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Association of Michigan's Older Adult Crashes with Roadway Features

FINAL REPORT

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16. Abstract

Studies have shown that older drivers (65yrs-and-older) are prone to an increased risk of crash involvement per vehicle mile traveled and are more likely to be severely injured or killed as a result of a crash. The Federal Highway Administration (FHWA) *2014 Handbook for Designing Roadways for the Aging Population* presents a list of roadway features and their associated design elements that need to be considered when designing with the aging adults in mind. While the Michigan Department of Transportation (MDOT) has placed an increased focus on implementing engineering countermeasures making driving safe for older drivers since 2004, there are additional opportunities to improve design guidance in accordance with the FHWA Handbook, as well as other published best practice resources. The main objective of this study was to analyze the association of older adult crashes with roadway features and provide guidance in roadway design to MDOT. With analysis results, a detailed review of the FHWA Handbook and understanding of MDOT's road design guidance, opportunities for potential enhancements to MDOT's design guidance were identified and are documented in this report.

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Executive Summary

Driving requires a number of psychological and physical abilities. These include cognitive, visual and psychomotor skills. Aging can produce declines in these abilities produced by medical conditions associated with aging and the medications used to treat these conditions but the degree will vary considerably across individuals (Charlton et al., 2004; Dobbs, 2005; Eby, Molnar, & Kartje, 2009). Studies have shown that older drivers are prone to an increased risk of crash involvement per vehicle-miles-traveled and are more likely to be severely injured or killed as a result of a crash (e.g., Lyman et al 2002). The Federal Highway Administration (FHWA) *2014 Handbook for Designing Roadways for the Aging Population* (FHWA, 2014) presents a list of roadway features and their associated design elements that need to be considered when designing with the aging adults in mind. While the Michigan Department of Transportation (MDOT) has placed an increased focus on implementing engineering countermeasures making driving safer for older drivers since 2004, there are additional opportunities to improve design guidance in accordance with the FHWA Handbook, as well as other published best practice resources. The main objective of this study was to analyze the association of Michigan's older adult crashes with roadway features and provide guidance in roadway design to MDOT.

To accomplish the research objectives, the research team examined the association between Michigan crashes involving drivers 65yrs-and-older and roadway features. A comprehensive literature review to uncover similar studies on roadway features and engineering improvements that benefit older adults was undertaken. After conducting a comprehensive literature review on factors associated with older adult crashes, a review of Michigan crash data was conducted to identify locations, time of the day, and weather conditions in which older drivers are disproportionately involved in crashes. The team then surveyed Michigan road users (with emphasis on the older adults) to obtain their opinions regarding the roadway features and potential improvements. The team then collected data on roadway geometry and analyzed safety factors associated with crashes observed. Statistical analyses were conducted to study the significance of the roadway factors and identify the most effective engineering design solutions to improve safety for the older adults. Lastly, the research team conducted a cost-benefit analysis of potential engineering solutions and developed guidance in roadway design to address older drivers' needs.

The survey was conducted by interviewing Michigan road users at locations such as restaurants, libraries, rest areas, Secretary of State (SOS) branch offices and “welcome” centers. The objectives of the survey were to identify: (1) perspectives of road users (especially those age 65yrs-and-older) on roadway features and identify issues they face as road users, (2) the type of driving and maneuvers the 65yrs-and-older drivers tend to avoid, (3) alternative transportation modes available to the 65yrs-and-older participants and other road users, and (4) to identify if age influences perspectives and performance (i.e., compare road users age 65 years-and-older to those age 64 years-and-younger). A questionnaire was used to collect data from the survey participants.

In the survey, participants reported personal car (both as a driver or a passenger), bicycle and walking as the most frequent transportation alternatives used. In addition, drivers 65yrs-and-older reported a higher tendency to avoid driving compared to drivers 64yrs-and-younger. These conditions included night-time, bad weather, when a left turn would be needed, driving alone, during peak travel times or busy time of day (rush hour), and intersections in unfamiliar areas. Driving during bad weather was stated to be the most avoided action by older drivers while driving alone was the least avoided. Drivers 65yrs-and-older also expressed concerns regarding different sections of the roadway with different features at different time of the day and condition.

