashes, but considering older drivers alone would not highlight the special characteristics among older drivers. Therefore, it was vital to conduct a comparison with other driver age groups. Thus, characteristic analysis was done including all drivers—young, middle-aged, and older, who had been involved in crashes during the period 2002 to 2006 in Kansas, presented in Table 4.1. Relationships between different crash categories and driver age groups were also identified using the test of independence as explained in the methodology section. The calculated chi-square values, degree of freedom values, and probabilities at 95% confidence level are also presented in Table 4.1 under each sub category.

4.1.1 Characteristics of Older Drivers Involved in Crashes

There were 43,290 police-reported crashes involving 45,741 older drivers in Kansas during the five-year period. A majority of the older drivers belonged to the 65-74 years age category and 36.4% were in the 75-84 years age group, while the remainders were above 84 years. Injury statistics show that a significant percentage of older drivers were not injured; however, 276 older drivers were killed during that time period. A small percentage, 1.3% of older drivers, was disabled as a result of crashes and 6.2% sustained non-incapacitating injuries. There was a 6.8% chance of possible injuries among older drivers, with the remaining number unknown. Gender distribution of older drivers involved in crashes showed that male drivers were more involved in crashes than female drivers. Despite that, older-driver license data indicated that there were more older female driver license holders than males *(42)* (Appendix-E). Possibly there could be exposure-related factors such as miles driven, which may explain the situation. Further, there weren't that many older drivers under the influence of alcohol at the time of crashes.

Most of the crashes involved collisions with other vehicles and this is further broken down by the manner of collision. Results showed 8.9% of vehicles collided with animals and 6.5% of vehicles struck an object. A majority of these crashes occurred during daytime, perhaps because older drivers mostly prefer to drive during daytime. Nighttime crashes comprised 7.3% and 6.7% of crashes on dark and lighted streets, respectively. About 87.8% of the crashes took place under no adverse weather conditions and 8.3% occurred in rainy conditions. Only 2.5% of them occurred in snow and windy weather conditions.

Table 4.1 Characteristics of Crashes Involving Young, Middle-Aged and Older Drivers in Kansas, 2002-2006

Description	*Young*		*Middle Aged*		*Older*		*Total*
	Number	*%*	*Number*	*%*	*Number*	*%*	
Number of crashes	154,313	35.3%	250,640	55.9%	43,290	9.7%	448,243
Number of drivers involved in crashes	180,016	32.4%	328,729	59.3%	45,741	8.2%	554,486
Injury severity							
F- Fatal injury	415	0.2%	916	0.3%	276	0.6%	1,607
D- Disabled-incapacitating	1,828	1.0%	3,803	1.2%	578	1.3%	6,209
I- Injury-not incapacitating	12,816	7.1%	18,847	5.7%	2,827	6.2%	34,490
P- Possible injury	13,138	7.3%	23,714	7.2%	3,121	6.8%	39,973
N- Not injured	143,391	79.7%	266,855	81.2%	36,599	80.0%	446,845
U- Unknown	8,428	4.7%	14,594	4.4%	2,340	5.1%	25,362
Total	180,016	100%	328,729	100%	45,741	100%	554,486
	Chi-square value= 661.7		***DF= 10***		***p<0.001***		
Gender							
Male	99,434	55.2%	189,414	57.6%	26,396	57.7%	315,244
Female	80,538	44.7%	139,226	42.4%	19,324	42.2%	239,088
Total	179,972	100%	328,640	100%	45,720	100%	554,332
	Chi-square value= 285.1		***DF= 2***		***p<0.001***		
Alcohol influence							
Yes	6,700	3.7%	9,535	2.9%	272	0.6%	16,507
No	173,316	96.3%	319,194	97.1%	45,469	99.4%	537,981
Total	180,016	100%	328,729	100%	45,741	100%	554,486
	Chi-square value= 1,251.2		***DF= 2***		***p<0.001***		
Major crash types							
Vehicle overturned	6,742	4.4%	7,657	3.1%	510	1.2%	14,909
Collision with vehicle in traffic	104,996	68.0%	162,898	65.0%	33,333	77.0%	301,227
Collision with parked vehicle	6,610	4.3%	8,970	3.6%	2,113	4.9%	17,693
Collision with animal	9,692	6.3%	37,111	14.8%	3,851	8.9%	50,654
Struck an object	23,460	15.2%	28,346	11.3%	2,816	6.5%	54,622
Other	2,813	1.8%	5,658	2.3%	667	1.5%	9,138
Total	154,313	100%	250,640	100%	43,290	100%	448,243
	Chi-square value= 11,195.6		***DF= 10***		***p<0.001***		
Lighting condition							
Daylight	103,122	66.8%	168,968	67.4%	35,548	82.1%	307,638
Dawn or dusk	6,812	4.4%	14,503	5.8%	1,612	3.7%	22,927
Dark	17,905	11.6%	31,558	12.6%	3,148	7.3%	52,611
Lighted	26,109	16.9%	35,020	14.0%	2,885	6.7%	64,014
Total	153,948	99.8%	250,049	99.8%	43,193	99.8%	447,190
	Chi-square value= 5,227.5		***DF= 6***		***p<0.001***		

Table 4.1 continued

Description	*Young*		*Middle Aged*		*Older*		*Total*
	Number	*%*	*Number*	*%*	*Number*	*%*	
Urban / Rural split							
Urban	108,498	70.3%	165,969	66.2%	29,357	67.8%	303,825
Rural	45,815	29.7%	84,671	33.8%	13,933	32.2%	144,420
Total	154,313	100%	250,640	100%	43,290	100%	448,243
	Chi-square value= 732.4		***DF= 2***		***p<0.001***		
Road classification							
Interstate and Freeways	16,989	11.0%	36,358	14.5%	3,578	8.3%	41,139
Arterials	77,633	50.3%	130,503	52.1%	25,441	58.8%	249,363
Collectors	22,931	14.9%	36,957	14.7%	5,839	13.5%	65,727
Local roads	36,760	23.8%	46,822	18.7%	8,432	19.5%	92,014
Total	154,313	100%	250,640	100%	43,290	100%	448,243
	Chi-square value= 3,427.2		***DF= 6***		***p<0.001***		
Weather condition							
No adverse conditions	129,510	83.9%	211,162	84.2%	38,021	87.8%	378,693
Rain	16,231	10.5%	24,233	9.7%	3,593	8.3%	44,057
Snow and wind	5,890	3.8%	10,255	4.1%	1,095	2.5%	17,240
Other	2,682	1.7%	4,990	2.0%	581	1.3%	8,253
Total	154,313	100%	250,640	100%	43,290	100%	448,243
	Chi-square value= 581.5		***DF= 6***		***p<0.001***		
Location							
Non intersection	62,019	40.2%	112,359	44.8%	15,774	36.4%	190,152
Intersection	65,001	42.1%	95,932	38.3%	20,586	47.6%	181,519
Other	27,293	17.7%	42,349	16.9%	6,930	16.0%	76,572
Total	154,313	100%	250,640	100%	43,290	100%	448,243
	Chi-square value= 1,894.83		***DF= 4***		***p<0.001***		
Vehicle maneuvering							
Straight following the road	107,672	59.8%	191,649	58.3%	25,167	55.0%	324,488
Left turn	19,118	10.6%	26,107	7.9%	6,423	14.0%	51,648
Stopped in traffic	10,831	6.0%	30,946	9.4%	2,791	6.1%	44,568
Backing	4,660	2.6%	10,224	3.1%	2,433	5.3%	17,317
Right turn	5,890	3.3%	10,088	3.1%	1,952	4.3%	17,930
Slowing or stopping	9,723	5.4%	20,122	6.1%	1,821	4.0%	31,666
Other	22,122	12.3%	39,593	12.0%	5,154	11.3%	66,869
Total	180,016	100%	328,729	100%	45,741	100%	554,486
	Chi-square value= 5593.6		***DF=12***		***p<0.001***		
Manner of collision							
Angle	46,191	29.9%	68,560	27.4%	17,556	40.6%	132,307
Rear end	43,114	27.9%	66,284	26.4%	9,388	21.7%	118,786
Sideswipe	9,267	6.0%	16,235	6.5%	3,554	8.2%	29,056
Other	6,424	4.2%	11,819	4.7%	2,835	6.5%	21,078
Total	104,996	68.0%	162,898	65.0%	33,333	77.0%	301,227
	Chi-square value=2,280.8		***DF= 6***		***p<0.001***		

Even though the public urban road miles represent less than 10% of total public road miles in Kansas (42), the percentage of crashes occurring on urban roads was much higher compared to crashes occurring on rural roads. Based on road classification, it is evident that

58.8% of crashes took place on arterials, whereas only 19.5% were at local roads. Number and percentage of crashes related to intersections were greater than crashes at non-intersection locations, indicating critical older-driver safety issues at intersections. When vehicle maneuvering was considered at the point of the crash, a majority (55%) occurred when vehicles were following the road straight and 14.0% were related to left turns. The rest of the crashes represented stopped in traffic, backing, right-turn-related crashes, etc. Out of the crashes that involved collisions with another vehicle, 40.6% were angle crashes and 21.7% were rear-end collisions. Sideswipe collisions were 8.2% according to the table, and other types of collisions added up to 6.5%.

4.1.1.1 Severity of Older-Driver-Involved Crashes

When identifying characteristics, it is important to consider the number of crashes occurring as well as severity of crashes. This is because there could be situations where higher injury severities are incorporated with lesser number of crashes occurring and vice versa. Table 4.2 presents the mean injury severity values calculated for each sub category using univariate analysis explained in Section 3.2.2. If the sub category is crash related, the respective μ_0 value is 2.1672, and if it is driver related, the μ_0 value is taken as 2.1266. These are the mean values calculated considering total number of crashes and older drivers, respectively. But for the manner of collision, the μ_0 value is considered as the mean value of "collisions with vehicles in traffic" (2.0912). In the real world, "manner of collision" explains the categories under multi-vehicle crashes. Bold values highlight the more severe cases with their respective probability values from the Z test.

Injury severities are higher among older drivers when vehicles are overturned and when they strike an object. However, in both cases the number of crashes occurring was less than compared to other sub categories considered in the analysis. There is no such difference to be identified with respect to injury severity under different lighting conditions, whereas under road classification, most of the rural road crashes were related to high-severity injuries. In urban areas, only freeways showed significant deviation. This is an interesting point to note and it further encourages studying the factors contributing to such circumstances. Intersection crashes were more severe as well as number of crashes occurring was also high. Similarly, roadside crashes were also more severe but number of crashes occurring was only 2.1% out of total crashes.

Table 4.2 Injury Severity of Older-Driver-Involved Crashes, 2002-2006

Description	Value	%	Mean Injury Severity	Variance	P Value
Number of crashes involving an older driver	43,290	-	2.1672	14.9782	-
Number of older drivers involved in crashes	45,741	-	2.1266	14.5041	-
Gender					
Male	26,396	57.7%	2.0947	14.1281	0.2762
Female	19,324	42.2%	2.1715	15.0293	0.1717
Major crash type					
Collision with vehicle in traffic	33,333	77.0%	2.0912	14.0862	0.0063
Collision with animal	3,851	8.9%	1.2218	3.0563	0.0000
Struck an object	2,816	6.5%	**4.1023**	33.8197	**0.0000**
Collision with parked vehicle	2,113	4.9%	1.4373	5.9337	0.0000
Vehicle overturned	510	1.2%	**6.9020**	47.8882	**0.0000**
Lighting condition					
Daylight	35,548	82.1%	2.1949	15.3011	0.3197
Dark- No street lights	3,148	7.3%	2.0807	13.9662	0.2249
Dark- Street lights on	2,885	6.7%	2.0239	13.2910	0.0533
Dawn or dusk	1,612	3.7%	1.9988	12.9932	0.0855
Road classification					
Urban	29,357	67.8%	1.9094	11.9053	0.0000
Interstate	1,437	3.3%	1.8086	10.6744	0.0005
Freeway	1,147	2.6%	**2.5501**	19.3158	**0.0010**
Arterials	19,446	44.9%	1.9474	12.3672	0.0000
Collectors	2,285	5.3%	1.7475	9.9104	0.0000
Local streets	5,042	11.6%	1.7192	9.5529	0.0000
Rural	13,933	32.2%	**2.7102**	21.0194	**0.0000**
Interstate	994	2.3%	**3.1127**	25.1394	**0.0000**
Arterials	5,995	13.8%	**3.0504**	24.5053	**0.0000**
Collectors	3,554	8.2%	**2.6466**	20.3468	**0.0000**
Local streets	3,390	7.8%	2.0572	13.6875	0.1099
Weather condition					
No adverse condition	38,021	87.8%	2.1684	14.9923	0.9648
Rain	3,593	8.3%	2.0676	13.8108	0.1371
Snow and wind	1,095	2.5%	2.1558	14.8610	0.9233
Location					
Non intersection	15,774	36.4%	1.9798	12.7585	0.0000
Intersection related	20,586	47.6%	**2.2568**	16.0162	**0.0068**
Parking lot driveway access	4,314	10.0%	1.8048	10.6222	0.0000
Interchange area	1,531	3.5%	2.0425	13.5165	0.2146
Roadside, off roadway	895	2.1%	**4.8950**	39.4028	**0.0000**
Vehicle maneuvering					
Straight following the road	25,167	55.0%	**2.3696**	17.2990	**0.0000**
Left turn	6,423	14.0%	2.2250	15.6515	0.0536
Stopped in traffic	2,791	6.1%	1.5769	7.7460	0.0000
Backing	2,433	5.3%	1.1036	1.4399	0.0000
Right turn	1,952	4.3%	1.4662	6.3125	0.0000
Slowing or stopping	1,821	4.0%	1.7457	9.8897	0.0000
Changing lanes	1,271	2.8%	1.4076	5.5440	0.0000
Stopped awaiting turn	1,248	2.7%	1.5609	7.5440	0.0000
Manner of collision					
Angle	17,556	52.7%	**2.3221**	16.7623	**0.0000**
Rear end	9,388	28.2%	1.8754	11.4902	0.0000
Sideswipe	3,554	10.7%	1.5515	7.4188	0.3206
Backed in	1,891	5.7%	1.0888	1.2365	0.0000
Head on	740	2.2%	**4.5946**	37.4538	**0.0000**

When looking at vehicle maneuvering at the time of the crash, most severe crashes occurred when older drivers were following a straight road. When looking at the manner of collision, head-on crashes were more severe followed by angle crashes.

4.1.2 Comparison of Characteristics between Different Driver Age Groups

When considering the location of crashes involving different driver age groups, there was a considerable difference in the trends when comparing three age groups over the past five years, 2002-2006. Figure 4.1 depicts trends related to crash locations. The trends clearly show there are problems pertaining to older drivers at intersections as compared to other age groups, since the percentage of intersection-related crashes are nearly 10% higher for older drivers than middle-aged and younger drivers. On the other hand, older-driver involvement in non-intersection crashes is low compared to both middle-aged and younger drivers. The overall difference between older drivers and younger drivers is around 10% in this case as well.

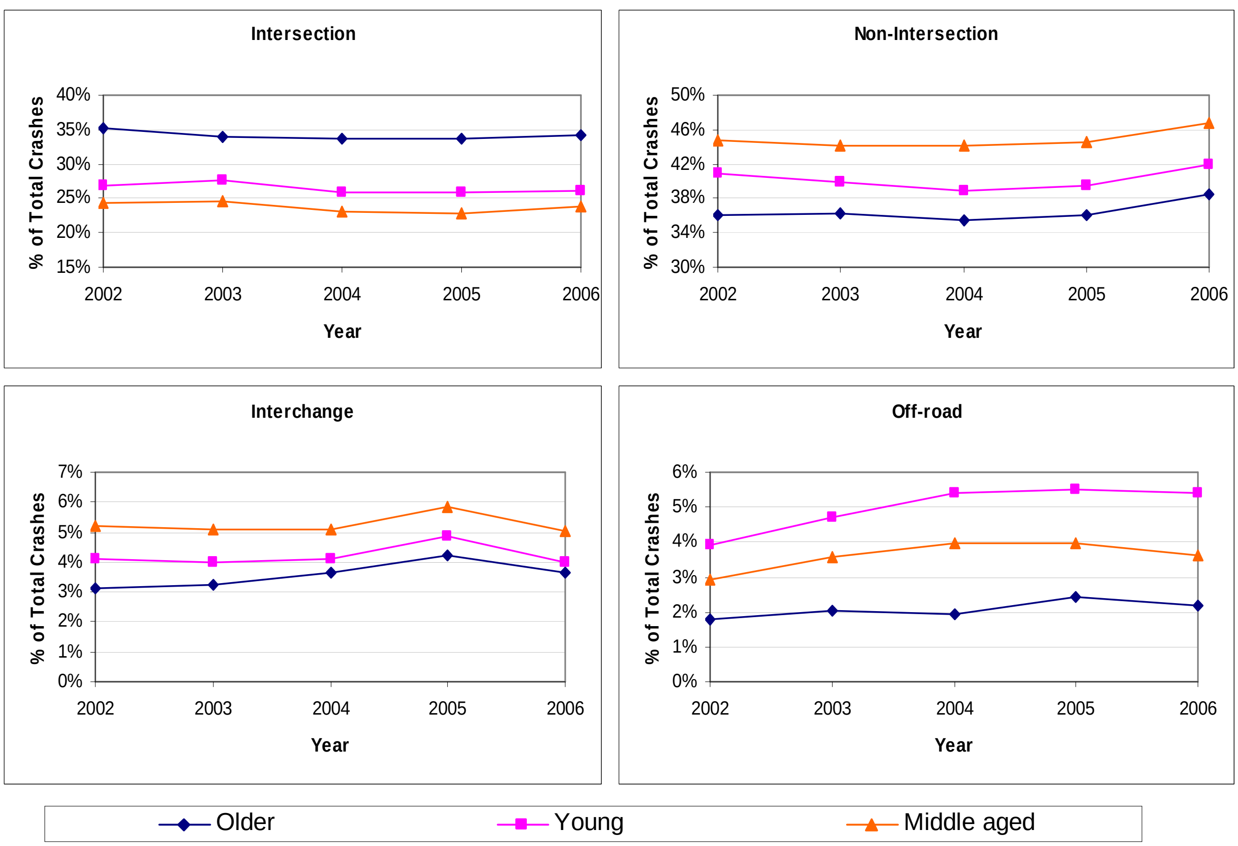

Figure 4.1 Crashes Involving Different Age Groups Based on Location

It is important to note that middle-aged drivers have higher percentages of non-intersection crashes, as compared to other groups. Both in interchange and off-road crashes, older drivers' representation is at the lowest level among the three age groups. Overall, when trends are considered, younger and middle-aged drivers followed exactly the same trend and older drivers also showed the same pattern, with few minor variations.

Crashes occurring under different light conditions had a high chi-square value (Table 4.1), indicating that a higher level of interdependency between driver age groups and different lighting conditions at the time crashes occurred. The following charts in Figure 4.2 depict the major trends observed.

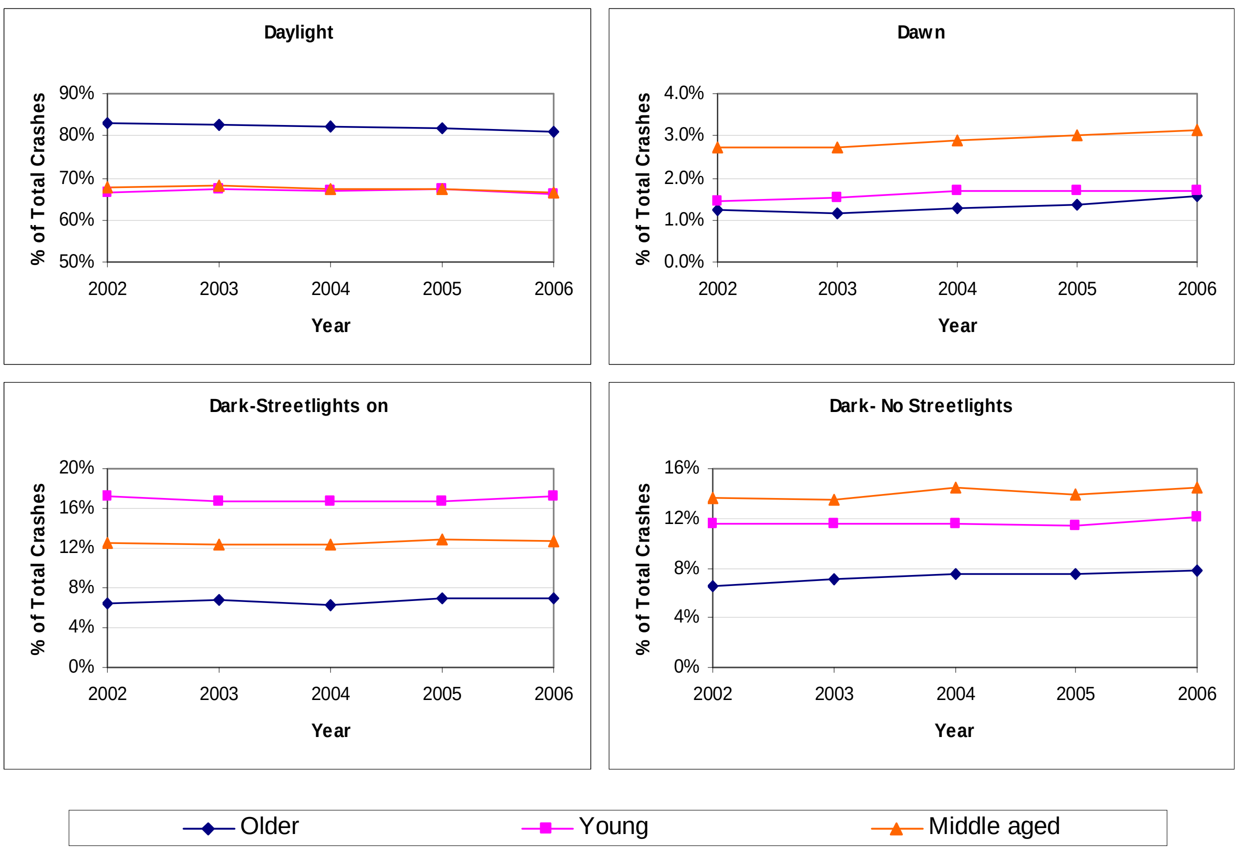

Figure 4.2 Crashes Involving Different Age Groups Based on Light Conditions

Older-driver-involved crashes were considerably high in daylight conditions compared to younger and middle-aged drivers. An average percentage difference of about 25% appears between the older drivers' and middle-aged drivers' trend lines. Furthermore, the trend lines belonging to younger and middle-aged drivers are overlapped, showing almost no difference.