At intersections, the 65yrs-and-older drivers reported concerns with opposing vehicle blocking their visibility of oncoming traffic when making a left turn, especially during night-time. They also reported concerns with insufficient visibility in night-time and bad weather conditions. There were statistically significant differences in concerns by 65yrs-and-older in every concern except when turning into a narrow lane for which there was no statistically significant difference between 65yrs-and-older drivers and 64yrs-and-younger drivers.

For pavement markings/signs at intersections, the 65yrs-and-older drivers reported that they have concerns with visibility of edge lines, lane markings on the pavement and the visibility and legibility of street name signs during night-time more than in daytime and bad weather.

For traversing highway-rail grade crossings, the 65yrs-and-older drivers report having concerns with visibility of highway-rail sign and identification of a safe path at an unlighted-rail grade crossing in rural areas in night-time more than in daytime and bad weather. There were statistically significant differences in identification of a safe path at an unlighted-rail grade crossing by 65yrs-and-older and the 64yrs-and-younger drivers in rural areas in night-time and bad weather.

For intersections with Yield/Stop signs, 65yrs-and-older drivers reported that they have concerns regarding difficulty in judging gaps. The concerns are higher in bad weather followed by night-time. There were statistically significant differences between drivers 65yrs-and-older and drivers 64yrs-and-younger in concerns about difficulty in judging gaps in night-time and bad weather. Multilane roundabouts also pose challenges to drivers, especially older adults. The survey indicated that more 65yrs-and-older drivers (33 percent) have concerns in choosing the proper lane at multilane roundabouts than drivers 64yrs-and-younger (17 percent).

Crash analysis focused on Michigan's five year (2010-2014) of data. First, general analysis of crashes was conducted to obtain an understanding of overall crash distributions. In this analysis, occurrence of crashes involving 65yrs-and-older drivers was compared to the occurrence of crashes that did not involve 65yrs-and-older drivers based on different factors such as weather condition, lighting condition, roadway condition, roadway type, number of lanes, access control, and traffic control. The analyses were then expanded to individual drivers who were involved in those crashes. Driver factors such as driving while intoxicated with alcohol or drugs and their actions prior to crash occurrence were investigated for all age groups. Table 0.1 presents the findings from the general crash analysis.

To control for the exposure, a more in-depth analysis using two-vehicle crashes which involved one 65yrs-and-older driver and one 64yrs-and-younger driver was conducted. This analysis was used to discern locations and their respective roadway features that are more likely to be problematic to the 65yrs-and-older drivers. Table 0.2 shows a summary of findings from these analyses. Under normal circumstances, each driver has a 50 percent chance of being responsible for the crash (i.e., committing hazardous action potentially causing the crash) when two vehicles are involved. The location or a design feature under study was considered to be potentially problematic to drivers of a specific age group if the chances of drivers in that age group to commit hazardous action was greater than 50 percent. This analysis provided an additional advantage of controlling for the exposure measure as we do not necessarily need to know how many 65yrs-and-older drivers or other drivers were on a given facility at the time of crash.

Table 0.1 Summary of general analysis of all crashes (2010-2014)

Item	Attribute/Feature	Data used	Summary of findings
Environmental characteristics	Daylight	All crashes, all age groups	• Higher proportion of 65yrs-and-older-related crashes occurred in daylight (76 percent) compared to crashes that involved drivers 64yrs-and-younger only (58 percent).The observation agreed with survey results in which 65yrs-and-older drivers reported to avoid driving in nighttime.
	Dark		• Most of the single-vehicle crashes for the drivers 64yrs-and-younger occurred in dark-unlighted conditions (43 percent) compared to the proportion for the 65yrs-and-older drivers (37 percent).
Roadway characteristics	Number of lanes	All crashes, all age groups	• Drivers 65yrs-and-older were more likely to have higher proportion of crashes in multilane roads, particularly on roads with greater than two lanes in each direction (22 percent) compared to drivers 64yrs-and-younger (16 percent).
	Access control		• Drivers 65yrs-and-older were more likely to have higher proportion of crashes in roads with no access control (83 percent) compared to drivers 64yrs-and-younger (79 percent).
Driver characteristics	Alcohol involvement	All crashes, all age groups	• 64yrs-and-younger were more likely to be intoxicated prior to crash compared to 65yrs-and-older drivers, especially for single-vehicle crashes (6 percent vs 2 percent).
	Driver action prior to a crash		• 65yrs-and-older drivers were more likely to be involved in a crash when turning left (14 percent) compared to 64yrs-and-younger drivers (10 percent).