Older drivers' preference to drive during daytime and avoidance during nighttime due to visual incapabilities may cause them to be involved in a higher number of crashes under daylight conditions. When considering crashes occurring during dawn, it was shown that older drivers and younger drivers were less likely to be involved in crashes at dawn, whereas middle-aged drivers contributed to a higher number of crashes in this category. This may be because middle-aged drivers mostly represent the workforce, whereas older and younger drivers generally do not. The working population normally commutes in early morning so their exposure is higher during dawn conditions. This explains why their involvement in crashes is higher at this time. When it is dark, older-driver-involved crashes were less than compared to the other two categories, irrespective of streetlights. This may strengthen the argument that older drivers try to avoid nighttime driving and prefer daytime driving.

Under different weather conditions, there was no significantly identifiable difference in trend except for no adverse conditions and rainy weather conditions. Figure 4.3 depicts the trends. Similar to daylight conditions, older-driver-involved crashes were higher under no adverse weather conditions, and younger and middle-age driver-involved crash trends were at lower levels closer to each other, compared to the trend line of older drivers. Even though both trends (under daylight and no adverse conditions) look similar, with under no adverse weather conditions, the average percentage difference was much less, around 4% compared to 25% in daylight conditions.

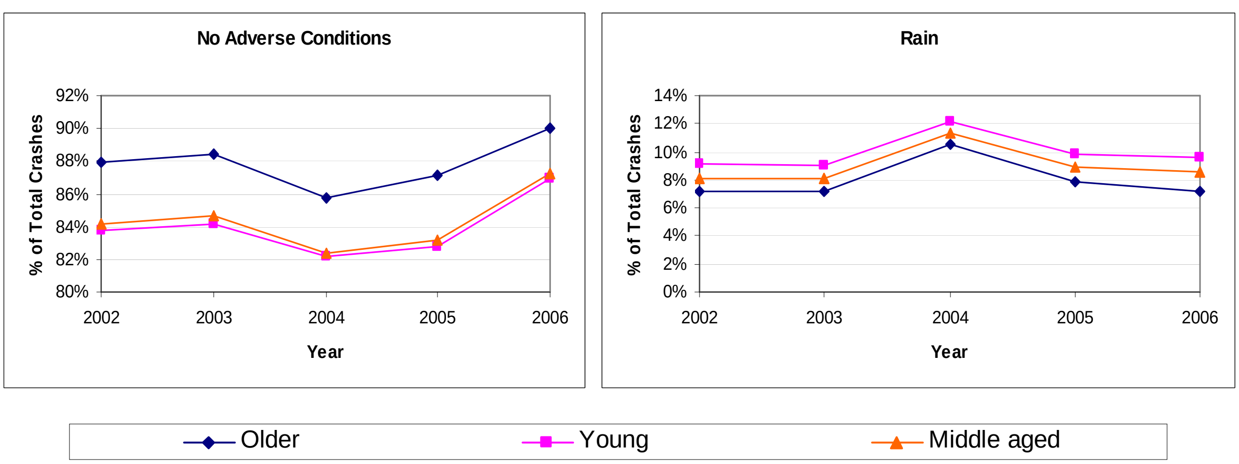

Figure 4.3 Crashes Involving Different Age Groups Based on Weather Conditions

Trends pertaining to manner of collision showed distinguishable differences under rear-end and angle collisions. Charts are presented in Figure 4.4. Older drivers were involved in fewer percentages of rear-end crashes compared to young and middle-aged drivers, with completely opposite numbers with angle collisions. Middle-aged and younger-driver-involved crash percentages were marginally close to each other in both cases. However, all three age groups followed the same pattern in both conditions. Where overall patterns were concerned, it is important to note that rear-end collisions were at an upward direction among all age groups, which is not a favorable indication with regard to safety; but angle collisions were at a downward trend, showing an improvement over the years. Attention should be paid to investigate reasons behind such increase in rear-end collisions. This may be due to quality improvement in facilities where drivers' drive faster.

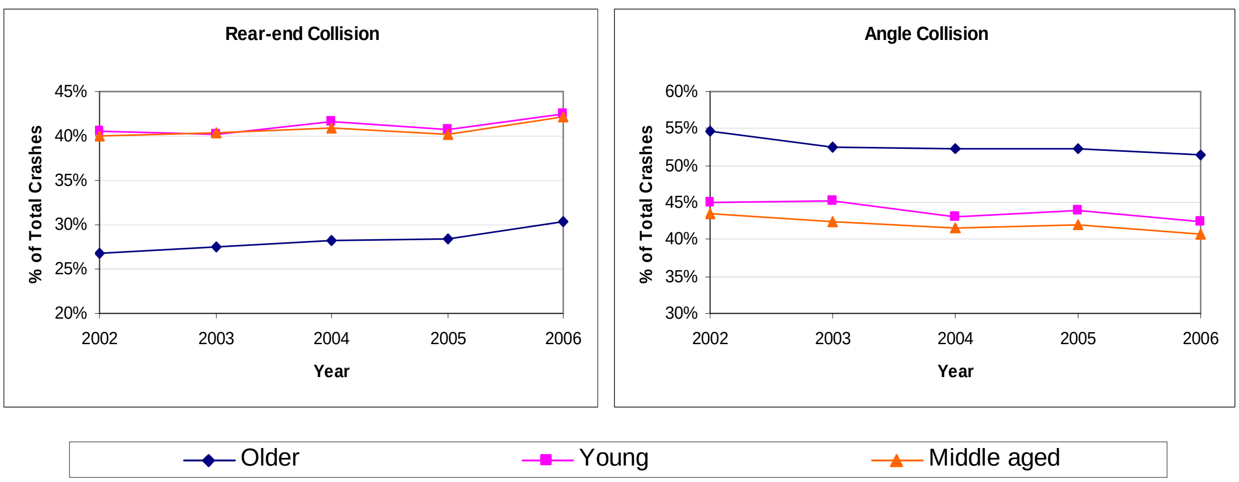

Figure 4.4 Crashes Involving Different Age Groups Based on Manner of Collision

Out of the vehicles overturned, younger drivers represented the majority whereas older drivers represented the least. Charts are depicted in Figure 4.5. Most of the time younger drivers tended to drive too fast for the prevailing conditions unlike older drivers, and this could be the reason for such an outcome. Middle-aged drivers were in between these two extremes. Vehicle speed was the major factor causing drivers to overturn and therefore these results were as expected. The next two charts in Figure 4.5 show that older drivers were more likely to collide with other motor vehicles irrespective of whether it was parked or on the road. But crashes involving older drivers colliding with motor vehicles on the road were much greater compared to the young and middle-age groups. Interestingly, middle-aged drivers were more likely to be involved in crashes colliding with animals than younger or older drivers. The possible reason could be related to their exposure conditions. As mentioned earlier, middle-aged drivers are more exposed to drive at dawn and nighttime where animals tend to come onto roads. Thus, there are high possibilities for middle-aged drivers to be involved in crashes with animals.

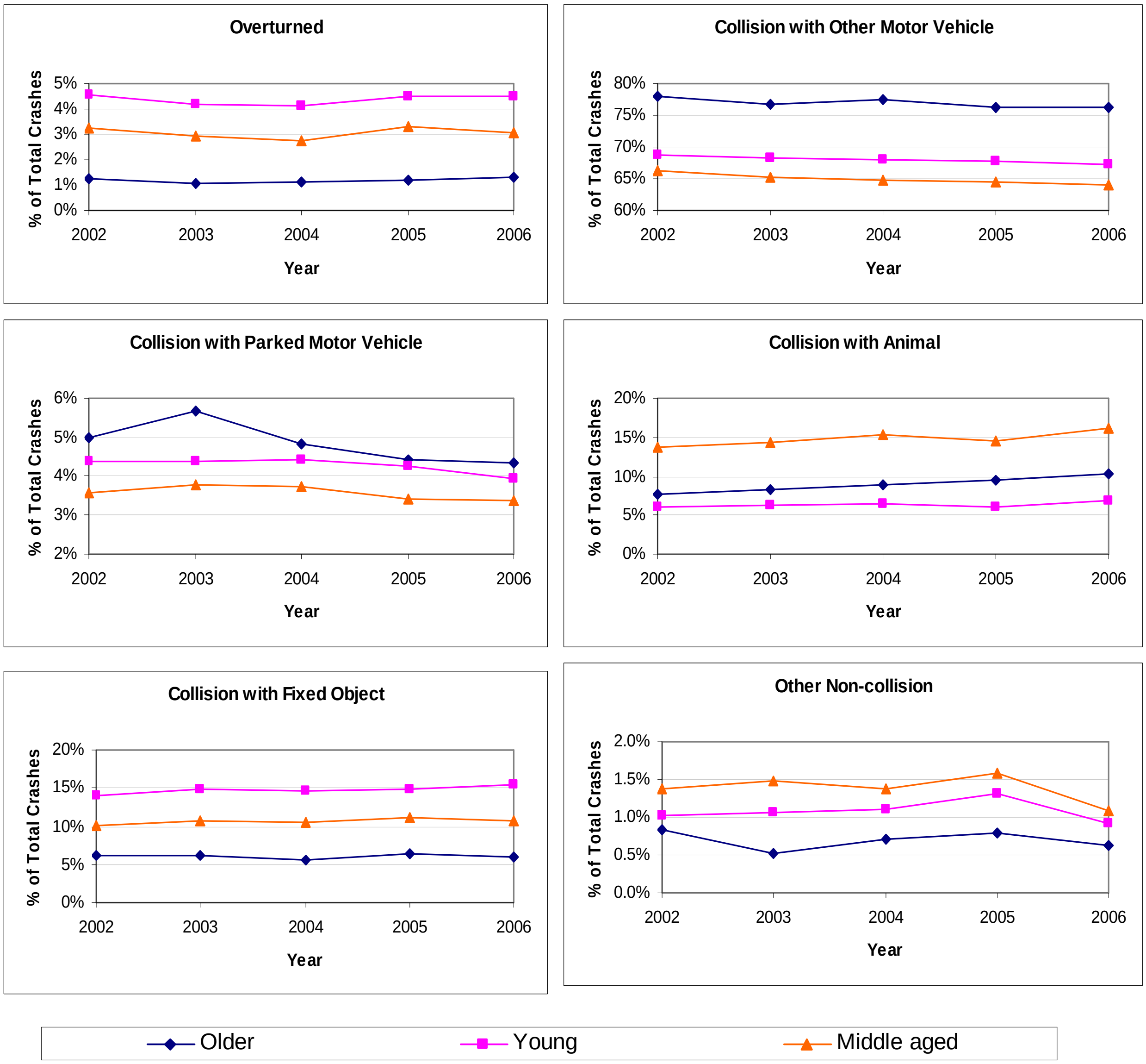

Figure 4.5 Crashes Involving Different Age Groups Based on Accident Class

The collision with fixed objects chart shows that older drivers were less likely to be involved in crashes hitting fixed objects, but younger drivers were more prone to it. The possible reasons could be older drivers are more likely to drive at lower speeds compared to others, and therefore it reduces the chances for them to run off the road and hit objects. Whereas, younger drivers are more likely to drive at higher speeds and are prone to run off the road and hit fixed objects. Further, the amount of experience of older drivers may also help them to maneuver vehicles better in such situations. On the other hand, as mentioned earlier, older drivers are more likely to collide with another vehicle on the road and this may reduce the number of crashes under the collision with fixed object category. Other non-collision categories also showed similar trends, as collision with fixed objects and older-driver representation were lower as well.

From the contingency tables (Table 4.1), it is evident that crashes in the urban environment were higher among all ages compared to crashes occurring in rural environments. According to the road classification, most of the crashes occurred on freeways and arterials. Charts in Figure 4.6 show the crashes occurring over the years in urban/rural environments on arterial roads. It is clear in urban environmental conditions that older-driver involvement in crashes was high in both principal and minor arterials compared to other drivers, whereas in rural environments older and middle-aged drivers represented the majority, alternately.

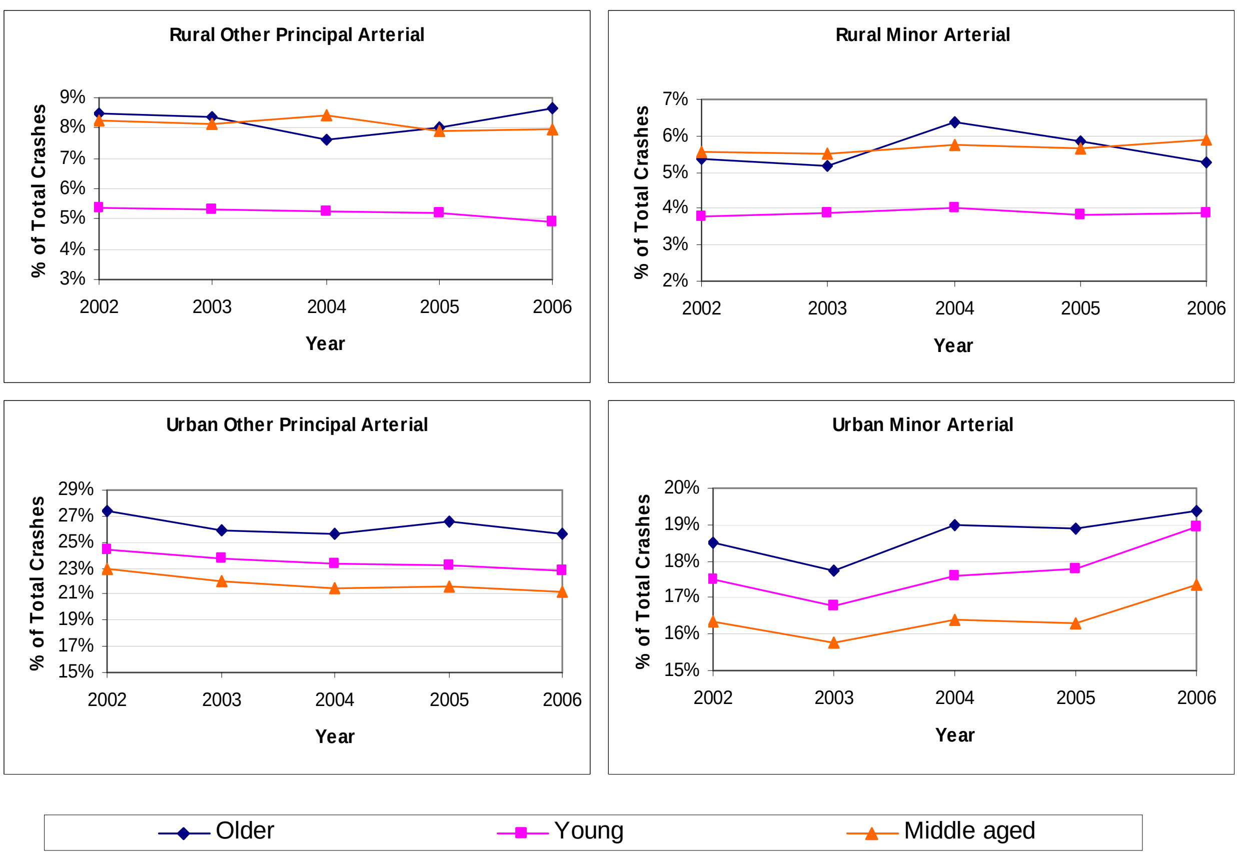

Figure 4.6 Crashes Involving Different Age Groups Based on Road Class

When looking at vehicle maneuvering at the point of crash, it can be seen why intersection-related crashes are higher among older drivers. Figure 4.7 depicts the trends based on vehicle maneuvering at the time of crashes.

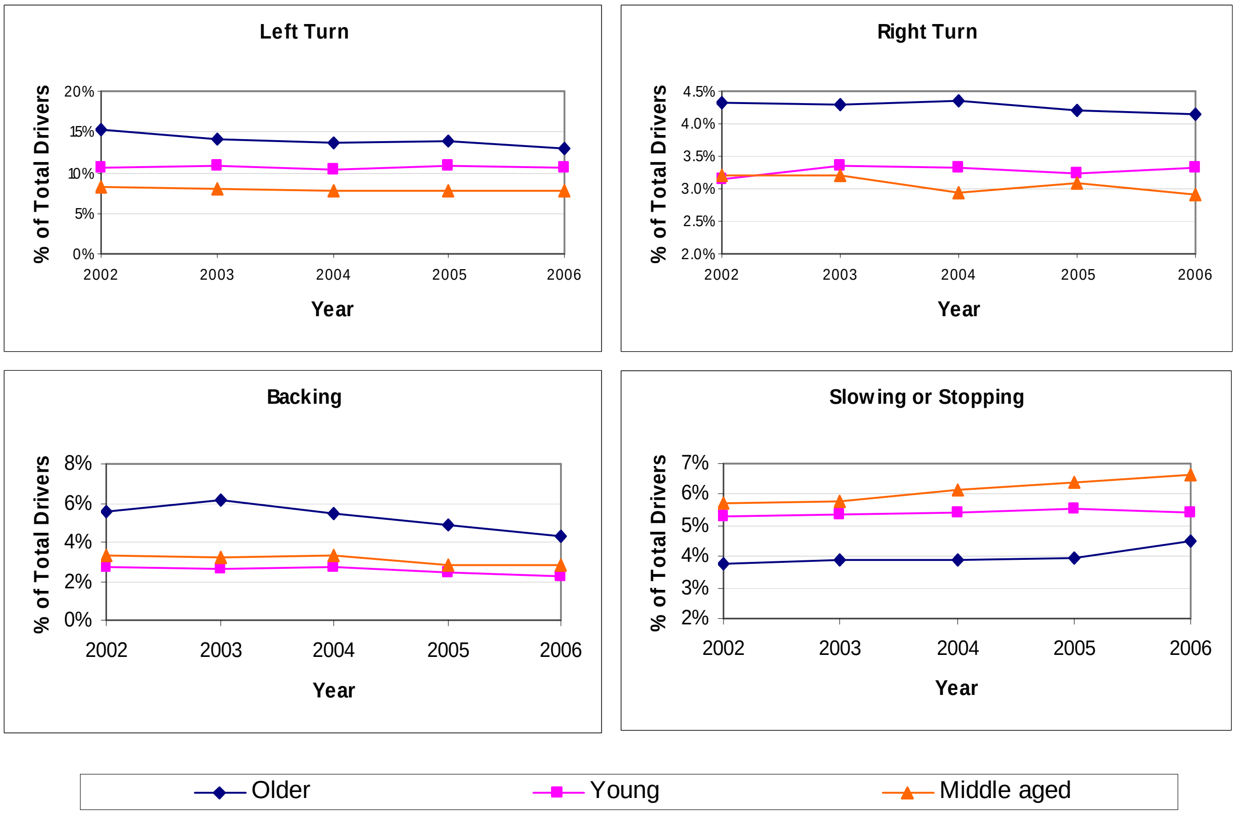

Figure 4.7 Crashes Involving Different Age Groups Based on Vehicle Maneuvering

Left-turn-related and right-turn-related crashes depicted in Figure 4.7 are high among older drivers compared to others. Left turns and right turns are required at intersections, and if older drivers experience any problems with these two maneuverings, it is quite obvious there will be more crashes at intersections. Similar trends can also be seen in backing-related crashes. A little improvement among older drivers can be seen over the years, but still their representation in this category is higher compared to other driver age groups. Trends with middle-aged and younger-driver-involved crashes are closer to each other and also indicate an improvement over the years, but not as much as older drivers. Vision and misjudgment of space could be reasons for the higher number of backing-related crashes among older drivers.

Alcohol is known to play a major role in crashes. In general, people believe that there are more alcohol-related crashes irrespective of age and this was disproved by crash data analysis. Figure 4-8 depicts trends over the years.

Data showed that around 3.5% to 4.0% of crashes involving younger drivers are alcohol influenced; that number is around 3.0% for middle-aged drivers. But when older drivers are considered, their involvement rate was around 0.5%, which is very low compared to others.

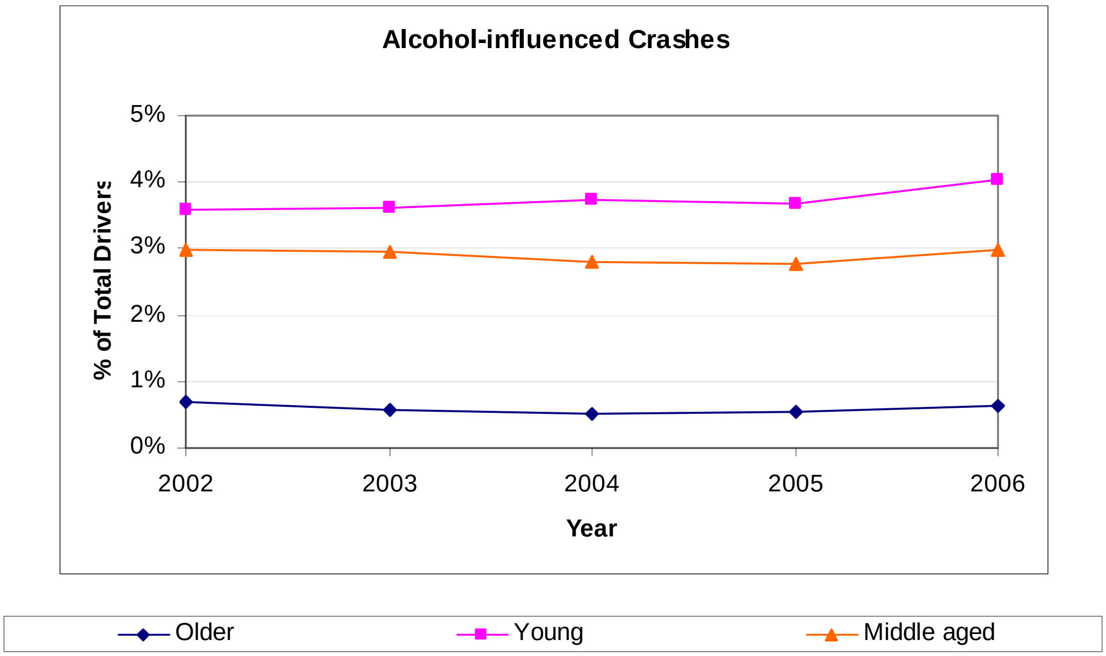

Figure 4.8 Crashes Involving Different Age Groups Based on Alcohol Influence

4.2 Older-Driver Survey

Analysis and results based on the older-driver survey are discussed in this section (survey form is given in Appendix-C). As the first step, simple percentages were calculated for every question to get an idea about the overall situation. When looking at the simple percentages, 97 percent of the respondents were currently driving and the remaining three percent of respondents had stopped driving very recently. Frequencies and percentages for general questions are shown in Table 4.3. Ninety two percent of the respondents had more than 50 years of driving experience and a majority drive cars and vehicles newer than 10 years old. Forty-one percent of older drivers drove every day, whereas a majority of the others drove at least two or three days a week. Sixteen percent of respondents drove more than 500 miles per month and among them about two percent drove more than 2000 miles per month. Out of the 284 respondents, 51 had been involved in crashes during the last 10 years. A majority of the older drivers hadn't been involved in any traffic violations after turning 65 years, whereas 12 percent had received tickets for speeding. There was no difference in gender when receiving speeding tickets, but it is important to note that out of 33 respondents who received speeding tickets, eight mentioned that they drink and drive. However, none of them had received any tickets related to DUI after turning age 65.

Table 4.3 Responses to General Survey Questions by Older Drivers in Kansas

	Question	Frequency	Percentage
1	*Do you currently drive?*		
	Yes	275	97%
	No	9	3%
2	*How long have you been driving?*		
	0 -10 years	0	0%
	11-20 years	1	0%
	21-30 years	0	0%
	31-40 years	6	2%
	41-50 years	15	5%
	More than 50 years	260	92%
3	*What type of vehicle do you usually drive?*		
	Car	222	78%
	SUV	19	7%
	Van	37	13%
	Pick up Truck	21	7%
	Other	7	2%
4	*How old is the vehicle you drive?*		
	0 -5 years	103	36%
	6- 10 years	110	39%
	11 -15 years	51	18%
	16-20 years	19	7%
	21-25 years	4	1%
	More than 25 years	1	0%
5	*How frequently do you drive?*		
	Everyday	116	41%
	4-6 days per week	58	20%
	2-3 days per week	76	27%
	Once a week	19	7%
	Once a month	2	1%
	Once in a while	11	4%
6	*Approximately how many miles do you drive each month?*		
	0 -100 miles	115	40%
	101 -200 miles	53	19%
	201 -500 miles	67	24%
	501 -1000 miles	27	10%
	1001- 2000 miles	12	4%
	More than 2000 miles	6	2%

Table 4.3 continued

	Question	Frequency	Percentage
24	*Has your seat belt usage changed over the years?*		
	Increased	144	51%
	Decreased	2	1%
	Almost the same	126	44%
	Don't know	7	2%
25	*Have you been involved in a crash during the last 10 years?*		
	Yes	51	18%
	No	229	81%
27	*If you have received a traffic violation after turning to 65 years, what best describes the reason?*		
	Never received	205	72%
	Speeding	33	12%
	Parking	6	2%
	DUI	0	0%
	Reckless driving	1	0%
	Expired tags/ license	6	2%
	Vehicle deficiencies	0	0%
	Other (specify)…………………….	11	4%
36	*When do you think you would stop driving?*		
	When my doctor advises	146	51%
	When my adult children interfere	43	15%
	When my vision gets poor	136	48%
	When my spouse advises	28	10%
	None of the above	22	8%

Frequencies and relevant percentages pertaining to demographic, socio-economic, and educational background-related questions are presented in Table 4.4. When looking at the distribution of the sample based on age, a fair distribution can be seen among all age group categories included in the survey form. According to the responses, 15 percent of respondents were between the ages of 65 to 70 years, 17 percent were between the ages of 71 and 75 years, 23 percent were between the two age groups from 76 to 80 and 81 to 85 years, and 21 percent were over the age of 85.

35 percent of the respondents had participated in driver education courses after turning 65 years of age. Almost all respondents had at least been to high school and only two percent hadn't had any formal schooling. There was about a 40/60 percentile split between males and females in the sample, and 46 percent were married and 38 percent widowed. Most of the respondents would stop driving either when their doctor advises or when his/her vision gets poor. Most of the older drivers' annual household income was greater than $20,000, and 43 percent of respondents were living in their own houses.

Table 4.4 Response to Demographic, Socio-Economic, and Educational Background-Related Questions by Older Drivers in Kansas

	Question	Frequency	Percentage
7	*What is your age group?*		
	65 - 70 years	42	15%
	71- 75 years	48	17%
	76 - 80 years	66	23%
	81- 85 years	66	23%
	More than 85 years	61	21%
33	*Have you participated in any type of driver education courses since the age of 65?*		
	Yes	98	35%
	No	184	65%
34	*What is your gender?*		
	Male	114	40%
	Female	170	60%
35	*Your marital status?*		
	Single	13	5%
	Married	132	46%
	Divorced	25	9%
	Widowed	108	38%
	Separated	6	2%
37	*Your educational qualification?*		
	No formal schooling	5	2%
	Some high school	66	23%
	Some college	81	29%
	Four year college	43	15%
	Graduate degree	65	23%
	Other (specify)…………………….	15	5%
38	*How much is your annual household income?*		
	Less than $ 9,999	12	4%
	$ 10,000 - $ 14,999	24	8%
	$ 15,000 - $ 19,999	30	11%
	$ 20,000 - $ 29,999	59	21%
	$ 30,000 - $ 49,999	61	21%
	$ 50,000 or above	52	18%
39	*Please select appropriate option regarding your current residence?*		
	Own house	122	43%
	Rental	145	51%

Table 4.5 shows exposure-related frequencies and percentages. When looking at seat belt usage among older drivers, it can be noted that 85 percent responded that they always wear seat belts while driving and 80 percent of them do the same as a passenger. In addition, 51 percent believe their seat belt usage has gone up over the past years, while 44 percent said it is almost the same. According to a past study, seat belt usage among older occupants hospitalized as a result of highway crashes was found to be 61 percent in Kansas *(51)*, which is well below the above usage rates mentioned by respondents in the survey.

Table 4.5 Frequencies, Percentages, and Likelihood of Occurrence Based on Exposure

	Question	Frequency	Percentage	Likelihood of Occurrence
8.a	*How often do you wear the seat belt while driving?*			95
	Never	1	1%	
	Very rarely	2	1%	
	Sometimes	9	3%	
	Most of the time	29	10%	
	Always	240	85%	
8.b	*How often do you wear the seat belt as a passenger?*			93
	Never	2	1%	
	Very rarely	1	1%	
	Sometimes	8	3%	
	Most of the time	39	16%	
	Always	200	80%	
9	*How often do you drive at night compared to day time?*			38
	Never	38	13%	
	Very rarely	86	30%	
	Sometimes	133	47%	
	Most of the time	11	4%	
	Always	11	4%	
10	*How often do you feel the street is not lit well enough when driving at night?*			38
	Never	44	15%	
	Very rarely	73	26%	
	Sometimes	106	37%	
	Most of the time	29	10%	
	Always	6	2%	
11	*How frequently do you drive on freeways?*			39
	Never	41	14%	
	Very rarely	74	26%	
	Sometimes	134	47%	
	Most of the time	29	10%	
	Always	4	1%	
12	*How often do you drive on following weather conditions?*			
a	*Rainy*			50
	Never	13	5%	
	Very rarely	55	19%	
	Sometimes	147	52%	
	Most of the time	42	15%	
	Always	22	8%	
b	*Snowy*			39
	Never	45	16%	
	Very rarely	80	28%	
	Sometimes	102	36%	
	Most of the time	26	9%	
	Always	14	5%	
c	*Windy*			56
	Never	5	2%	
	Very rarely	35	12%	
	Sometimes	141	50%	
	Most of the time	56	20%	
	Always	29	10%	

Table 4.5 continued

	Question	Frequency	Percentage	Likelihood of Occurrence
13	*How often do you make sudden stops or slow down on road without real necessity?*			18
	Never	119	42%	
	Very rarely	127	45%	
	Sometimes	24	8%	
	Most of the time	3	1%	
	Always	4	1%	
14	*How often do you drive after consuming medicine?*			39
	Never	77	27%	
	Very rarely	71	25%	
	Sometimes	63	22%	
	Most of the time	39	14%	
	Always	31	11%	
15	*How often do you drive after consuming alcohol?*			5
	Never	242	85%	
	Very rarely	24	8%	
	Sometimes	11	4%	
	Most of the time	1	1%	
	Always	2	1%	
16	*How often do you drive alone?*			64
	Never	4	1%	
	Very rarely	23	8%	
	Sometimes	92	32%	
	Most of the time	133	47%	
	Always	29	10%	

In general, past studies have found that among belted drivers, an older driver was nearly seven times more likely to be killed or hospitalized than a younger driver *(8)*.

Unlike the quantitative-type questions, qualitative questions are more difficult to compare. Thus, a common methodology which has been extensively used in the past was used here to evaluate the answers. This method assigns different weights to each answer and selected weights range from 0 to 100. Following that, an average weighted value was calculated for each question, which will represent the standpoint of respondents in a quantitative manner. Further, this number will describe the likelihood of occurrence as a probability. Calculated values for each question are presented in the last column of the Table 4.5 and Table 4.7, headed as likelihood of occurrence. For example, likelihood of occurrence indicates the chance of a randomly selected person being in compliance with a particular event.

The assigned weights are as follows:

- Never- 0
- Very rarely- 25
- Sometimes- 50
- Most of the time- 75
- Always- 100

Accordingly, 95 percent said they wear seat belts while driving and 93 percent as a passenger. In other words, if an older driver was randomly selected, there was a 95 percent chance of that driver indicating that he/she wears a seat belt while driving. Similarly, if an older passenger was selected, there was a 93 percent chance of that particular passenger wearing a seat belt. But if no response cases were considered as "never," seat belt usage as a passenger went down to 82 percent and as a driver there was no change.

Eighty-five percent of respondents stated they do not drive after consuming alcohol, but one percent responded that they always drink and drive. There was about a 38 percent chance for an older driver to be driving at night compared to daytime, and 38 percent considered that the streets were not lit well enough at night. Chance of driving on a freeway was recorded as 39 percent.

In the case of exposure to different weather conditions, there were 50 and 56 percent chances of driving in rainy and windy weather conditions, respectively, whereas in snowy conditions it came down to 39 percent. According to the analysis, there was an 18 percent chance in making sudden stops or slowing down on roads without real necessity. There was a 39 percent chance of driving after consuming medicine, whereas only a five percent chance after consuming alcohol. There was around a 64 percent chance of an older driver driving alone, according to the survey.

Table 4.6 presents frequencies and percentages for questions focused on challenging situations. Roundabouts seemed to be the major type of intersection where older drivers were in obscurity. Left turns pointed to the most challenging maneuvering for older drivers at intersections, especially where there were no signal lights or green arrows. However, almost all older drivers seemed to be confident about right turns and left turns with green arrows. Similar results were found in prior research stating that older drivers were no more likely to make right-turn-related crashes compared to younger drivers, but they were over represented twice as often as younger drivers in left-turn-related crashes *(8)*. There is evidence from prior research that some drivers modify or self regulate their driving habits in certain driving situations like high-traffic roads *(52).* According to the survey data, 50 percent of the respondents would like to avoid high-traffic roads when driving, whereas preference for local roads and urban minor roads are high among older drivers. The frequencies for different types of roads and conditions that older drivers would like to avoid are depicted in Figure 4.9.

Table 4.6 Response to Challenging Situation Survey Questions by Older Drivers in Kansas

	Question	Frequency	Percentage
28	*Do you have any difficulties at intersections compared to driving on roadways?*		
	Yes	21	7%
	No	255	90%
29	*If yes, what type of intersection(s) makes you difficult to deal with?*		
	Stop light/ traffic lights	2	1%
	STOP sign controlled	3	1%
	YIELD sign controlled	12	4%
	Roundabouts	32	11%
	No control	15	5%
30	*What are the driving tasks that have become more challenging for you at intersections? (mark multiple answers if applicable)*		
	Making Left Turns with no signal lights	53	19%
	Making Left Turns at traffic signals without a green arrow	35	12%
	Making Left Turns at traffic signals with a green arrow	1	1%
	Making Left Turns at un-signalized intersections	44	15%
	Making Right Turns	1	1%
	Yielding or Stopping	12	4%
	Passing through	3	1%
	None of the above	178	63%
32	*Which type of roads would you like to avoid when driving?*		
	Freeways	77	27%
	Urban major roads	43	15%
	Urban minor roads	16	6%
	High traffic roads	141	50%
	Two lane undivided highways	54	19%
	Rural roads	52	18%
	Local roads	6	2%
	None of the above	62	22%

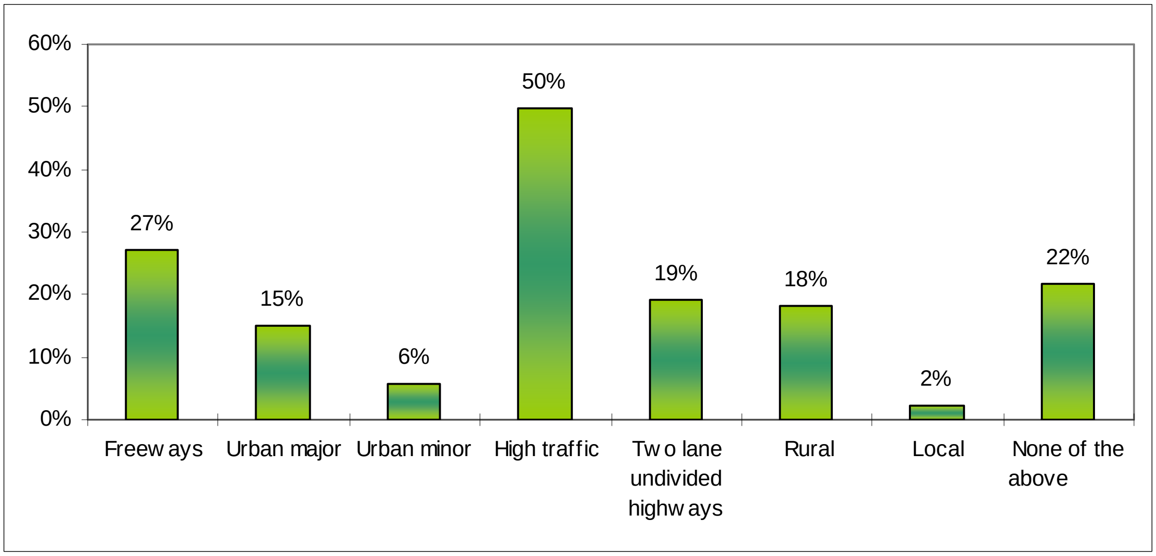

Figure 4.9 Types of Roads Avoided by Older Drivers

Table 4.7 presents the response-to-difficulty-type survey questions and respective likelihood of occurrence values have been calculated. When looking at the difficulty-type questions, 14 percent have a difficulty associated with stopping or slowing down, and eight percent with straight following the road. Nineteen percent have difficulties in lane changing and 22 percent have difficulties with merging into traffic. Nineteen percent have difficulties in judging gaps when merging or making a turn, and 12 percent in negotiating curves. Nineteen percent showed difficulties with diverging with traffic and 24 percent showed difficulties with identifying speeds and distance of oncoming traffic.

Table 4.7 Response to Difficulty-Type Survey Questions by Older Drivers in Kansas

	Question	Frequency	Percentage	Likelihood of Occurrence
17	*How often do you have any difficulty associated with stopping, stopped waiting to turn, or slowing down?*			14
	Never	150	54%	
	Very rarely	109	39%	
	Sometimes	16	6%	
	Most of the time	2	1%	
	Always	2	1%	
18	*How often do you encounter any difficulty with straight following the road?*			8
	Never	203	72%	
	Very rarely	74	26%	
	Sometimes	4	1%	
	Most of the time	0	0%	
	Always	1	1%	
19	*How often do you have difficulty in lane changing?*			19
	Never	107	38%	
	Very rarely	142	50%	
	Sometimes	31	11%	
	Most of the time	2	1%	
	Always	1	1%	
20	*How often do you have difficulty with merging into traffic?*			22
	Never	90	32%	
	Very rarely	141	50%	
	Sometimes	48	17%	
	Most of the time	3	1%	
	Always	0	0%	
21	*How often do you have difficulty in judging gaps when merging or making a turn?*			19
	Never	105	38%	
	Very rarely	140	50%	
	Sometimes	32	11%	
	Most of the time	3	1%	
	Always	0	0%	
22	*How often do you have difficulty with diverging from the traffic?*			19
	Never	100	36%	
	Very rarely	148	53%	
	Sometimes	28	10%	
	Most of the time	2	1%	
	Always	0	0%	
23	*How often do you have difficulty with negotiating curves?*			12
	Never	165	58%	
	Very rarely	102	36%	
	Sometimes	14	5%	
	Most of the time	1	1%	
	Always	1	1%	
31	*Is there any difficulty associated with identifying speeds and distance of oncoming traffic?*			24
	Not at all	87	31%	
	Very rarely	126	45%	
	Sometimes	59	21%	
	Most of the time	6	2%	
	Always	1	1%	

4.2.1 Differences Based on Gender

Table 4.8 shows the cross relationships between the gender of older-driver respondents and different types of difficulties addressed in the survey form. In the table, the likelihood percentage is also calculated and presented for each case. This cross classification would help to identify high-difficulty levels associated with gender if present. To be more prudent, chi-square values were also calculated for each case. According to the percentage and likelihood, it can be mentioned that there was a higher level of difficulty associated with males compared to females with respect to stopping, stopped waiting to turn, or slowing down situations. This relationship was proven by the chi-square test at 94.8% confidence level (χ^2=5.922, p=0.0518). There was only a slight difference shown in the difficulty associated with straight following the road with respect to gender (χ^2=1.131, p>0.5), and with respect to lane changing there was no difference shown at all (χ^2=0.447, p>0.5). When merging and judging gaps to merge or turn, females showed higher levels of difficulty than males. But there was no evidence for a strong co-relationship between these two situations according to confidence level calculations. It was about 89% and 73% for these two cases, respectively (χ^2=4.352, p=0.1135 and χ^2=2.614, p=0.271, respectively). With respect to diverging, males indicated a higher level of difficulty compared to females, and on the other hand, females indicated a higher level of difficulty than males when negotiating curves. The relationship with diverging cannot be proven by a chi-square test (χ^2=0.605, p>0.5). With negotiating curves, there was a relationship at the 74% confidence level (χ^2=2.714, p=0.257).

However, a significant difference can be observed with the difficulty associated with identifying speeds and distance of oncoming traffic conditions. In those situations, females showed a very higher level of difficulty compared to males, and it was statistically proven with the chi-square test at the 99.9% confidence level (χ^2=16.765, p<0.001).

Table 4.8 Gender vs. Response to Difficulty Type Survey Questions

Level of Difficulty	Q-17		Q-18		Q-19		Q-20	
	Male	Female	Male	Female	Male	Female	Male	Female
Never	50%	57%	75%	70%	38%	38%	34%	30%
Very rarely	39%	39%	21%	30%	52%	49%	54%	48%
Sometimes	9%	4%	3%	1%	9%	12%	11%	21%
Most of the time	1%	1%	0%	0%	1%	1%	2%	1%
Always	2%	0%	1%	0%	1%	0%	0%	0%
Weighted value	**17**	**12**	**7**	**8**	**19**	**19**	**20**	**23**
Level of Difficulty	**Q-21**		**Q-22**		**Q-23**		**Q-31**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
Never	43%	34%	33%	38%	63%	55%	45%	22%
Very rarely	46%	52%	55%	52%	33%	38%	38%	50%
Sometimes	10%	13%	12%	9%	4%	6%	17%	24%
Most of the time	1%	1%	0%	1%	0%	1%	0%	4%
Always	0%	0%	0%	0%	0%	1%	1%	0%
Weighted value	**17**	**20**	**20**	**18**	**10**	**13**	**19**	**27**

Note: Response rates are shown in percentages.

Q-17 is difficulty associated with stopping, stopped waiting to turn or slowing down.

Q-18 is difficulty with straight following the road.

Q-19 is difficulty in lane changing.

Q-20 is difficulty with merging in to traffic.

Q-21 is difficulty in judging gaps when merging or making a turn.

Q-22 is difficulty with diverging from traffic.

Q-23 is difficulty with negotiating curves.

Q-31 is difficulty associated with identifying speeds and distance of oncoming traffic.

In Table 4.9, driving frequency, miles driven, and crash involvement percentages were tabulated based on gender. Accordingly, 20 percent more males drive every day than females and this is counterbalanced in other options. Further, percentage of females who drive once in a while is high which supports the idea that older females drive less frequently compared to older males. In general, prior researchers have found that older drivers with functional impairment were more likely to drive less than four days per week, while older drivers with a history of cataracts or high blood pressure were more likely to report a low number of days driven per week *(53)*.