Table 0.2 Summary of in-depth analysis of two-vehicle crashes involving one 65yrs-and-older driver and one 64yrs-and-younger driver

Item	Attribute/Feature	Data used	Finding
Crash location as defined by MDOT	• Intersection • Midblock • Interchange	Crashes by location as defined by MDOT	• Among all locations, intersections had the higher instances of 65yrs-and-older drivers who committed hazardous actions potentially causing the crash (54 percent) as compared to 64yrs-and-younger driver (46 percent).
Intersections	Traffic control	• Crashes at STOP-controlled intersections • Crashes at signal-controlled intersections	• At STOP-controlled intersections, drivers 65yrs-and-older were found to have committed hazardous actions potentially causing the crash in more instances (57 percent) than the 64yrs-and-younger drivers(43 percent) • The same was observed at signal-controlled intersections but with relatively lower proportion of drivers 65yrs-and-older committing hazardous actions (53 percent vs 47 percent). • Turning left was the most problematic maneuver for drivers 65yrs-and-older for all control type. In more than 60 percent of two-vehicle crashes, driver 65yrs-and-older was the one who committed hazardous action when turning left.
	Intersection skewness	• Crashes at major intersections (arterial and collectors) in Michigan. • 10,934 intersections were used in the analysis	• Skewed intersections with small angle were associated with more instances of 65yrs-and-older drivers who committed hazardous actions potentially causing the crash when they were making left turn maneuver compared to drivers 64yrs-and-younger. • The effect of intersection skewness was more noticeable at STOP-controlled intersections compared to signal-controlled intersections for 65yrs-and-older drivers compared to 64yrs-and-younger drivers (71 percent vs 29 percent).
	Raised median	• Crashes that occurred at intersections	• Relative to the 64yrs-and-younger drivers, 65yrs-and-older drivers were

Item	Attribute/Feature	Data used	Finding
		joining state-owned roads • A total of 285 intersections, of which 25 intersections had a raised median	less likely to be responsible for crashes that occurred at intersections with raised median (52 percent) compared to intersections without raised median (59 percent).
	Offset left-turn lanes	• Crashes that occurred at intersections joining state-owned roads • A total of 195 intersections with left-turn bay, out of which 6 intersections had offset left-turn lane(s)	• Relative to the 64yrs-and-younger drivers, the 65yrs-and-older drivers were less likely to be responsible for crashes that occurred at intersections with offset left-turn lane (55 percent) compared to intersections without offset left-turn lane (58 percent).
	Intersection lighting	Crashes that occurred at all intersections as reported in the crash data.	• 65yrs-and-older drivers were found to be less responsible for crashes in dark-lighted condition compared to dark-unlighted conditions. The difference was more pronounced at rural intersections (57 percent in dark-lighted compared to 63 percent in dark-unlighted).
Midblocks	Driveways away from intersection	Crashes that occurred at driveways away from intersections as reported in the crash data.	• 65yrs-and-older drivers were found to have committed hazardous actions potentially causing the crash in more instances (57 percent) than the 64yrs-and-younger drivers (43 percent) at driveways away from the intersections. • Most of the crash types were angle (51 percent), rear-end (11 percent) and sideswipe same direction (10 percent). • Most of the 65yrs-and-older drivers failed to yield when they were turning left to enter the roadway from the driveways or when entering the driveway from the main road.
	Median crossover	Crashes that occurred at median crossover as reported in the crash data.	• 65yrs-and-older drivers had 62 percent chance of being responsible for a crash compared to 64yrs-and-younger driver (38 percent). • Common crash types that were observed include angle (34 percent), rear-end (19 percent), sideswipe-same (19 percent).