Table 4.9 Gender vs. Driving Frequency, Miles Driven, and Crash Involvement

Driving Frequency	Male	Female
Everyday	53%	33%
4-6 days per week	18%	23%
2-3 days per week	25%	29%
Once a week	4%	9%
Once a month	1%	1%
Once in a while	1%	6%
Miles Driven	**Male**	**Female**
0 -100 miles	28%	50%
101 -200 miles	12%	24%
201 -500 miles	27%	22%
501 -1000 miles	19%	3%
1001- 2000 miles	10%	1%
More than 2000 miles	4%	1%
Involved in a Crash	**Male**	**Female**
Yes	19%	17%
No	81%	83%

On average, more than 20 percent of females drive less than 100 miles per month compared to males, and this was nearly 12 percent in the next mileage category. When number of miles driven per month increases, the male percentage gets higher compared to female percentage. Based on the survey data, an average number of miles driven can be calculated by assigning an average value for each mileage category considered. For the last category, which is over 2,000 miles, an average value of 2,500 was considered. Accordingly, on average, an older driver drives around 325 miles per month. Values indicated that on average, older males drive around 525 miles per month and older females drive only 185 miles per month. According to the National Household Travel Survey 2001 (NHTS), an average male in Kansas drives 850 miles per month and an average female drives around 400 miles per month. An average older driver drives around 650 miles per month as per NHTS data irrespective of gender. This difference could arise for two reasons, either sample size or sample mix corresponding to age and gender. The NHTS sample size was less than half compared to the study sample size, and males younger than 75 years of age were over-represented as well.

A higher percentage of males were involved in crashes among respondents compared to females. However, prior research has found that older females have higher accident involvement rates than older males *(54)*. When a similar calculation was carried out based on the number of miles traveled, males showed a crash rate of 3.69 for 10,000 vehicle miles driven, whereas females showed a much higher crash rate of 9.4 for 10,000 vehicle miles driven. This illustrates a higher crash involvement risk with respect to females compared to males.

Answers provided to question number 26 (Appendix-F), explaining about crashes involving older drivers during the last 10 years, were analyzed and identified who was at fault in each crash. This analysis revealed that the more females were at fault compared to males, even though the absolute number of females who met with crashes was less.

Table 4.10 Driver and Passenger Seat Belt Usages vs. Gender

Gender	Driver	Passenger
Male	97.0	91.8
Female	91.9	94.4
Average	94.9	93.4

Note: Values represent the likelihood of occurrence based on survey response.

According to past studies in Kansas, seat belt usage among older crash victims was high compared to other age groups. But, irrespective of age, a majority of the crash victims were males and their seat belt usage was lower compared to females *(51)*. Similar results were found from the survey as well. Seat belt usage was high both as a driver and as a passenger, and according to Table 4.10, more male drivers wore their seat belts as compared to females. However, fewer males wore seat belts as passengers as compared to females.

4.2.2 Differences Based on Age

Similar to gender, it is important to identify different older-driver behaviors associated with their age. When looking at the mileage driven based on age, it can be observed that in general, number of miles driven reduces as age increases (χ^2=47.714, p<0.001). Figure 4.10 shows the variation. Further, there is a high co-relationship between driving frequency and age of the older driver (χ^2=29.190, p<0.001). Considering the information revealed from these two situations, it is possible to state that older male drivers drive more frequently and more miles compared to older female drivers, confirming previous findings *(9)*.

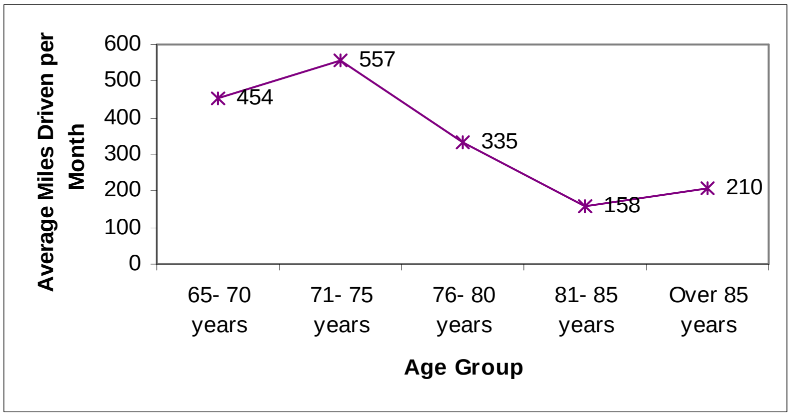

Figure 4.10 Average Miles Driven per Month by an Older Driver Based on Age

Table 4.11 shows the percentages for likelihood of occurrence with respect to difficulty-level questions based on age. The percentages above the average are highlighted.

Table 4.11 Age Vs Response to Difficulties Type Survey Questions

Age Group	Q-17	Q-18	Q-19	Q-20	Q-21	Q-22	Q-23	Q-31
65- 70 years	11.9	**9.5**	17.9	20.8	17.3	14.6	10.1	19.6
71- 75 years	11.7	6.3	15.1	18.2	**19.3**	18.2	12.0	20.2
76- 80 years	**14.0**	**8.0**	**20.8**	**21.9**	**19.6**	**19.8**	11.7	23.1
81- 85 years	**16.7**	**9.2**	**22.7**	**26.9**	**21.1**	**22.7**	**14.0**	**28.5**
Over 85 years	13.8	5.3	16.4	19.7	17.2	17.2	11.9	**25.4**
Average	*13.9*	*7.6*	*18.9*	*21.8*	*19.0*	*18.9*	*12.1*	*23.8*

Note: Values represent their likelihood of occurrence based on survey response.

Values greater than the average are bolded.

Q-17 is difficulty associated with stopping, stopped waiting to turn or slowing down.

Q-18 is difficulty with straight following the road.

Q-19 is difficulty in lane changing.

Q-20 is difficulty with merging in to traffic.

Q-21 is difficulty in judging gaps when merging or making a turn.

Q-22 is difficulty with diverging from traffic.

Q-23 is difficulty with negotiating curves.

Q-31 is difficulty associated with identifying speeds and distance of oncoming traffic.

At a glance, it can be seen that age groups from 76-80 years and 81-85 years have more difficulties than other age groups, or in other words, their difficulty levels are above the average. Further, it can be observed that the 81-85 years age group shows a higher probability of having difficulties compared to the 76-80 years age group in all cases. When considering the overall situation, numbers illustrate that likelihood of difficulty increases as age increases but have a slight decrease when it comes to the above 85 years age group. Occasionally a few other age groups also indicate values above the average with no consistent pattern and thus can be disregarded as random variations.

From the past research studies, it was well known that older drivers make modifications to their driving behavior over time in order to compensate for physical and cognitive changes associated with their aging. As a result, they either avoid driving in demanding situations or reduce the number of miles traveled *(30)* under such conditions. Question 12 was used to identify the older-driver preference towards driving under different weather conditions. Similarly, question 9 was asked to see their preference for nighttime driving over daylight conditions, and question 11 dealt with driving on freeways. Table 4.12 shows the preference of driving under different demanding situations in relation to different age groups.

Table 4.12 Older-Driver Age vs. Willingness to Drive in Demanding Conditions

Age Group	Rainy	Snowy	Windy	Night	Freeways
65- 70 years	58.3	53.0	63.1	47.62	43.45
71- 75 years	58.5	45.7	63.3	46.74	47.92
76- 80 years	53.1	42.9	56.3	40.91	43.18
81- 85 years	46.9	33.9	56.7	34.23	33.33
Over 85 years	39.6	25.0	45.9	27.50	32.50
Average	*50.4*	*39.1*	*56.5*	*38.44*	*39.45*

Note: Values represent their likelihood of occurrence based on survey response.

From the table, it can be seen that among all three weather conditions, the highest willingness to drive average is 56.5 percent. Most of drivers hesitated to drive in snowy weather conditions compared to windy and rainy weather conditions. Overall, it can be seen that as older drivers age, their willingness to drive under all these weather conditions decreases gradually. Preferences for driving at night and on the freeway also seemed to be as low as driving under snowy weather conditions. It can be noted that, more or less willingness to drive at night and on the freeway also decreases with aging.

Miles driven by an older driver could be governed by various other factors such as income level, age, gender, etc. A chi-square test was carried out to identify the relationships statistically. For the income vs. miles driven, the calculated chi-square value (χ^2) was 23.010 and the tabular value at 95% confidence level with 12 degrees of freedom was 21.026. Therefore, the calculated value was greater than the tabular value, and the relationship was statistically significant at the 5% level.

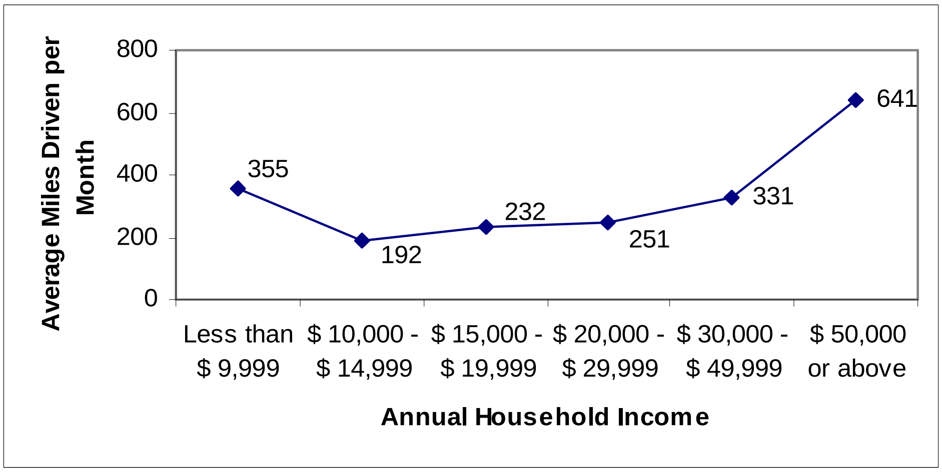

Figure 4.11 Annual Household Income vs. Average Miles Driven by an Older Driver per Month

Generally, higher individual income levels increase the number of miles driven *(55)*. This is true with older drivers as well according to the survey data. Higher incomes increase time value for individuals and considering transportation, they wish to reduce travel time in various ways. They especially tend to drive at higher speeds and sometimes even try to follow less safe driving actions, which can increase fatal risks *(55)*. However, the applicability of this situation to the older driver segment is questionable, since their time value is not that high compared to other age groups and therefore, further investigation is needed before arriving at conclusions. Increased demand for transportation increases exposure to crashes *(55)* and according to the survey, average number of miles driven per month has gone up with increased household income levels. As mentioned before, for age vs. miles driven, the calculated χ^2 was 47.714 and the tabular value for 12 degrees of freedom was 21.026. This shows a correlation between age and miles driven as well. Similarly, gender and miles driven also showed a very high correlation (χ^2=50.147, DF=4, p<0.001), indicating a relationship between gender and miles driven by older drivers.

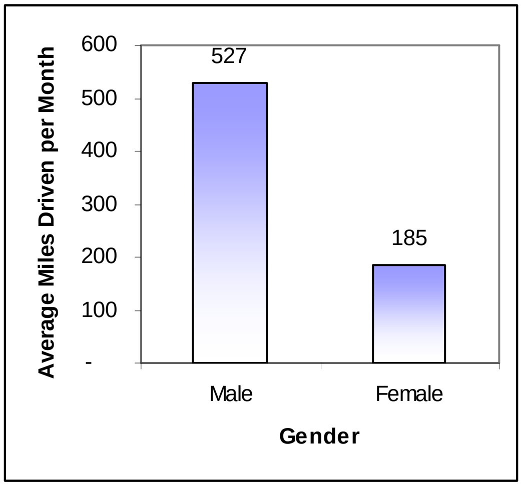

Figure 4.12 Gender vs. Average Miles Driven by an Older Driver per Month

When looking at seat belt-usage distribution with respect to different older-driver age groups, seat belt usage was below the average level in age groups from 65 to 70 and 71 to 75, for driver as well as passengers. This clearly indicates that seat belt usage increases as drivers age.

It was a commonly addressed issue in past studies that decisions about limiting or stopping driving was one of the most difficult tasks faced by older drivers. Therefore a question was included in the survey form inquiring, “When do you think you would stop driving?” The summary of responses is presented in the Table 4.13.

For this question, 270 older drivers responded and 14 who were asked did not. Since multiple answers were accepted for this question, the total number of responses was greater than 270. Accordingly, the majority would like to stop driving either when their doctors advise or when their vision gets poor. When looking at the classification based on gender, females were more willing to listen to their doctors and adult children compared to males. Furthermore, female drivers would prefer to stop driving when their vision gets poor compared to older male drivers. On the other hand, more male drivers were willing to hear about the decision to stop driving from their spouses compared to female drivers.

Table 4.13 Older Drivers' Decisions to Stop Driving vs. Gender

When would you stop driving?	Total Responses	%	Gender	
			Male (%)	Female (%)
Doctor advises	146	54%	59 (53%)	87 (78%)
Adult children interfere	43	16%	7 (6%)	36 (32%)
Vision gets poor	136	50%	50 (45%)	86 (77%)
Spouse advises	28	10%	15 (14%)	13 (12%)
None of the above	22	8%	9 (8%)	13 (12%)

Table 4.14 shows the percentages of respondents' marital status based on gender. There have been several studies carried out in the past related to the decision when to stop driving with aging. D'Ambrosio et al. *(30)* had said that older drivers' decisions to stop driving were more influenced by their spouses if married and living with their spouse. Secondly, they would like to listen mostly to their doctors and adult children. But the results were slightly different in this study based on the survey conducted. Even though most of the respondents were married, still they would like to hear about the decision to stop driving from their doctors rather than from their spouses.

Table 4.14 Marital Status vs. Gender

Marital Status	Male	Female
Single	4%	5%
Married	68%	32%
Divorced	7%	10%
Widowed	18%	52%
Separated	4%	1%

High-traffic roads, freeways, and two-lane undivided highways were among the less preferred roads by older drivers. According to Figure 4.13, their likelihood of avoidance of these roads increases as they get older, but there was a slight decrease indicated when drivers reached the age of 85 years.

In general, alcohol consumption by drivers increases with higher income levels *(55)*. However, this issue was not truly visible among older drivers according to the survey data. But number of respondents with annual household income greater than $ 20,000 was higher, and the number of people who drink and drive was also higher according to the survey. When looking at the percentage distribution, drivers driving after consuming alcohol remained almost the same for all income levels, showing no bias toward high-income earners.

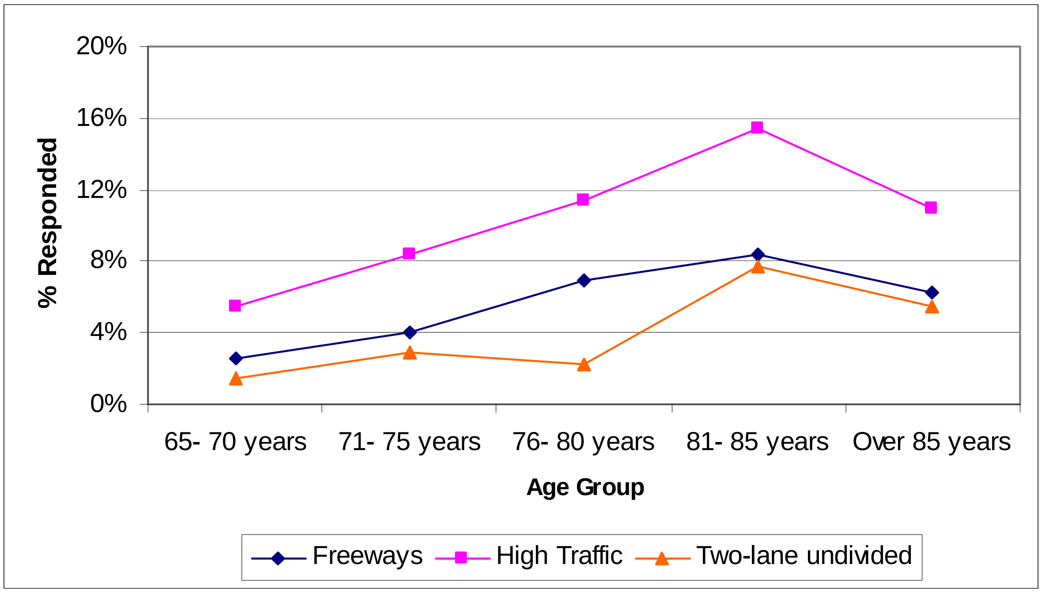

Figure 4.13 Different Types of Roads Avoided by Older Drivers Based on Age

From prior studies, it was found that older drivers with a history of at-fault crashes in the past five years reported more avoidance to challenging conditions than those who had crash-free records *(52)*. There was no such difference found in the survey data, but it is important to note that number of years considered in this survey was not five years, instead of ten years. Further, no detailed comparison was done with crash-free respondents' exposure since such data was not acquired.

4.2.3 Crashes and Contributing Factors

Crude odds ratios were calculated and presented in Table 4.15 for some selected variables. The methodology was explained in detail in Section 3.2.3. A variable name was given for selected questions and a relevant question number was presented in front of the variable. Questions were selected from demographic, general, exposure, and difficult sections where there could be a possibility of a relationship in connection with crash involvement. Even though answers for the difficulty-level and exposure-related questions were in ordinal format, it can be considered that either, respondents had no difficulty/exposure or had difficulty/exposure in some degree and therefore were re-classified as a binary ("yes" or "no") variable. In the marital status situation, it was considered as married vs. single (including divorced, separated, and widowed).

For questions with ordinal responses, the first option was selected as the reference group and odds were calculated for others relative to the first.

Table 4.15 Crude Odds Ratios (OR's) and 95% Confidence Intervals (CI's) for Crash Involvement

Variable		OR's	95% CI	Variable			OR's	95% CI
9	*NIGHT*	1.10	0.43, 2.81	***7***	*AGE*	65 – 70 years	*Reference*	
11	*FREE*	0.88	0.38, 2.05			71 – 75 years	1.26	0.37, 4.33
12a	*RAIN*	2.27	0.28, 18.14			76 – 80 years	1.35	0.43, 4.26
12b	*SNOW*	1.17	0.49, 2.82			81 – 85 years	3.12	1.06, 9.17
12c	*WIND*	0.68	0.07, 6.70			> 85 years	1.45	0.46, 4.60
13	*STOP*	1.06	0.57, 1.97					
14	*MEDIC*	1.35	0.65, 2.81	***38***	*INC*	< $20,000	*Reference*	
15	*ALCO*	1.06	0.44, 2.57			$20,000 - $30,000	1.37	0.52, 3.60
16	*ALONE*	-	-			$30,000 - $50,000	1.32	0.50, 3.45
17	*SLOW*	0.97	0.52, 1.82			> $50,000	1.61	0.61, 4.25
18	*STRAT*	0.95	0.48, 1.87					
19	*LANE*	1.25	0.66, 2.37	***37***	*EDU*	High School	*Reference*	
20	*MERG*	1.43	0.72, 2.85			College	1.27	0.60, 2.67
21	*GAPS*	1.32	0.69, 2.53			Graduate	1.50	0.65, 3.46
22	*DIVG*	1.96	0.97, 3.96					
23	*CURV*	1.05	0.57, 1.94	***6***	*MILE*	0 – 100 miles	*Reference*	
31	*SPED*	2.40	1.11, 5.19			101 – 200 miles	0.95	0.41, 2.18
34	*GEND*	1.15	0.62, 2.13			201 – 500 miles	0.89	0.41, 1.95
33	*COURS*	1.88	1.01, 3.47			501 – 1000 miles	0.93	0.32, 2.73
35	*MART*	1.03	0.56, 1.89			> 1001 miles	0.51	0.11, 2.39
39	*RES*	0.49	0.25, 0.94					
				5	*FREQ*	Everyday	*Reference*	
						4 - 6 days/ week	0.93	0.41, 2.14
						2 -3 days/ week	1.10	0.53, 2.30
						Once in a while	0.90	0.31, 2.61

Odds values are based on respondents who had met with crashes during the last 10 years and the word "respondents" will refer to the same definition hereafter in this discussion. Nighttime driving among respondents was 10 percent higher compared to others who don't drive at night and conversely driving on freeways was 12 percent less compared to respondents who don't frequently drive on freeways. When looking at different exposure conditions, exposure was high in rainy and snowy weather conditions, but less in windy weather conditions. This implies that more exposure to rainy and snowy weather conditions increases the chances of older drivers being involved in crashes. For all difficulty-type questions, respondents' representation was higher except for the stopping-related situation and straight following the road situation. It should be noted that the margins were less than five percent and therefore, it was not advisable to disregard it completely. Though most of the values were marginally higher, respondents showed 43 percent higher levels of difficulty with respect to merging and 96 percent higher levels of difficulty with diverging. Moreover, difficulties associated with identifying speeds and distance of oncoming traffic showed 2.4 times (140%) higher difficulty levels compared to respondents who didn't experience such difficulties.

Some odds ratios were calculated based on a few demographic questions in order to see how they are related to driving behavior of older drivers. Respondents who took driving education courses showed higher likeliness to be involved in crashes compared to others who haven't participated in such courses. This presumably could be due to the fact that, consequently, older drivers take a driving course after being involved in a crash. When considering older-driver groups based on age, the 65 to 70 years age group was considered the reference group and, odds ratios have revealed that other drivers older than the 65 to 70 years group are overly involved in crashes compared to the reference group. Furthermore, it is important to highlight that the age group from 81 to 85 years had 3.12 times higher involvement rate compared to reference group. A similar pattern can be observed with respect to income levels and in relation to education. Higher annual income earners were more likely to be involved in crashes and the same could be seen with higher levels of education, where chances of being involved in a crash also increased. As number of miles driven increased, chances of being involved in a crash have decreased, according to the ratios. This was probably due to the increased number of miles per week increasing their experience. On the other hand, it may be due to the fact that people with more difficulties try to minimize driving *(53, 56)* and at the same time have high chances of being involved in crashes. Driving frequency shows that respondents who drive two to three days per week have slightly higher involvement rates compared to respondents who drive every day.

Odds ratios calculated based on gender using fewer variables and relevant confidence intervals are presented in Table 4.16. In all exposure conditions examined, males were overrepresented compared to females, and males were 3.3 times overrepresented in drinking and driving situations. For different difficulty type questions, odds ratios were presented and results were the same as discussed in Section 4.2.1. With respect to different types of roads that older drivers would like to avoid, females were overrepresented in a majority of the types, apart from rural and local roads. Males were overrepresented in speeding tickets, and at different types of intersections there was no significant difference in difficulties between males and females. Female older drivers showed a problem with making left turns compared to males, and further investigation is required to find out what factors are causing such difficulties among females. Males were overrepresented in use of SUVs, vans, and particularly with trucks (10.44 times higher) compared to females.

Table 4.16 Crude Odds Ratios (OR's) and 95% Confidence Intervals (CI's) for Older Drivers Involved in Crashes Based on Gender

Variable		OR's	95% CI	Variable			OR's	95% CI
9	*NIGHT*	3.48	1.47, 8.21	***32***	*ROAD*	Freeway	0.29	0.16, 0.54
11	*FREE*	3.18	1.41, 7.18			Urban major	0.68	0.34, 1.35
12a	*RAIN*	3.94	0.86, 18.12			Urban minor	0.66	0.22, 1.96
12b	*SNOW*	2.44	1.18, 5.07			High traffic	0.44	0.27, 0.72
12c	*WIND*	-	-			Two lane	0.46	0.23, 0.88
13	*STOP*	1.14	0.70, 1.85			Rural	1.12	0.61, 2.05
14	*MEDIC*	1.89	1.08, 3.31			Local	1.50	0.30, 7.59
15	*ALCO*	3.37	1.64, 6.91					
16	*ALONE*	0.67	0.09, 4.82	***27***	*VIO*	Ticket	1.69	0.81, 3.49
17	*SLOW*	1.33	0.82, 2.14					
18	*STRAT*	0.75	0.44, 1.28	***29***	*INTER*	Yield	1.07	0.33, 3.45
19	*LANE*	1.01	0.62, 1.64			Roundabout	0.88	0.41, 1.88
20	*MERG*	0.84	0.50, 1.39			No control	0.99	0.34, 2.87
21	*GAPS*	0.68	0.41, 1.10					
22	*DIVG*	1.21	0.73, 2.00	***30***	*TURNS*	LT no light	0.8	0.43, 1.49
23	*CURV*	0.71	0.44, 1.16			LT without arrow	0.4	0.17, 0.91
31	*SPED*	0.34	0.20, 0.58			LT no control	0.38	0.18, 0.81
				3	*VEH*	Car	0.46	0.26, 0.82
						SUV	2.16	0.84, 5.56
						Van	1.69	0.84, 3.38
						Truck	10.44	3.00, 36.35

4.3 Rural / Urban Crashes and Contributing Factors

From 2002 to 2006, a total of 43,290 older-driver-involved crashes were reported in Kansas. A majority of these crashes occurred in urban areas. A similar trend can be observed with middle-aged and younger drivers. Despite the number of crashes, injury-severity analysis indicated that rural road crashes are more severe compared to urban road crashes. On the other hand, when looking at the public road miles in Kansas, there are about 123,694 rural highway miles and 11,768 urban highway miles classified according to the U.S. Department of Transportation reports for the year 2005 *(42)*. Synthesizing these findings created an interest to elaborate more on older-driver-involved crashes classified under rural and urban areas, concentrating more on injury severity to identify contributing factors which could be used to improve safety of older drivers.

4.3.1 Analysis Using Decomposition Method

As the first step, decomposition ratios were calculated considering combined crash data for a five-year period followed by a yearly breakdown, as shown in Table 4.17. The methodology was explained in Section 3.2.4. The higher the fatal crash incidence density, the more critical the factor towards creating higher fatalities for vehicle miles traveled. Similarly, the higher the injury fatality rate, the more critical the factor creating fatalities when there are crashes with injuries. If the crash injury rate is higher, the factor is more critical towards creating injuries when crashes occur, and crash-incidence density indicates the criticalness of getting involved in crashes per number of miles traveled.

Fatal crash-incidence densities calculated for rural and urban areas indicated vast differences. Even after adjusting for older drivers' exposure, there are higher chances for older drivers to experience fatal injuries if crashes occur on rural roads compared to crashes on urban roads. When looking at the injury fatality rate for the same scenario, there is a high likeliness for a rural older driver to experience fatal injuries when considering crashes causing any sort of injuries. But when looking at the crash injury rates, the difference is less between urban and rural, and when it comes to crash-incidence density, the difference is unobservable.

Table 4.17 Decomposition Ratios for Older-Driver-Involved Crashes in Kansas

Area	No. of fatal crashes	No. of injury crashes	No. of total crashes	No. of miles driven (in millions)	A	B	C	D
2002-2006								
Rural	217	2,636	13,933	3,716	5.84	82	189	3.75
Urban	58	4,017	29,357	7,559	0.77	14	136	3.88
Rural/Urban ratio	3.74	0.656	0.475	0.492	7.61	5.70	1.38	0.97
2006								
Area	**No. of fatal crashes**	**No. of injury crashes**	**No. of total crashes**	**No. of miles driven (in millions)**	**A**	**B**	**C**	**D**
Rural	55	479	2,515	752	7.32	114	190	3.35
Urban	14	747	5,415	1,530	0.92	18	137	3.54
Rural/Urban ratio	3.93	0.64	0.46	0.49	7.99	6.13	1.38	0.95
2005								
Area	**No. of fatal crashes**	**No. of injury crashes**	**No. of total crashes**	**No. of miles driven (in millions)**	**A**	**B**	**C**	**D**
Rural	34	508	2,533	747	4.55	66	200	3.39
Urban	16	775	5,416	1,519	1.05	20	143	3.57
Rural/Urban ratio	2.13	0.66	0.47	0.49	4.32	3.24	1.40	0.95
2004								
Area	**No. of fatal crashes**	**No. of injury crashes**	**No. of total crashes**	**No. of miles driven (in millions)**	**A**	**B**	**C**	**D**
Rural	46	555	2,888	745	6.18	82	192	3.88
Urban	5	773	6,035	1,515	0.33	6	128	3.98
Rural/Urban ratio	9.20	0.72	0.48	0.49	18.72	12.81	1.50	0.97
2003								
Area	**No. of fatal crashes**	**No. of injury crashes**	**No. of total crashes**	**No. of miles driven (in millions)**	**A**	**B**	**C**	**D**
Rural	38	507	3,009	746	5.10	74	168	4.04
Urban	8	795	6,049	1,516	0.53	10	131	3.99
Rural/Urban ratio	4.75	0.64	0.50	0.49	9.66	7.45	1.28	1.01
2002								
Area	**No. of fatal crashes**	**No. of injury crashes**	**No. of total crashes**	**No. of miles driven (in millions)**	**A**	**B**	**C**	**D**
Rural	44	587	2,988	727	6.05	74	196	4.11
Urban	15	927	6,442	1,478	1.01	16	143	4.36
Rural/Urban ratio	2.93	0.63	0.46	0.49	5.96	4.63	1.37	0.94

Note: A- Fatal crash incidence density, B- Injury fatality rate, C- Crash injury rate, and D- Crash incidence density

This is an important factor to note: in both categories of roads the crash incidence densities (D) are almost the same, there was a significant difference between fatal crash incidence densities (A), indicating that rural road crashes are more severe compared to urban road crashes. A similar pattern can be observed when looking at a yearly basis analysis presented in the same table as well. This verified the fact that has been already revealed in injury severity analysis and accordingly in the next step, contributing factors to such circumstances are identified. In Table 4.18, a summary of yearly basis analysis is presented followed by Figure 4.14 depicting the trends over the five-year period.

Table 4.18 Summary of Decomposition Ratios for Older-Driver-Involved Crashes in Kansas

Area	Year	Fatal crash incidence density (A)	Injury fatality rate (B)	Crash injury rate (C)	Crash incidence density (D)
Rural	***2006***	7.32	114	190	3.35
	2005	4.55	66	200	3.39
	2004	6.18	82	192	3.88
	2003	5.10	74	168	4.04
	2002	6.05	74	196	4.11
Urban	***2006***	0.92	18	137	3.54
	2005	1.05	20	143	3.57
	2004	0.33	6	128	3.98
	2003	0.53	10	131	3.99
	2002	1.01	16	143	4.36
Rural/Urban ratio	***2006***	7.99	6.13	1.38	0.95
	2005	4.32	3.24	1.40	0.95
	2004	18.72	12.81	1.50	0.97
	2003	9.66	7.45	1.28	1.01
	2002	5.96	4.63	1.37	0.94

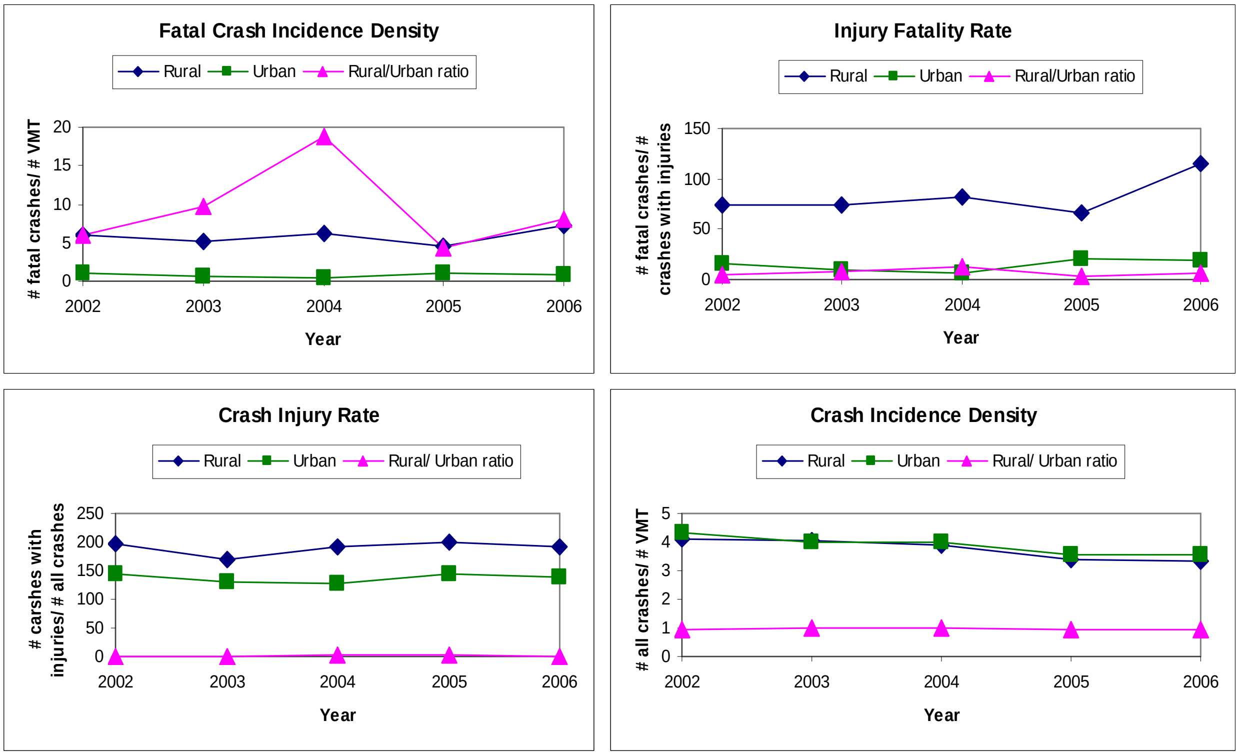

Figure 4.14 Decomposition Ratios Over the Five-Year Period

Table 4.19 shows the rates based on age and gender classification. Both male and female drivers in rural areas are at a higher risk compared to urban areas. In rural areas, all four rates increase as age increases, but a significant jump can be observed for the 85 years and older age group irrespective of gender. This is heavily highlighted in the fatality incidence density compared to other rates.

Table 4.19 Decomposition Ratios Based on Age and Gender

Gender and Age	No. of drivers with fatalities	No. of drivers with injuries	No. of drivers involved	No. of miles driven (in millions)	A	B	C	D
<u>Male</u>								
Rural								
65-69	34	455	3,125	944	3.6	75	146	3.3
70-74	24	393	2,400	703	3.4	61	164	3.4
75-79	39	349	1,915	448	8.7	112	182	4.3
80-84	29	255	1,204	256	11.3	114	212	4.7
>85	27	179	730	130	20.7	151	245	5.6
Urban								
65-69	14	546	5,161	1,878	0.7	26	106	2.7
70-74	4	482	4,337	1,318	0.3	8	111	3.3
75-79	8	398	3,585	982	0.8	20	111	3.7
80-84	5	338	2,565	619	0.8	15	132	4.1
>85	3	154	1,374	235	1.3	19	112	5.9
Rural/ Urban ratio								
65-69	2.4	0.8	0.6	0.5	4.8	2.9	1.4	1.2
70-74	6.0	0.8	0.6	0.5	11.2	7.4	1.5	1.0
75-79	4.9	0.9	0.5	0.5	10.7	5.6	1.6	1.2
80-84	5.8	0.8	0.5	0.4	14.0	7.7	1.6	1.1
>85	9.0	1.2	0.5	0.6	16.2	7.7	2.2	1.0
<u>Female</u>								
Rural								
65-69	12	295	1,544	426	2.8	41	191	3.6
70-74	15	239	1,234	335	4.5	63	194	3.7
75-79	17	229	1,090	275	6.2	74	210	4.0
80-84	11	175	792	153	7.2	63	221	5.2
>85	10	131	554	46	21.8	76	236	12.1
Urban								
65-69	3	598	3,837	882	0.3	5	156	4.3
70-74	3	531	3,432	701	0.4	6	155	4.9
75-79	6	488	3,186	517	1.2	12	153	6.2
80-84	7	352	2,295	269	2.6	20	153	8.5
>85	5	215	1,359	160	3.1	23	158	8.5
Rural/ Urban ratio								
65-69	4.0	0.5	0.4	0.5	8.3	8.1	1.2	0.8
70-74	5.0	0.5	0.4	0.5	10.5	11.1	1.3	0.8
75-79	2.8	0.5	0.3	0.5	5.3	6.0	1.4	0.6
80-84	1.6	0.5	0.3	0.6	2.8	3.2	1.4	0.6
>85	2.0	0.6	0.4	0.3	7.0	3.3	1.5	1.4

Note: A- Fatal crash incidence density, B- Injury fatality rate, C- Crash injury rate, and D- Crash incidence density

Tables 4.20 and 4.21 present the ratios calculated based on road type and posted speed limits on the roads, respectively. Since there is no classification given in NHTS data to calculate number of miles driven by older drivers in each road category, the total number of rural miles driven was used for all road types. This has an effect on the fatal crash incidence density and crash-incidence density values to some extent. But since there is no other better alternative available to calculate ratios, the same number was used for all cases. However, doing that has no effect on injury fatality rates and crash injury rates, because they are based solely on crash data with no involvement in exposure conditions. In general, crash injury rates (C) are decreasing from rural interstate to rural local roads and a similar pattern can be observed for urban roads as well. When looking at the rate B, it can be observed that rural arterial crashes are more severe and this is verified by rate A as well. When looking at the urban case, arterials are more severe according to rate A but according to rate B and C, interstates are more severe in terms of non fatal injuries.

Table 4.20 Decomposition Ratios Based on Road Type

Road type	No. of fatal crashes	No. of injury crashes	No. of total crashes	No. of miles driven (in millions)	A	B	C	D
Rural								
Interstate	13	213	994	3,716	0.35	61	214	0.27
Arterial	120	1,300	5,995	3,716	3.23	92	217	1.61
Collector	54	684	3,554	3,716	1.45	79	192	0.96
Local	30	439	3,390	3,716	0.81	68	129	0.91
Urban								
Interstate	12	388	1,437	7,559	0.16	31	270	0.19
Arterial	34	2,820	19,446	7,559	0.45	12	145	2.57
Collector	5	284	2,285	7,559	0.07	18	124	0.30
Local	7	525	5,042	7,559	0.09	13	104	0.67
Rural/ Urban ratio								
Interstate	1.08	0.55	0.69	0.49	2.20	1.97	0.79	1.41
Arterial	3.53	0.46	0.31	0.49	7.18	7.66	1.50	0.63
Collector	10.80	2.41	1.56	0.49	21.97	4.48	1.55	3.16
Local	4.29	0.84	0.67	0.49	8.72	5.13	1.24	1.37

Note: A- Fatal crash incidence density, B- Injury fatality rate, C- Crash injury rate, and D- Crash incidence density

According to the laws of physics, higher speeds cause higher injury severity in the case of motor vehicle crashes and it can be seen in our study as well. When looking at Table 4.21, it can be observed that on rural roads speed limits between 46 to 65 mph are highly vulnerable to crash severity compared to roads with other speed limits. On urban roads, more severe crashes occurred when the speed limit was higher than 65 mph compared to crashes on roads with lower speed limits. In crash injury rates, there was no pattern to be observed in both rural and urban roads and neither in crash incidence densities. The previous findings based on road type are verified by the speed limit study, because arterials typically have speed limits between 45 to 64 mph, and interstates and freeways are usually above the speed limit of 64 mph.

Table 4.21 Decomposition Ratios Based on Speed Limit

Speed Limit (mph)	No. of fatal crashes	No. of injury crashes	No. of total crashes	No. of miles driven (in millions)	Fatal crash incidence density (A)	Injury fatality rate (B)	Crash injury rate (C)	Crash incidence density (D)
Rural								
21-35	12	299	2,602	3,716	0.32	40	114	0.70
36-45	7	188	845	3,716	0.19	37	222	0.23
46-55	78	842	3,660	3,716	2.10	92	230	0.98
56-65	89	851	3,933	3,716	2.39	104	216	1.06
>65	19	303	1,259	3,716	0.51	62	240	0.34
Urban								
21-35	22	2,389	18,300	7,559	0.29	9	130	2.42
36-45	10	1,019	6,345	7,559	0.13	9	160	0.84
46-55	6	139	722	7,559	0.08	43	192	0.10
56-65	7	227	1,550	7,559	0.09	30	146	0.21
>65	6	45	258	7,559	0.08	133	174	0.03
Rural/Urban ratio								
21-35	0.55	0.13	0.14	0.49	1.11	4.36	0.88	0.29
36-45	0.70	0.18	0.13	0.49	1.42	3.79	1.39	0.27
46-55	13.00	6.06	5.07	0.49	26.44	2.15	1.19	10.31
56-65	12.71	3.75	2.54	0.49	25.86	3.39	1.48	5.16
>65	3.17	6.73	4.88	0.49	6.44	0.47	1.38	9.93

Crashes involving single vehicles have been an issue for a long time among researchers. According to the decomposition ratios presented in Table 4.22, multi-vehicle crashes involving older drivers are more severe in rural areas, whereas it is the other way around in urban areas except for rate A. Such differences could occur because the number of miles driven is not classified under single-vehicle or multi-vehicle categories. Therefore rates B and C are much more reliable and accurate in such instances. In urban areas, single-vehicle crashes are more likely to cause injuries and fatalities compared to multi-vehicle crashes. Further, when looking at rate B and C corresponding to rural/ urban, higher levels of injuries pertaining to multi-vehicle crashes in rural areas can be observed.

Table 4.22 Decomposition Ratios Based on Number of Vehicles Involved in a Crash

Number of vehicles involved	No. of drivers with fatalities	No. of injury crashes	No. of total crashes	No. of miles driven (in millions)	A	B	C	D
Rural								
Single Vehicle	75	1,103	6,846	3,716	2.02	68	161	1.84
Multi Vehicle	142	1,533	7,087	3,716	3.82	92	216	1.91
Urban								
Single Vehicle	15	426	2,909	7,559	0.20	35	146	0.38
Multi Vehicle	43	3,591	26,448	7,559	0.57	11	135	3.50
Rural/Urban ratio								
Single Vehicle	5.00	2.59	2.35	0.49	10.17	1.93	1.10	4.79
Multi Vehicle	3.30	0.43	0.27	0.49	6.72	7.74	1.59	0.55

Note: A- Fatal crash incidence density, B- Injury fatality rate, C- Crash injury rate, and D- Crash incidence density

When considering crash severity based on types of vehicles involved, in rural areas pickup trucks and SUVs driven by older drivers are highly involved in high-severity crashes. Ratios are presented in Table 4.23.

Table 4.23 Decomposition Ratios Based on Vehicle Type

Vehicle type	No. of drivers with fatalities	No. of drivers with injuries	No. of drivers involved	No. of miles driven (in millions)	A	B	C	D
Rural								
Car	121	1,569	8,094	3,716	3.26	77	193	2.18
Van	15	224	1,323	3,716	0.40	66	169	0.36
Pickup truck	54	600	3,628	3,716	1.45	90	165	0.98
SUV	13	134	657	3,716	0.35	97	203	0.18
Urban								
Car	44	3,123	21,661	7,559	0.58	14	144	2.87
Van	6	317	2,700	7,559	0.08	18	117	0.36
Pickup truck	5	422	4,611	7,559	0.07	11	91	0.61
SUV	0	154	1,462	7,559	0.00	0	105	0.19
Rural/Urban ratio								
Car	2.75	0.50	0.37	0.49	5.59	5.47	1.34	0.76
Van	2.50	0.71	0.49	0.49	5.09	3.54	1.44	1.00
Pickup truck	10.80	1.42	0.79	0.49	21.97	7.60	1.81	1.60
SUV	N.A	0.87	0.45	0.49	N.A	N.A	1.94	0.91

Note: A- Fatal crash incidence density, B- Injury fatality rate, C- Crash injury rate, and D- Crash incidence density

Presence of passengers at the time of a crash was discussed heavily in the literature and an outline is presented in the literature review section. Similarly, presence of passengers was considered here in two situations where there are no passengers, or the presence of one or more passengers in a vehicle that was driven by an older driver. Further, the same conditions were subdivided according to the type of vehicle driven by the older driver to see whether there was any relationship. Relevant decomposition ratios are presented in Table 4.24.

Fatality incidence densities are higher in rural areas when there are no passengers present and injury rate is also observed to be high. But, no such difference can be observed with respect to injury fatality rates. When classified according to type of vehicle, pickup trucks and SUVs play a significant role in representing higher injury fatality rates. It is important to note that injury rate corresponding to cars is also high and leads to higher fatality incidence densities. When passengers are present, the pickup truck category showed a reduction in rate B, but there was still no such improvement with respect to SUVs.

Table 4.24 Decomposition Ratios Based on Presence of Passengers and Type of Vehicle

Presence of passengers	No. of drivers with fatalities	No. of drivers with injuries	No. of drivers involved	No. of miles driven (in millions)	A	B	C	D
Rural								
No Passenger	152	1,910	9,762	3,716	4.09	79	195	2.63
One or More Passengers	66	790	4,832	3,716	1.78	83	163	1.30
Urban								
No Passenger	48	3,187	23,088	7,559	0.63	15	138	3.05
One or More Passengers	10	915	8,058	7,559	0.13	10	113	1.07
Rural/Urban ratio								
No Passenger	3.17	0.60	0.42	0.49	6.44	5.28	1.42	0.86
One or More Passengers	6.60	0.86	0.60	0.49	13.42	7.64	1.44	1.22
Rural								
No Passenger								
Car	78	1,084	5,227	3,716	2.10	71	207	1.41
Van	7	127	693	3,716	0.19	55	183	0.19
Pickup truck	46	477	2,746	3,716	1.24	96	173	0.74
SUV	7	74	390	3,716	0.19	94	189	0.10
One or More Passengers								
Car	43	485	2,867	3,716	1.16	88	169	0.77
Van	8	97	629	3,716	0.22	82	154	0.17
Pickup truck	8	123	882	3,716	0.22	65	139	0.24
SUV	6	60	267	3,716	0.16	100	224	0.07
Urban								
No Passenger								
Car	36	2,434	16,141	7,559	0.48	14	150	2.14
Van	5	211	1,774	7,559	0.07	23	118	0.23
Pickup truck	4	347	3,641	7,559	0.05	11	95	0.48
SUV	0	114	1,024	7,559	0.00	0	111	0.14
One or More Passengers								
Car	8	689	5,519	7,559	0.11	11	124	0.73
Van	1	106	922	7,559	0.01	9	114	0.12
Pickup truck	1	75	970	7,559	0.01	13	77	0.13
SUV	0	40	438	7,559	0.00	0	91	0.06

Note: A- Fatal crash incidence density, B- Injury fatality rate, C- Crash injury rate, and D- Crash incidence density

Identification of driver contribution towards crashes and crash severity is highly important in suggesting possible countermeasures to improve safety. Decomposition ratios are calculated for a number of potential contributing factors. For a given crash, there could be more than one contributing factor and as a result, the summation of contributing factors is greater than the actual number of crashes occurring. According to the injury fatality rates calculated, driving on the wrong side or going the wrong way, driving under influence of drugs or alcohol, failing to comply with traffic signs or signals, and high-speed driving are among the top-ranked contributions to crashes by older drivers. When considering crash injury rates, failed to yield right of way, fell asleep, and ill or poor medical condition have contributed towards injuries other than the factors highlighted under injury fatality rates. Tables 4.25 and 4.26 show the rates calculated for rural areas and urban areas, respectively.

Table 4.25 Decomposition Ratios Based on Driver Contribution in Rural Roads

Driver Contribution	No. of fatal crashes	No. of injury crashes	No. of total crashes	No. of miles driven (in millions)	A	B	C	D
under influence of drugs	2	5	20	3,716	0.05	400	250	0.01
under influence of alcohol	10	70	145	3,716	0.27	142	482	0.04
failed to yield right of way	53	608	1,875	3,716	1.43	87	324	0.50
disregard traffic signs,signal	25	171	424	3,716	0.67	146	403	0.11
exceeded posted speed limit	5	28	60	3,716	0.13	178	466	0.02
too fast for conditions	12	199	679	3,716	0.32	60	293	0.18
made improper turn	6	103	413	3,716	0.16	58	249	0.11
wrong side or wrong way	32	101	197	3,716	0.86	316	512	0.05
followed too closely	5	122	504	3,716	0.13	40	242	0.14
improper lane change	6	41	214	3,716	0.16	146	191	0.06
improper backing	1	17	515	3,716	0.03	58	33	0.14
improper passing	3	47	209	3,716	0.08	63	224	0.06
improper or no signal	0	16	56	3,716	0.00	0	285	0.02
improper parking	0	7	31	3,716	0.00	0	225	0.01
fell asleep	11	189	336	3,716	0.30	58	562	0.09
failed to give time and attn	70	960	3,958	3,716	1.88	72	242	1.07
did not comply w lic restric	2	22	66	3,716	0.05	90	333	0.02
other distraction	0	36	141	3,716	0.00	0	255	0.04
avoidance or evasive action	12	118	366	3,716	0.32	101	322	0.10
impeding traffic, too slow	2	18	48	3,716	0.05	111	375	0.01
ill or medical condition	15	154	233	3,716	0.40	97	660	0.06
distraction - mobile phone	1	10	21	3,716	0.03	100	476	0.01
distraction - electronic devices	1	3	7	3,716	0.03	333	428	0.00
aggressive/antagonistic driving	0	2	13	3,716	0.00	0	153	0.00
reckless / careless driving	1	20	57	3,716	0.03	50	350	0.02

Note: A- Fatal crash incidence density, B- Injury fatality rate, C- Crash injury rate, and D- Crash incidence density

Table 4.26 Decomposition Ratios Based on Driver Contribution in Urban Roads

Driver Contribution	No. of fatal crashes	No. of injury crashes	No. of total crashes	No. of miles driven (in millions)	A	B	C	D
under influence of drugs	1	15	56	7,559	0.01	66	267	0.01
under influence of alcohol	3	81	294	7,559	0.04	37	275	0.04
failed to yield right of way	14	1291	7,892	7,559	0.19	10	163	1.04
disregard traffic signs,signal	8	635	2,808	7,559	0.11	12	226	0.37
exceeded posted speed limit	4	57	143	7,559	0.05	70	398	0.02
too fast for conditions	8	232	1,287	7,559	0.11	34	180	0.17
made improper turn	2	175	1,385	7,559	0.03	11	126	0.18
wrong side or wrong way	5	69	236	7,559	0.07	72	292	0.03
followed too closely	0	302	2,470	7,559	0.00	0	122	0.33
improper lane change	1	65	1,339	7,559	0.01	15	48	0.18
improper backing	0	31	1,048	7,559	0.00	0	29	0.14
improper passing	0	14	208	7,559	0.00	0	67	0.03
improper or no signal	0	13	60	7,559	0.00	0	216	0.01
improper parking	1	9	40	7,559	0.01	111	225	0.01
fell asleep	2	39	93	7,559	0.03	51	419	0.01
failed to give time and attn	24	1778	13,425	7,559	0.32	13	132	1.78
did not comply w lic restric	0	42	182	7,559	0.00	0	230	0.02
other distraction	0	49	252	7,559	0.00	0	194	0.03
avoidance or evasive action	2	53	372	7,559	0.03	37	142	0.05
impeding traffic, too slow	0	12	72	7,559	0.00	0	166	0.01
ill or medical condition	9	183	332	7,559	0.12	49	551	0.04
distraction - mobile phone	0	7	56	7,559	0.00	0	125	0.01
distraction -electronic devices	0	1	14	7,559	0.00	0	71	0.00
aggressive/antagonistic driving	1	8	29	7,559	0.01	125	275	0.00
reckless / careless driving	3	43	134	7,559	0.04	69	320	0.02

Note: A- Fatal crash incidence density, B- Injury fatality rate, C- Crash injury rate, and D-Crash incidence density

Decomposition rates pertaining to different road characteristics are presented in Table 4.27. On rural roads, curved roads are more associated with crashes with injury (C) compared to straight road conditions. Injury fatality rates indicate that crashes are more severe at hill crests irrespective of the curvature.

Table 4.27 Decomposition Ratios Based on Road Character

Road character	No. of fatal crashes	No. of injury crashes	No. of total crashes	No. of miles driven (in millions)	A	B	C	D
Rural								
Straight and level	148	1,767	10,117	3,716	3.98	84	175	2.72
Straight on grade	42	519	2,473	3,716	1.13	81	210	0.67
Straight at hillcrest	10	88	344	3,716	0.27	114	256	0.09
Curved and level	7	145	503	3,716	0.19	48	288	0.14
Curved on grade	9	97	354	3,716	0.24	93	274	0.10
Curved at hillcrest	1	9	21	3,716	0.03	111	429	0.01
Urban								
Straight and level	41	3,122	23,200	7,559	0.54	13	135	3.07
Straight on grade	8	635	4,429	7,559	0.11	13	143	0.59
Straight at hillcrest	1	41	294	7,559	0.01	24	139	0.04
Curved and level	4	103	718	7,559	0.05	39	143	0.09
Curved on grade	3	75	504	7,559	0.04	40	149	0.07
Curved at hillcrest	0	5	22	7,559	0.00	0	227	0.00
Rural/ Urban ratio								
Straight and level	3.61	0.57	0.44	0.49	7.34	6.38	1.30	0.89
Straight on grade	5.25	0.82	0.56	0.49	10.68	6.42	1.46	1.14
Straight at hillcrest	10.00	2.15	1.17	0.49	20.34	4.66	1.83	2.38
Curved and level	1.75	1.41	0.70	0.49	3.56	1.24	2.01	1.42
Curved on grade	3.00	1.29	0.70	0.49	6.10	2.32	1.84	1.43
Curved at hillcrest	N.A	1.80	0.95	0.49	N.A	N.A	1.89	1.94

Note: A- Fatal crash incidence density, B- Injury fatality rate, C- Crash injury rate, and D-Crash incidence density

In Table 4.28, decomposition ratios calculated based on road location are present. Median off roadway, roadside including shoulder off roadway, interchange area on roadway, and intersection on roadway are more critical to causing injuries when crashes occur. Given a crash has occurred; roadsides including shoulders, intersection, and non-intersection on roadways are more likely to experience fatalities.

Table 4.28 Decomposition Ratios Based on Road Location

Road location	No. of fatal crashes	No. of injury crashes	No. of total crashes	No. of miles driven (in millions)	A	B	C	D
Rural								
non-intersection-on roadway	99	1,122	7,861	3,716	2.66	88	142	2.12
intersection-on roadway	73	838	3,084	3,716	1.96	87	271	0.83
intersection-related-on roadway	6	171	972	3,716	0.16	35	175	0.26
pklot-drvway access-on roadway	6	136	1,071	3,716	0.16	44	126	0.29
interchange area-on roadway	3	48	226	3,716	0.08	62	212	0.06
roadside-off roadway	28	283	633	3,716	0.75	98	447	0.17
median-off roadway	2	33	65	3,716	0.05	60	507	0.02
Urban								
non-intersection-on roadway	21	814	7,913	7,559	0.28	25	102	1.05
intersection-on roadway	21	1,975	11,717	7,559	0.28	10	168	1.55
intersection-related-on roadway	6	581	4,813	7,559	0.08	10	120	0.64
pklot-drvway access-on roadway	2	372	3,243	7,559	0.03	5	114	0.43
interchange area-on roadway	4	164	1,305	7,559	0.05	24	125	0.17
roadside-off roadway	2	87	262	7,559	0.03	22	332	0.03
median-off roadway	1	20	61	7,559	0.01	50	327	0.01
Rural/Urban ratio								
non-intersection-on roadway	4.71	1.38	0.99	0.49	9.59	3	1.39	2.02
intersection-on roadway	3.48	0.42	0.26	0.49	7.07	8	1.61	0.54
intersection-related-on roadway	1.00	0.29	0.20	0.49	2.03	3	1.46	0.41
pklot-drvway access-on roadway	3.00	0.37	0.33	0.49	6.10	8	1.11	0.67
interchange area-on roadway	0.75	0.29	0.17	0.49	1.53	2	1.69	0.35
roadside-off roadway	14.00	3.25	2.42	0.49	28.48	4	1.35	4.91
median-off roadway	2.00	1.65	1.07	0.49	4.07	1	1.55	2.17

Note: A- Fatal crash incidence density, B- Injury fatality rate, C- Crash injury rate, and D- Crash incidence density

4.3.2 Analysis Using Ordered Probit Modeling

The ordered probit modeling technique was used to identify the contributing factors for older-driver injury severity. Two separate models were developed to assess older-driver injury severity in rural and urban areas by considering nearly 50 explanatory variables using statistical modeling software, SAS version 9.1. The response variable was taken as injury severity. Variable names, description about how variables are determined, and corresponding mean values are given in Table 4.29.

Table 4.29 Variable Description for Older-Driver Injury Severity Models

Variable Type	Variable Name	Description	Mean	
			Rural	Urban
Driver Age	AG_1	If age is between 65-69 years=1, otherwise=0	0.33	0.29
	AG_2	If age is between 70-74 years=1, otherwise=0	0.25	0.25
	AG_3	If age is between 75-79 years=1, otherwise=0	0.21	0.22
	AG_4	If age is between 80-84 years=1, otherwise=0	0.13	0.16
Driver Gender	GD_1	If male=1, otherwise=0	0.64	0.54
Vehicle Type	VT_1	If it is a car=1, otherwise=0	0.56	0.70
	VT_2	If it is a van=1, otherwise=0	0.09	0.09
	VT_3	If it is a pick-up truck=1, otherwise=0	0.24	0.14
	VT_4	If it is a SUV=1, otherwise=0	0.05	0.05
Passengers	NP_1	If no passengers=1, otherwise=0	0.65	0.74
Vehicle Maneuvering	VM_1	If going straight=1, otherwise=0	0.69	0.50
	VM_2	If making a left turn=1, otherwise=0	0.09	0.17
	VM_3	If making a right turn=1, otherwise=0	0.02	0.05
	VM_4	If stopped/stopped waiting or slowing down=1, otherwise=0	0.05	0.17
	VM_5	If backing=1, otherwise=0	0.06	0.04
	VM_6	If lane changing=1, otherwise=0	0.01	0.03
Seat Belt	SB_1	If wearing seat belt=1, otherwise=0	0.89	0.96
Alcohol Flag	AF_1	If yes=1, otherwise=0	0.01	0.00
Function Class	FC_11/51	If occurred on an interstate=1, otherwise=0	0.08	0.09
	FC_12/53	If occurred on an arterial=1, otherwise=0	0.44	0.67
	FC_21/61	If occurred on a collector=1, otherwise=0	0.26	0.08
	FC_31/71	If occurred on a local street=1, otherwise=0	0.22	0.16
Accident Location	AL_12	If occurred at an intersection=1, otherwise=0	0.30	0.57
	AL_16	If occurred on roadway=1, otherwise=0	0.95	0.99
Light Condition	LC_1	If occurred during daylight=1, otherwise=0	0.69	0.89
	LC_2	If occurred in dark-street light on=1, otherwise=0	0.04	0.07
	LC_3	If occurred in dark-no street lights=1, otherwise=0	0.21	0.01
Road Surface Condition	RS_1	If surface is dry=1, otherwise=0	0.87	0.85
Road Surface Character	RC_1	If road is straight=1, otherwise=0	0.93	0.96
	RC_2	If road is curved=1, otherwise=0	0.07	0.04
	RC_3	If road is on grade or at hillcrest=1, otherwise=0	0.24	0.18
Road Surface Type	RT_1	If road surface is black top or concrete=1, otherwise=0	0.89	0.99
Day of the Week	DW_1	If it is a week day=1, otherwise=0	0.76	0.82
Weather Condition	WC_1	If occurred in no adverse weather condition=1, otherwise=0	0.88	0.88
	WC_2	If occurred in rainy weather condition=1, otherwise=0	0.06	0.09
	WC_3	If occurred in snowy weather condition=1, otherwise=0	0.02	0.01
Accident Class	AC_1	If collided with other motor vehicle =1, otherwise=0	0.52	0.91
	AC_2	If collided with parked motor vehicle =1, otherwise=0	0.04	0.04
	AC_3	If collided with an animal =1, otherwise=0	0.26	0.01
	AC_4	If collided with a fixed object =1, otherwise=0	0.12	0.03
Manner of Collision	CV_1	If it is a head on collision=1, otherwise=0	0.02	0.02
	CV_2	If it is a rear end collision=1, otherwise=0	0.11	0.27
	CV_3	If it is a angle collision=1, otherwise=0	0.25	0.50
	CV_4	If it is a sideswipe collision=1, otherwise=0	0.08	0.08
Posted Speed	SL_1	Posted speed in mph	51.74	36.05
Number of Vehicles	NV_2	If it is a multi vehicle crash=1, otherwise=0	0.48	0.92
Time of Accident	TA_1	If it is occurred during peak times=1, otherwise=0	0.24	0.23

As the selection criteria of variables to be included in the model, a 95% confidence level was used in which the probability should be less than 0.05. Co-linearity of individual variables were also checked before considering variables into the model and if such relationship existed one of the two correlated variables was discarded based on the lowest mean value criterion.

Model results are given in Table 4.30 for rural roads and in Table 4.31 for urban roads. Coefficients were estimated using the maximum likelihood method as explained in Section 3.2.5. Likelihood ratio indexes (LRI) are presented for each model along with Estrella values and log likelihood values. In the rural model, more explanatory variables became significant and almost all variables showed significant results under the decomposition method and were included in the model. By looking at the two sets of values obtained for the two models, it can be stated that the injury severity model for rural roads has a better fit compared to injury severity model for urban roads. The likelihood ratio index value for the rural injury severity model is 0.1738 and 0.0653 for the urban injury severity model. Thus, the injury severity model for rural roads has a better capability of explaining injury severity causes to older drivers with a selected set of explanatory variables compared to the model for injury severity on urban roads. Past studies based on ordered probit modeling have shown that the goodness of fit value is typically low. In the model developed by Ma and Kockelman *(37),* it was around 0.05 and in the models developed by Kockelman and Kweon *(39)*, the highest LRI value was around 0.08. There are many other studies in the past which had similar results *(38, 40)*. Therefore, the reliability of the overall model can be considered as acceptable.

The variables considered in this analysis can be broadly classified under four sections: driver related, crash related, roadway related, and environment related. Thus, the discussion of model results is also presented under the same sections for better understanding.

4.3.2.1 Driver Related

When looking at both models, most of the driver-related variables significantly affect the injury severity of older drivers. On rural roads, if a driver's age is less than 85 years, there is a tendency for reduction in injury severity and on urban roads, no such clear differentiation is indicated. In the decomposition method, similar results were also found and verified in this analysis.

Table 4.30 Parameter Estimates for Older-Driver Injury Severity Model on Rural Roads

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|
Intercept	-0.828826	0.149059	-5.56	<.0001
AG_1	-0.272326	0.053151	-5.12	<.0001
AG_2	-0.223695	0.053805	-4.16	<.0001
AG_3	-0.178505	0.054387	-3.28	0.0010
AG_4	-0.172793	0.057616	-3.00	0.0027
GD_1	-0.171875	0.032299	-5.32	<.0001
VT_1	0.303921	0.062906	4.83	<.0001
VT_2	0.358855	0.075919	4.73	<.0001
VT_3	0.163581	0.063576	2.57	0.0101
VT_4	0.355625	0.085488	4.16	<.0001
NP_1	0.066461	0.031729	2.09	0.0362
VM_2	-0.257139	0.048354	-5.32	<.0001
VM_3	-0.558938	0.107845	-5.18	<.0001
VM_4	-0.296730	0.067741	-4.38	<.0001
VM_5	-0.593927	0.117124	-5.07	<.0001
SB_1	-0.834594	0.039004	-21.40	<.0001
AF_1	0.444390	0.120278	3.69	0.0002
FC_12	0.374287	0.054924	6.81	<.0001
FC_21	0.370818	0.061487	6.03	<.0001
FC_31	0.200343	0.069236	2.89	0.0038
AL_12	0.089227	0.039232	2.27	0.0229
AL_16	-0.248387	0.056147	-4.42	<.0001
LC_3	0.115579	0.047127	2.45	0.0142
RS_1	0.173417	0.041064	4.22	<.0001
AC_1	-0.881880	0.067288	-13.11	<.0001
AC_2	-0.786810	0.111487	-7.06	<.0001
AC_3	-1.822413	0.072100	-25.28	<.0001
AC_4	-0.150069	0.055960	-2.68	0.0073
CV_1	1.515346	0.090261	16.79	<.0001
CV_2	0.480353	0.061857	7.77	<.0001
CV_3	0.635253	0.056802	11.18	<.0001
SL_1	0.020760	0.001298	15.99	<.0001
TA_1	-0.071920	0.033522	-2.15	0.0319
_Limit2	0.373200	0.012214	30.56	<.0001
_Limit3	1.150968	0.024151	47.66	<.0001
_Limit4	1.685025	0.035345	47.67	<.0001
Estrella		0.2496		
Adjusted Estrella		0.2439		
McFadden's LRI		0.1738		
Log Likelihood		-7230		

Table 4.31 Parameter Estimates for Older-Driver Injury Severity Model on Urban Roads

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|
Intercept	-1.155491	0.131992	-8.75	<.0001
AG_4	0.055627	0.026021	2.14	0.0325
GD_1	-0.181644	0.020523	-8.85	<.0001
VT_1	0.146027	0.023314	6.26	<.0001
NP_1	0.060906	0.022686	2.68	0.0073
VM_1	0.112912	0.024827	4.55	<.0001
VM_3	-0.448224	0.057992	-7.73	<.0001
VM_4	0.087839	0.037813	2.32	0.0202
VM_5	-0.554538	0.098822	-5.61	<.0001
VM_6	-0.769964	0.101859	-7.56	<.0001
SB_1	-0.799173	0.039467	-20.25	<.0001
AF_1	0.299045	0.114402	2.61	0.0089
FC_53	0.091127	0.022015	4.14	<.0001
AL_12	0.133606	0.022421	5.96	<.0001
LC_3	0.212464	0.091788	2.31	0.0206
RC_3	0.051463	0.024792	2.08	0.0379
WC_1	0.325479	0.065982	4.93	<.0001
WC_2	0.263742	0.072562	3.63	0.0003
AC_2	-0.270038	0.111640	-2.42	0.0156
AC_3	-1.185102	0.189744	-6.25	<.0001
AC_4	0.490960	0.099267	4.95	<.0001
CV_1	1.079411	0.072338	14.92	<.0001
CV_2	0.465327	0.046634	9.98	<.0001
CV_3	0.607489	0.043605	13.93	<.0001
SL_1	0.013123	0.001055	12.44	<.0001
NV_2	-0.767203	0.098139	-7.82	<.0001
_Limit2	0.466329	0.009774	47.71	<.0001
_Limit3	1.399145	0.025332	55.23	<.0001
_Limit4	2.019307	0.049719	40.61	<.0001
Estrella		0.0687		
Adjusted Estrella		0.0666		
McFadden's LRI		0.0653		
Log Likelihood		-13529		

The variable associated with gender has a negative estimate in both models indicating that when older male drivers are involved in crashes, there is a tendency for low injury severity compared to older female drivers involved in crashes. In other words, older females are at higher risk as compared to males, irrespective of where the crash occurs. This may be due to the fact that females are generally not as competent as males of bearing physical or mental trauma resulting from crashes *(35)*. In both models, if no passengers are present, there is a tendency towards having more severe injuries as a result of crashes, which was revealed under the decomposition method as well. When passengers are present, they might be active in adverse conditions providing extra support and information to drivers *(21)*, and if a crash occurs, there is higher chance for someone to remain uninjured who could ask emergency services for help.

Seat belt usage has reduced injury severity in both models, while presence of alcohol has raised injury severity among older drivers. Drunk older drivers do not take evasive maneuvers to prevent crashes most of the time *(13)* and this could lead to higher injury severity among them. A careful observation of estimates gives more specific details about how far this affects injury severity.

4.3.2.2 Crash Related

Among different types of vehicles driven by older drivers, cars, vans, pickup trucks, and SUVs indicate significant influence towards explaining injury severity in the rural model. But, in the urban injury severity model, only cars have a significant influence towards explaining injury severity. In the rural injury severity model, variables belonging to vehicle type estimates show a similar kind of effect from all four vehicle types except pickup trucks which have lesser impact on injury severity. Significant variables associated with vehicle maneuvering in the rural injury severity model indicated a negative impact on older-driver injury severity, but in the urban model no such consistent pattern is observed.

It was unexpected to see that all variables related to accident class indicated negative estimates in the rural model. This was perhaps due to the other alternatives causing more severity compared to the ones considered in the model. For example, an overturned vehicle situation was highlighted in the previous analysis as causing more damage and this may have affected the model parameters. Similar types of results can be observed in the urban injury severity model except for the positive impact when older-driver vehicles crashed into fixed objects. Head-on crashes, rear-end crashes, and angle crashes are significant in both rural and urban models with positive parameter estimates indicating there is a tendency for high injury severity.

The number of vehicles involved in a crash becomes insignificant in the rural model, but in the urban model, multi-vehicle crashes showed significant results. The negative estimates revealed that single-vehicle crashes are more severe on urban roads and this verifies the findings in decomposition method.

4.3.2.3 Roadway Related

According to the model estimates, intersection-related crashes involving older drivers on rural roadways have a tendency towards high severe injuries, whereas on-road type crashes have an opposite effect compared to off-road type crashes. Similarly in urban roads, intersection-related crashes have a positive relationship with injury severity, but whether the crash is on-road or off-road is not significant in the urban model. This is quite obvious because there are higher chances for rural crashes to end up on off-roads causing severe injuries due to the higher speed limits (mean of 52 mph) and lack of facilities available on the roadside such as guard rails, shoulder lanes, and lighting etc. But on urban roads, where speeds are little lower (mean of 36) and with better facilities, the chances are lower for such type of crashes.

Variables related to rural arterials, collectors, and local roads are significant in the rural model having higher estimates for arterials and collectors. The rural interstate variable is not significant according to the model output and the same results were observed using the decomposition method as well. In the urban model, only arterials became significant and had a positive effect on injury severity.

Speed is a major criterion toward injury severity based on the laws of physics. Verifying that, model results indicated that speed has a proportional relationship with injury severity and estimates further explain that the rate is a little higher on rural roads compared to urban roads.

4.3.2.4 Environment Related

Both cases when streets are dark without street lights became significant with a tendency of increasing injury severity. Crashes occurring during peak times on rural roads have negative effects with respect to injury severity over off-peak time crashes. Different weather conditions showed no significance in the rural severity model, and in the urban severity model, neither adverse weather conditions nor rainy weather conditions showed significant results.

CHAPTER 5 - Summary, Conclusions and Recommendations

5.1 Summary and Conclusions

Crash data obtained from Kansas Department of Transportation through years 2002 to 2006 were analyzed with the intention of identifying characteristics of older drivers involved in crashes in Kansas. Detailed characteristic and statistical analysis was carried out for older drivers involved in crashes under a number of categories. Similar analysis was done for some identified categories involving younger and middle-aged drivers where older-driver-related analysis showed significant results. Thus, comparisons were made and issues related to older drivers were highlighted. Categories were made mainly based on driver-related, crash-related, roadway-related, and environment-related factors.

According to analysis results, contingency tables followed by the chi-square test revealed a significant relationship between age groups and different categories of crashes. Number of older male drivers involved in crashes was higher compared to older female drivers, even though older-driver licensees' data indicates that there are more female drivers holding drivers license compared to male drivers. When severity is considered, there was no significant difference among drivers based on gender. Most of the older-driver-involved crashes occurred in good environmental conditions, such as during daylight and no adverse weather conditions. But, from the statistical analysis, it was revealed that neither lighting conditions nor weather conditions had any significant effect on injury severity. A significant percentage of older-driver-involved crashes occurred at intersections, whereas most of the young and middle-aged-drivers-involved crashes took place at non-intersections. At the same time, intersection-related crashes ended up with severe injuries and off-roadway crashes reported even higher levels of severity. A majority of older drivers involved in crashes were in the age of 65 to 74 years and an insignificant percentage of older drivers were under the influence of alcohol at the time of the crash. A significant number of older drivers crashed at an angle compared to other driver groups involved in crashes, yet on the other hand, their involvement in rear-end crashes was comparatively low. But, both angle and rear-end crashes were associated with higher severity levels. A lesser number of older-driver-driven vehicles were overturned as a result of crashes, but driver injuries were more severe. A higher number of vehicles collided with another motor vehicle rather than hitting a fixed object. Hitting another vehicle indicated no significance in respect to severity, but hitting fixed objects did. A higher number of older drivers were involved in left-turn and right-turn-related crashes, which mostly occurred at intersections. Further, older drivers were involved in a higher number of backing-related crashes compared to other age groups, but their involvement in slowing down or stopping-related crashes was at lower levels. Again, none of them were insignificant in regard to crash severity; however, crashes occurring on straight sections of the road caused high severity levels.

It was not possible to make a final conclusion about older drivers based on the two methods considered in this study, since these might be governed by various other external factors such as exposure conditions, driver skills, road conditions, etc. Therefore, a safety survey was conducted among older drivers and conclusions were as follows.

From the initial percentage calculations, it can be concluded that most of older drivers have more than 50 years of experience, drive cars which are not older, and drive at least two days per week. Seat belt usage was found to be high among both drivers and passengers. Roundabouts seemed to be not popular among older drivers and left turns point to the most challenging maneuvering task for older drivers, especially at un-signalized intersections. However, older drivers showed maximum confidence for right-turn maneuvering as well as left-turn maneuvering where signals with green arrows were present. Avoidance of high-traffic roads was more common among older drivers and conversely, preference for local roads and urban minor roads was high.

When looking at differences based on gender, males are overrepresented with the difficulties of stopping, stopped waiting to turn, or slowing down. On the other hand, females showed higher levels of difficulty associated with identifying speeds and distance of oncoming traffic compared to males. The average number of miles driven by female older drivers is less compared to male older drivers, and females have a higher propensity for involvement in crashes.

Analysis based on age revealed that the level of difficulty associated with older drivers increases with aging and similarly, preference to avoid demanding conditions such as snowy weather, nighttime driving, and use of freeways also rises with aging. Co-relationships were found for miles driven with income, age, and gender. Number of miles driven was higher as income increased but with increasing age, number of miles driven decreased. A majority of older drivers would like to stop driving either when their doctors advise or when their vision gets poor.

Based on the respondents who met with at least a single crash during the last 10 years, some interesting facts were found. Their exposure to rainy and snowy weather conditions were high and they reported higher difficulties especially in association with merging, diverging, and identifying speeds and distance of oncoming traffic. Further, statistics showed that drivers older than 70 years were highly involved in crashes, and those with elevated income levels and education had higher involvement in crashes; however, when number of miles driven increased, chances of being involved in crashes decreased.

Following the characteristic and injury severity analysis, it was found that injury severity is higher in crashes occurring on rural roads compared to urban roads. Under several situations, such as gender, age, road type, speed limit, number of vehicles involved, driver contribution, road character, road location, vehicle type, and presence of passengers, the decomposition ratios were calculated to identify contributing factors to such severity levels.

Results showed that higher fatal crash incidence densities and injury fatality rates occurred in rural compared to urban areas and verified prior research findings. There was no noticeable difference between driver gender, but drivers older than 84 years indicated a higher chance of getting severe injuries when involved in crashes. Crashes occurring on rural arterials and speed limits between 46 to 65 mph resulted with higher crash severity. Multi-vehicle crashes occurring on rural roads had higher fatal crash incidence density rates compared to single-vehicle crashes. Among driver contributions towards fatal crashes, driving on the wrong side or going the wrong way, driving under influence of drugs or alcohol, failure to comply with traffic signs or signals, and high-speed driving were at the top of the list. Both straight and curved hill crests were associated with higher fatal crash incidence densities as were as roadside crashes, including shoulder-off-roadway crashes. Pickup trucks and SUVs were highly represented in higher number of fatalities on rural roads. Presence of passengers seemed to contribute more toward the reduction in fatalities on rural roads. Where no passengers were present, crash fatalities were higher.

The decomposition ratio method identified contributing factors towards higher crash/ injury severity on rural and urban roads. Variables were considered one at a time to identify their individual effect towards crash/ injury severity. Using the ordered probit modeling, a similar study was done, but the objective was to determine the combined effect of variables contributing towards higher injury severity. Variables under driver-related, crash-related, roadway-related and environment-related were considered.

Most driver-related variables were significant in the model and older drivers aged less than 85 years were at a lower risk compared to other older age categories in rural areas. Males had a tendency for lower injury severity both on urban and rural roads compared to females. Seat belt usage and presence of passengers led to a reduction in injury severity among older drivers, whereas presence of alcohol raised injury severity. Cars, vans, pickup trucks, and SUVs were significant in the rural road model, whereas in the urban road model, only cars were significant in increasing injury severity of older drivers. Single-vehicle crashes were more severe on urban roads resulting in higher injury severity for older drivers; but on rural roads, the number of vehicles involved in crashes was not significant. Crashes occurring on both rural and urban arterials resulted in higher injury severity to older drivers and speed was also found as a major contributing factor toward injury severity. In both models, intersection-related crashes and crashes occurring under no streetlight conditions showed a higher tendency towards increasing injury severity among older drivers. Off-road-type crashes and crashes occurring during off-peak times in rural areas had a tendency to cause more severe injuries to older drivers.

5.2 Recommendations

The study can be extended to analyze different other sub-categories highlighted in the injury severity analysis, such as intersection related crashes, to find out specific contributing factors to such circumstances. Further, collection and use of more exposure type of data would lead to identify more behavioral related factors, which would help to improve the safety of older drivers.

5.2.1 Possible Countermeasures

Based on the study, a number of countermeasures can be suggested to improve the safety of older drivers in Kansas. In general, implementation of these countermeasures is a lengthy process with several stages such as planning, designing, implementation, and output evaluation. All these steps require financing and each improvement will be associated with a certain amount of costs plus benefits. However, all these cost-associated issues are beyond the scope of this research study and thus, no accountability was given when suggesting countermeasures to improve older-driver safety in Kansas. In addition, the countermeasures suggested in this section are exclusively based on the approach of improving safety of older drivers and they may have different implications towards other driver groups, road users, or other related parties. These may include increased travel times for both vehicles and passengers, processes becoming more complicated and requiring more resources, and becoming exasperating among other driver-age groups, etc. Thus, the selection of countermeasures for implementation should be made with sufficient care given to state policies, capabilities, future plans, etc.

Most of the countermeasures are from the older driver's perspective, because the study mainly focused on older drivers' behaviors and related involvements. But still, there are some countermeasures which can be implemented by the city engineer and all are discussed in this section in detail.

At present, older-driver license renewals are required every four years. But the study revealed that when drivers are aging, likeliness toward involvement in crashes as well as injury severity are high. A four-year period is a considerable time, especially when considering drivers older than 75 years. Chances are higher for various physical and mental deterioration during such time periods. These may go unnoticed by the authorities and consequently older drivers may risk their lives as well as others every day by driving on public roadways. Therefore, it might be necessary to reduce the duration of the driver's license renewal policy in order to make sure drivers on roads have sufficient capabilities to drive safely. In addition, it was found that older drivers are very reluctant to make the decision of driving cessation unless influenced by a professional or an outside party. Further, when looking at the driver's license renewal system, the same tests are required for older drivers as other drivers and this possibly requires a change. Older-drivers' tests need more emphasis on evaluating specific capabilities highlighted in the study to ensure they pursue required levels of skills to be safe and responsible drivers. The bottom line is that driver's license renewal program for older drivers needs to be re-organized in such a way that it can improve the safety of older drivers as well as other road users.

Learning or education programs would help to improve the safety of older drivers to a great extent. Many researchers have suggested this as a good countermeasure, but still the efficiency of such programs is yet to be evaluated. There are agencies that conduct such programs today and following their lead could address the issues needed to be emphasized by older drivers. First of all, these types of programs will help older drivers to understand the difficulties they have when they are aging. This is the most important objective to be achieved before exercising any modifications, because as human beings, they are reluctant or hesitant to change their mind set to accept any of these medical and physical conditions as a result of aging. Once understood, it is easier to modify driving behaviors of older drivers toward identifying and paying more attention to individual circumstances. For example, if an older driver is having difficulties seeing at night, but has no other problem with respect to driving skills, then he or she needs not to stop driving completely, but instead avoid driving at nighttime. These modifications can be easily done through an educational program, because older drivers are willing to hear from professionals regarding their driving decisions. Further, these programs will help to acknowledge the challenging situations faced by older drivers and provide guidelines to handle such situations more effectively. At the last resort, educational programs would identify older drivers who need to stop driving and will encourage doing so with fewer complications.

Similarly, introduction of best practices through various sources will improve the safety of older drivers as well as others. Use of seat belts; having passengers when driving, especially on rural roads; reducing the number of left turns and other demanding conditions; avoiding drunk driving; and no speeding are some of best practices that can be introduced at this stage. The media could be used to approach older drivers in this regard and there are many programs which have the capability of doing this effectively.

As mentioned earlier, there are improvements which can be done on roadways to improve safety of older drivers as well. From the study it was found that crash severity is higher at hill crests and curvatures. Therefore, a reduction in major vertical differences and an increase in the radius of curvatures are appropriate in relation to older-driver safety enhancement. Most severe crashes occurred at off-road conditions and consequently, overturned crashes and vehicles struck with fixed objects were at top of the list. Thus, the necessity for more clear zones is evident, especially in rural areas and these clear zones need to have lesser slopes to prevent overturning. Guard rails and rumble strips will also help in preventing run-off-the-road crashes, and removal of fixed objects closer to roads will help to reduce severity when crashes occur. More road signs may help to overcome some driver-related errors contributing to crashes, such as driving on the wrong side or going the wrong way, failing to yield, inability to comply with traffic signals, and so on. Better street lighting facilitates will improve visibility at night, and better road markings will facilitate conflicts or misjudgments in vehicle maneuverings.

Separate left-turn arrows in signalized intersections or introduction of more roundabouts will reduce the number of older-driver-involved crashes occurring at intersections due to conflicting conditions. Further, introduction of a one-way road system may also a good solution for this matter.

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Appendix A - People Involvement in Crashes in Kansas, 1997-2006

Table A.1 All People Involved in Crashes in Kansas, 1997-2000

	1997	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Number of total crashes	76,641	79,112	78,694	78,242	78,856	78,314	75,011	74,119	68,675	65,460
Number of people involved	**191,933**	**198,445**	**196,422**	**192,193**	**192,131**	**190,032**	**180,296**	**177,416**	**162,541**	**154,726**
-Drivers	124,750	129,024	128,470	127,328	127,459	126,792	120,674	119,237	110,299	105,276
-Other occupants	66,064	68,389	66,931	63,920	63,697	62,284	58,726	57,277	51,363	48,620
-Pedestrians	1,119	1,032	1,021	945	975	956	896	902	879	830
Injury Severity Level										
F- Fatal injury	**481**	**493**	**540**	**461**	**494**	**507**	**469**	**459**	**428**	**468**
-Drivers	322	337	339	324	349	*351*	*309*	*310*	*302*	*344*
-Other occupants	122	114	161	111	117	*127*	*130*	*125*	*98*	*95*
-Pedestrians	37	42	40	26	28	*29*	*30*	*24*	*28*	*29*
D- Disabled-incapacitating	**2,787**	**2,715**	**2,552**	**2,319**	**2,203**	**2,004**	**2,014**	**1,862**	**1,870**	**1,745**
-Drivers	1,770	1,742	1,626	1,511	1,407	*1,306*	*1,279*	*1,238*	*1,264*	*1,167*
-Other occupants	851	854	809	695	657	*604*	*616*	*524*	*501*	*479*
-Pedestrians	166	119	117	113	139	*94*	*119*	*100*	*105*	*99*
I- Injury-not incapacitating	**13,453**	**13,280**	**12,607**	**12,281**	**11,562**	**11,277**	**10,347**	**10,097**	**10,006**	**10,081**
-Drivers	8,527	8,433	8,119	7,978	7,638	*7,440*	*6,867*	*6,720*	*6,797*	*6,917*
-Other occupants	4,398	4,341	4,002	3,859	3,483	*3,349*	*3,063*	*2,954*	*2,763*	*2,730*
-Pedestrians	528	506	486	444	441	*488*	*417*	*423*	*446*	*434*
P- Possible injury	**15,453**	**15,211**	**15,484**	**14,511**	**15,077**	**13,792**	**12,437**	**11,824**	**10,847**	**10,494**
-Drivers	10,044	9,934	10,155	9,595	9,994	*9,253*	*8,387*	*8,061*	*7,437*	*7,124*
-Other occupants	5,068	4,952	4,986	4,594	4,750	*4,240*	*3,767*	*3,448*	*3,152*	*3,118*
-Pedestrians	341	325	343	322	333	*299*	*283*	*315*	*258*	*252*
N- Not injured	**159,759**	**166,746**	**165,239**	**162,621**	**162,795**	**162,444**	**140,501**	**134,408**	**123,819**	**118,982**
-Drivers	104,087	108,578	108,231	107,920	108,071	*108,436*	*94,051*	*90,183*	*84,121*	*80,962*
-Other occupants	55,625	58,128	56,973	54,661	54,690	*53,962*	*46,419*	*44,205*	*39,679*	*38,009*
-Pedestrians	47	40	35	40	34	*46*	*31*	*20*	*19*	*11*

Table A.2 Elderly People Involved in Crashes in Kansas, 1997-2000

	1997	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Number of total crashes	10,641	11,049	10,940	10,410	10,421	10,385	9,953	9,846	8,768	8,696
Number of people involved	**13,557**	**14,094**	**13,926**	**13,184**	**13,056**	**12,974**	**12,552**	**12,313**	**10,892**	**10,859**
-Drivers	10,293	10,641	10,565	10,024	10,021	9,953	9,624	9,440	8,346	8,378
-Other occupants	3,215	3,415	3,310	3,120	2,992	2,979	2,887	2,827	2,503	2,450
-Pedestrians	49	38	51	40	43	42	41	46	43	31
Injury Severity Level										
F- Fatal injury	**104**	**83**	**100**	**83**	**87**	**83**	**67**	**87**	**68**	**90**
-Drivers	*63*	*60*	*61*	*55*	*57*	*59*	*46*	*51*	*50*	*70*
-Other occupants	*32*	*21*	*34*	*20*	*23*	*20*	*16*	*26*	*14*	*16*
-Pedestrians	*9*	*2*	*5*	*8*	*7*	*4*	*5*	*10*	*4*	*4*
D- Disabled-incapacitating	**274**	**263**	**238**	**199**	**197**	**182**	**158**	**161**	**194**	**140**
-Drivers	*175*	*175*	*161*	*144*	*146*	*121*	*110*	*116*	*133*	*98*
-Other occupants	*83*	*75*	*67*	*47*	*44*	*53*	*39*	*38*	*47*	*35*
-Pedestrians	*16*	*13*	*10*	*8*	*7*	*8*	*9*	*7*	*14*	*7*
I- Injury-not incapacitating	**983**	**1,003**	**974**	**856**	**887**	**814**	**722**	**754**	**725**	**772**
-Drivers	*679*	*723*	*719*	*650*	*642*	*627*	*531*	*557*	*540*	*572*
-Other occupants	*288*	*265*	*235*	*194*	*225*	*169*	*177*	*186*	*175*	*184*
-Pedestrians	*16*	*15*	*20*	*12*	*20*	*18*	*14*	*11*	*10*	*16*
P- Possible injury	**1,177**	**1,030**	**1,179**	**1,040**	**1,044**	**1,015**	**871**	**857**	**798**	**698**
-Drivers	*833*	*752*	*830*	*761*	*758*	*744*	*649*	*627*	*587*	*514*
-Other occupants	*337*	*270*	*333*	*267*	*278*	*261*	*211*	*212*	*198*	*181*
-Pedestrians	*7*	*8*	*16*	*12*	*8*	*10*	*11*	*18*	*13*	*3*
N- Not injured	**11,019**	**11,715**	**11,435**	**11,006**	**10,841**	**10,880**	**9,955**	**9,583**	**8,407**	**8,599**
-Drivers	*8,543*	*8,931*	*8,794*	*8,414*	*8,418*	*8,402*	*7,675*	*7,378*	*6,481*	*6,663*
-Other occupants	*2,475*	*2,784*	*2,641*	*2,592*	*2,422*	*2,476*	*2,278*	*2,205*	*1,924*	*1,935*
-Pedestrians	*1*	*0*	*0*	*0*	*1*	*2*	*2*	*0*	*2*	*1*

Appendix B - People Involved in Crashes in Kansas Based on Injury Severities, 1997-2006

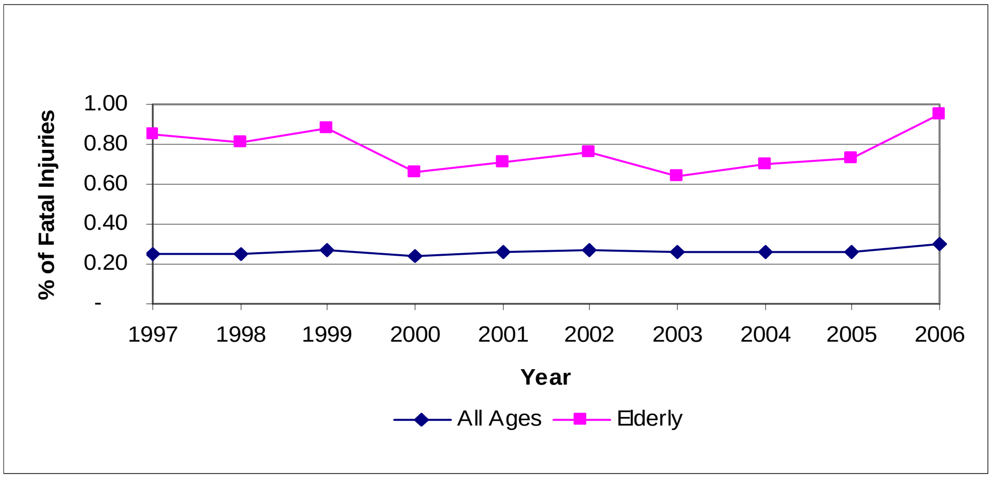

Figure B.1 Comparison of Fatal Injuries Caused to Elderly People vs. All Ages

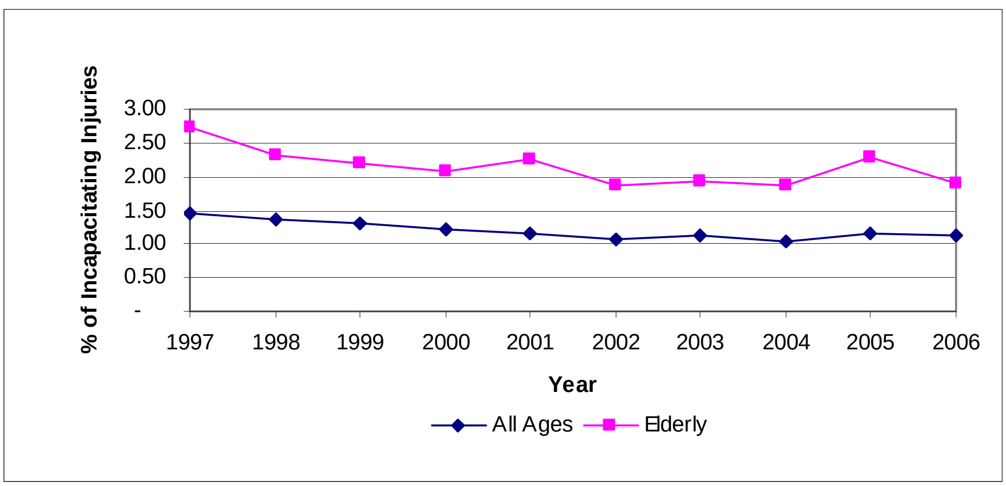

Figure B.2 Comparison of Incapacitating Injuries Caused to Elderly People vs. All Ages

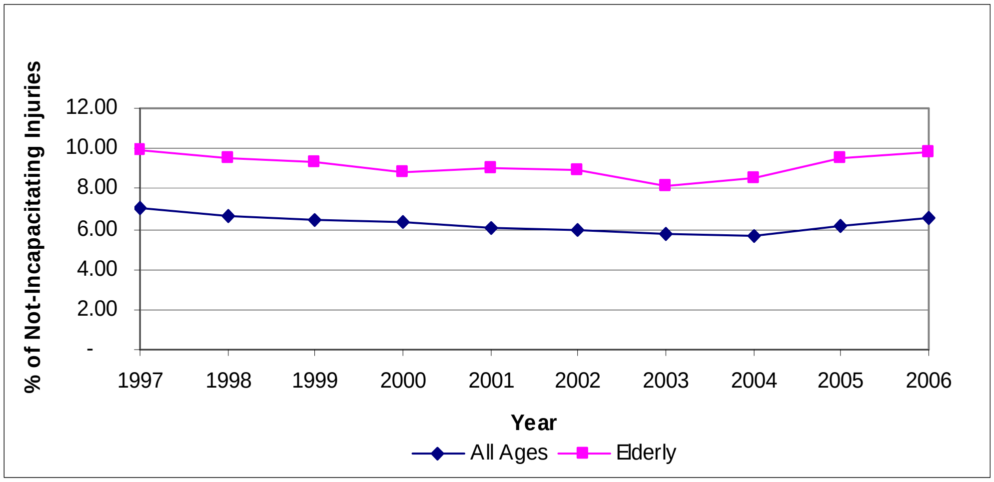

Figure B.3 Comparison of Not-Incapacitating Injuries Caused to Elderly People vs. All Ages

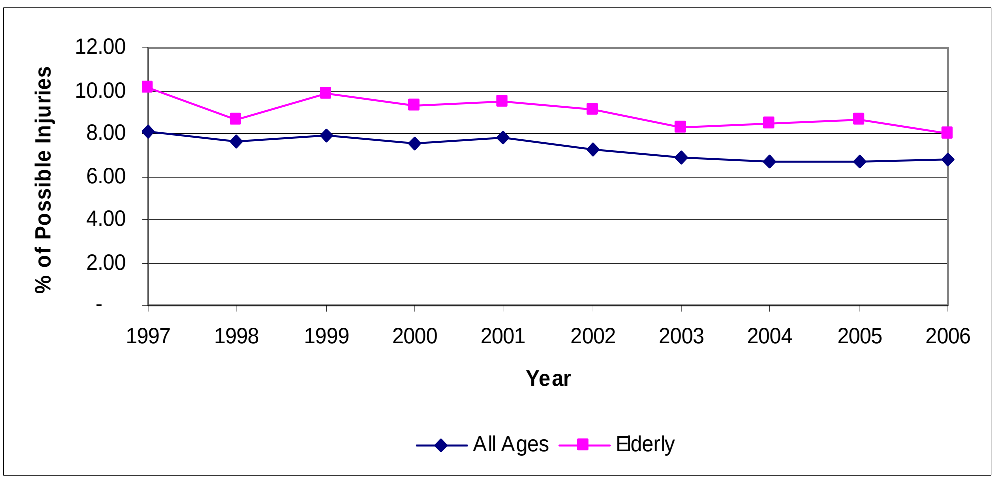

Figure B.4 Comparison of Possible Injuries Caused to Elderly People vs. All Ages

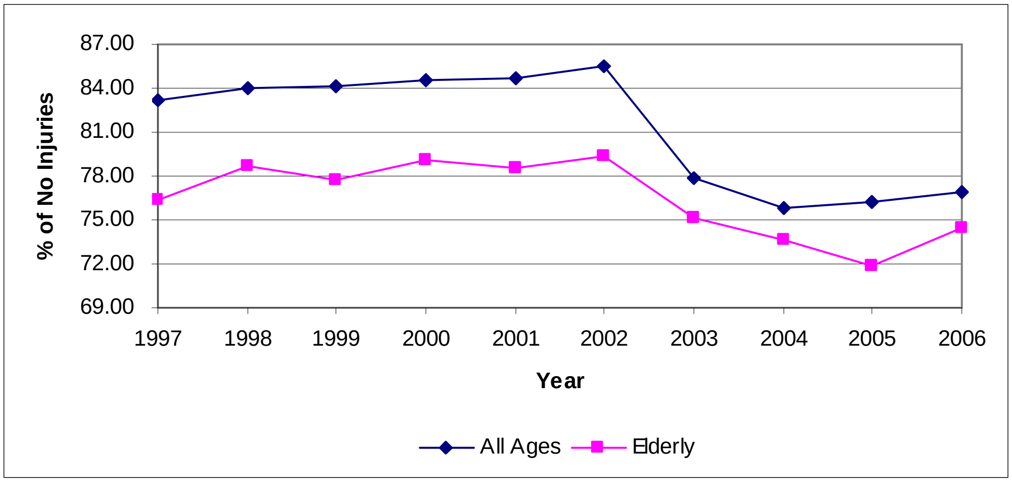

Figure B.5 Comparison of No Injuries Caused to Elderly People vs. All Ages

Appendix C - Survey Form

Older Driver Safety Survey Form

We are conducting a survey on highway safety issues of older drivers in Kansas with the intention of improving traffic safety. Please show your support by answering the following questions. Information collected will be used for research purposes only. The participation in the survey is completely voluntary and you may quit anytime. If you have any questions please free to contact Dr. Sunanda Dissanayake, 2118 Fiedler Hall, KSU, Manhattan, KS 66506, Tel:785-532-1540 or Dr. Rick Scheidt, 203 Fairchild Hall, KSU, Manhattan, KS 66506 Tel: 785-532-3224

Please check the appropriate response(s).

1. Do you currently drive?
   O Yes O No

2. How long have you been driving?
   O 0 -10 years O 11-20 years
   O 21-30 years O 31-40 years
   O 41-50 years O More than 50 years

3. What type of vehicle do you usually drive?
   O Car O SUV
   O Van O Pick up Truck
   O Other ………………… (Please specify)

4. How old is the vehicle you drive?
   O 0 -5 years O 6- 10 years
   O 11 -15 years O 16-20 years
   O 21-25 years O More than 25 years

5. How frequently do you drive?
   O Everyday O 4-6 days per week
   O 2-3 days per week O Once a week
   O Once a month O Once in a while

6. Approximately how many miles do you drive each month?
   O 0 -100 miles O 101 -200 miles
   O 201 -500 miles O 501 -1000 miles
   O 1001- 2000 miles O More than 2000 miles

7. What is your age group?
   O Less than 65 years O 65 - 70 years
   O 71- 75 years O 76 - 80 years
   O 81- 85 years O More than 85 years

	Never	Very rarely	Sometimes	Most of the time	Always
8. How often do you wear the seat belt…					
➢ while driving?	O	O	O	O	O
➢ as a passenger?	O	O	O	O	O
9. How often do you drive at night compared to day time?	O	O	O	O	O
10. How often do you feel the street is not lit well enough when driving at night?	O	O	O	O	O
11. How frequently do you drive on freeways?	O	O	O	O	O
12. How often do you drive on following weather conditions?					
➢ Rainy	O	O	O	O	O
➢ Snowy	O	O	O	O	O
➢ Windy	O	O	O	O	O
13. How often do you make sudden stops or slow down on road without real necessity?	O	O	O	O	O
14. How often do you drive after consuming medicine?	O	O	O	O	O
15. How often do you drive after consuming alcohol?	O	O	O	O	O
16. How often do you drive alone?	O	O	O	O	O
17. How often do you have any difficulty associated with stopping, stopped waiting to turn or slowing down?	O	O	O	O	O
18. How often do you encounter any difficulty with straight following the road?	O	O	O	O	O
19. How often do you have a difficulty in lane changing?	O	O	O	O	O
20. How often do you have difficulty with merging in to traffic?	O	O	O	O	O
21. How often do you have difficulty in judging gaps when merging or making a turn?	O	O	O	O	O
22. How often do you have difficulty with diverging from the traffic?	O	O	O	O	O
23. How often do you have difficulty with negotiating curves?	O	O	O	O	O

24. Has your seat belt usage changed over the years?

O Increased O Decreased
O Almost the same O Don't know

25. Have you been involved in a crash during the last 10 years?

O Yes O No

26. If yes, explain about how severe it was? Who's at fault? & etc…………..

…………………………………………………………………………………

…………………………………………………………………………………

………………………………………………………………………………...

27. If you have received a traffic violation after turning to 65 years, what best describes the reason?

O Never received O Speeding
O Parking O DUI
O Reckless driving O Expired tags/ license
O Vehicle deficiencies O Other (specify)…………………….

28. Do you have any difficulties at intersections compared to driving on roadways?

O Yes O No

29. If yes, what type of intersection(s) makes you difficult to deal with?

O Stop light/ traffic lights O Roundabouts
O STOP sign controlled O No control
O YIELD sign controlled

30. What are the driving tasks that have become more challenging for you at intersections? (*mark multiple answers if applicable*)

O Making Left Turns with no signal lights
O Making Left Turns at traffic signals without a green arrow
O Making Left Turns at traffic signals with a green arrow
O Making Left Turns at un-signalized intersections
O Making Right Turns
O Yielding or Stopping
O Passing through
O None of the above

31. Is there any difficulty associated with identifying speeds and distance of oncoming traffic?

O Not at all O Most of the time
O Very rarely O Always
O Sometimes

32. Which type of roads would you like to avoid when driving?
(*mark multiple answers if applicable*)

O Freeways
O Two lane undivided highways
O Urban major roads
O Rural roads
O Urban minor roads
O Local roads
O High traffic roads
O None of the above

33. Have you participated in any type of driver education courses since the age of 65?

O Yes
O No

34. What is your Gender?

O Male
O Female

35. Your marital status?

O Single
O Married
O Divorced
O Widowed
O Separated

36. When do you think you would stop driving?

O When my doctor advises
O When my adult children interfere
O When my vision gets poor
O When my spouse advises
O None of the above

37. Your educational qualification?

O No formal schooling
O Some high school
O Some college
O Four year college
O Graduate degree
O Other (specify)…………………….

38. How much is your annual household income?

O Less than $ 9,999
O $ 10,000 - $ 14,999
O $ 15,000 - $ 19,999
O $ 20,000 - $ 29,999
O $ 30,000 - $ 49,999
O $50,000 or above

39. Please select appropriate option regarding your current residence?

O Own house
O Rental

40. Your zip code is…? __ __ __ __ __

Thank you for your time.
Have a great day!!

Appendix D - NHTS Midwest Data

Table D.3 Total Number of Vehicle Miles Traveled (VMT) by Midwest Sample Drivers Based on Age

Age	Rural		Urban		Total
	Male	Female	Male	Female	
65-69	4,695,670	1,495,242	8,093,516	3,191,874	**17,476,302**
70-74	3,278,750	944,752	6,083,364	2,516,937	**12,823,803**
75-79	1,535,191	620,730	3,988,831	1,783,400	**7,928,152**
80-84	714,956	324,469	2,304,703	672,707	**4,016,835**
85+	197,544	49,300	580,886	217,470	**1,045,200**
Total	**10,422,111**	**3,434,493**	**21,051,300**	**8,382,388**	**43,290,292**

Table D.4 Number of Drivers in Midwest Sample Based on Age

Age	Rural		Urban		Total
	Male	Female	Male	Female	
65-69	303	227	659	587	**1,776**
70-74	234	159	581	508	**1,482**
75-79	149	115	443	441	**1,148**
80-84	82	78	274	231	**665**
85+	29	28	119	89	**265**
Total	**797**	**607**	**2,076**	**1,856**	**5,336**

Table D.3 Average Number of VMT by a Driver in Midwest Based on Age

Age	Rural		Urban	
	Male	Female	Male	Female
65-69	15,497	6,587	12,282	5,438
70-74	14,012	5,942	10,471	4,955
75-79	10,303	5,398	9,004	4,044
80-84	8,719	4,160	8,411	2,912
85+	6,812	1,761	4,881	2,443

Appendix E - Driver's License Data in Kansas

Table E.5 Licensed Drivers in Kansas based on Age and Gender

Year-Gender/ Age	65-69	70-74	75-79	80-84	85 and Over	Total
2006- Male	43,782	35,195	30,072	21,253	14,586	**144,888**
2006- Female	46,581	39,014	35,386	25,904	19,563	**166,448**
2005- Male	43,239	34,747	30,536	21,115	13,949	**143,586**
2005- Female	45,970	38,810	35,839	26,193	18,727	**165,539**
2004- Male	42,972	35,087	30,516	20,888	13,301	**142,764**
2004- Female	45,493	39,567	35,821	26,075	18,180	**165,136**
2003- Male	42,910	35,455	30,988	20,182	12,977	**142,512**
2003- Female	45,340	40,229	36,157	25,696	17,828	**165,250**
2002- Male	40,942	35,502	30,418	19,487	12,386	**138,735**
2002- Female	43,522	40,353	35,429	25,209	17,018	**161,531**
Total	**440,751**	**373,959**	**331,162**	**232,002**	**158,515**	**1,536,389**

Appendix F - Answers to Survey Question-26

1. 2001. Other car came through a stop sign, I had the through street. Bent frame so totaled car
2. 2000. Stop sign violation……….*(unreadable)*
3. Person backed out of a parking space. Very minor damage. Other person at fault.
4. My fault. In parking lot. While backing from parking place, hit car backing out from 2nd adjacent parking place (little damage)
5. minor- other driver
6. The person driving behind me, made a turn the same time I did, was speeding and hit me on the back end of my car.
7. No one was injured, my car was totaled. I did not receive a ticket on citation.
8. Left turn across 4 lane traffic- 21 rd Fairlawn.
9. Car ahead of me suddenly stopped- I stopped and car behind hit me and shoved me into car ahead of me. She was charged.
10. I was stopped at a stop sign and a car rounding a curve barely hit front bumper.
11. I was broad.-sided. Other car received ticket- did not stop at STOP sign – I was on thru street.
12. Car struck me from behind when stopped for traffic (sudden stop)
13. Backed in to speeding vehicle in parking lot. 2004. The only accident I've had in my life time.
14. *(Nothing written)*
15. Very minor. Other vehicle, only bumper dented on mine.
16. I was a passenger in the vehicle.
17. No traffic light and confusion about right of way. My fault.
18. I have a shorter leg on the left side of the body. I stepped from the brake to the gas pedal at slow speed.
19. An uninsured motorist ran into me and totaled my car.
20. My fault- didn't I realized there was a through lane that didn't stop, vehicle damage. No one cited. Pick up pulled out slowly into road with 70 mile speed limit. Vehicle damage
21. Severe, my fault, did not yield to oncoming traffic

Severe, not my fault, other driver did not yield right of way.

22. Minor. My fault-rounding the curve on Kimbell. A fire truck was pulled across both lanes. The car ahead of me got stopped before I did.
23. Dec. 2, 2007. A car pulled in front of the car I riding in. then we hit other driver. He did not stop. I was taken to the hospital by ambulance. Stayed about 3 hours.
24. Turned in front of a car trying to yield for an ambulance, no ticked issued.
25. No one was at fault. The car in front of me was slowing. I put my blinker on. No one would get over.
26. While waiting for light to change, my car was rear ended by a driver who failed to stop.
27. I turn in front of car partially caused by speed.
28. Hit a retread truck tire in my lane and traffic prohibited changing lanes.
29. Minor scrape. No fault. No ticket.
30. Totaled my car. Other driver at fault.
31. Car in front pulled out from behind a car trying to make a left turn. I slammed into the car.
32. Was rear ended. Wasn't my fault
33. I was at fault in turning at corner and hit another car also turning into my lane.
34. I had being complaining for no reason ……*(unreadable)*
35. I was at fault. I passed out sitting at a red light. The car hit a tree.
36. Because car 1997- totaled it out. Was other drivers fault.
37. I was rear ended. Totaled the car. Other driver received ticket.
38. No ticket. 3-4 car sudden stop. All 3-4 ran into back of one in front. No fault-don't know about those at head of line
39. Deer hit driver side and rear door. Motorcyclist from side street hit rear door + rear tire-his insurance paid.
40. I was waiting for a car to turn left, I thought she was moving on- she wasn't. I hit her. Totaled my car. She had a Mercedes B. no damage to her car.
41. Failure to yield car on my right. Had to get a new bumper for my car. My fault.
42. 1st -power steering went out. Not too severe. No fault
    2nd- severe, my fault.
43. Hit an left wheel. …. *(unreadable)* Never stopped and turned into the police.

44. Not severe. The girls fault for pulling out of exit at sonic.

45. Deer

46. Not severe. Other driver was found to be at fault.

47. Backing up I scraped a vehicle was too close.

48. Not at fault.

49. Someone hit my bumper, so it’s not my fault.