Item	Attribute/Feature	Data used	Finding
			• Majority of the 65yrs-and-older drivers who committed hazardous action were turning left prior to the crash.
	Transition Areas	Crashes that occurred at segments with lane drop as reported in the crash data.	• 65yrs-and-older drivers were found to have committed hazardous actions potentially causing a crash in more instances (58 percent) than the 64yrs-and-younger drivers (42 percent) at transition areas. • Common crash types observed at these locations include sideswipe same direction (27 percent) rear-end (26 percent) and angle crashes (17 percent) • Failure to yield and improper lane use were overrepresented for the 65yrs-and-older drivers.
	Curved road segments	Crashes that occurred at curved road segments as reported in the crash data.	• Single-vehicle crashes were overrepresented at curved segments for all age groups. Majority of single-vehicle crashes associated with speeding occurred when the roadway was icy or snowy (57 percent for 64yrs-and-younger single-vehicle crashes and 49 percent for 65yrs-and-older single vehicle crashes).
	Parking areas along the roadside	Crashes which occurred at road segment with parking along the road	• 65yrs-and-older drivers were found to have committed hazardous actions potentially causing a crash in more instances (57 percent) than the 64yrs-and-younger drivers (43 percent) at parking areas alongside the road. • Improper backing and failure to yield were the most frequent hazardous actions committed by drivers 65yrs-and-older.

A key to implementing effective treatments to improve the safety of the transportation system for the aging population in Michigan is providing appropriate guidance related to the use of such treatments. In addition to the evaluation of existing facilities and safety treatments with respect to older drivers, it was also necessary to compare MDOT's existing design guidance with the resources identified as a part of this evaluation. While MDOT has placed an increased focus on implementing engineering countermeasures making driving safe for older drivers since 2004, there are additional opportunities to improve design guidance in accordance with the *FHWA Handbook for Designing Roadways for the Aging Population*, as well as other published best practice resources (FHWA 2014).

In order to assess the current state of MDOT's design guidance with respect to older drivers, a detailed comparison was completed with the *FHWA Handbook for Designing Roadways for the Aging Population*. Each aspect of the guidance provided in the handbook was compared with MDOT's existing guidance and rated using the following scale:

1. No guidance from MDOT on this topic
2. Ambiguous guidance from MDOT
3. Clear guidance from MDOT but inconsistent with the handbook
4. Optional or similar guidance from MDOT consistent with the handbook
5. Guidance from MDOT consistent with the handbook

Recommended countermeasures and strategies identified from the handbook or in other publications which currently do not have specific guidance from MDOT, or those which currently have ambiguous guidance, are summarized in Table 5.1 in Chapter 5. The treatments listed within Table 5.1 represent opportunities for potential MDOT design guidance enhancements considering leading practices in the area of older drivers. The design areas where these countermeasures fall include, but are not limited to:

- Intersection skew, including providing the FHWA recommended intersection geometry between 75-105 degrees for new construction where feasible.
- Channelization, especially right-turn channelization design,
- Intersection sight distance, by considering a gap of no less than 8 seconds plus 0.5 seconds for each additional lane crossed.
- Offset left-turn lanes, by considering the use of positive offset left-turn lane using pavement markings on lower speed undivided highways.
- Delineation of edge lines and curbs, by considering edge lines and retroreflective pavement markings on the faces of the medians.

- Additional ground mounted signal (i.e., consider providing an additional ground mounted signal head in the far left corner of multi-lane approaches with permissive left-turns).
- Street name signs, by partnering with local agencies to develop a plan for applying overhead street name signs at signalized intersections.
- At construction/work zones, consider the use of some enhanced guidance for portable changeable message signs as being suggested by the National Committee on Uniform Traffic Control Devices.
- MDOT should consider conducting a pilot Work Zone Road Safety Audit (RSA) as part of its RSA contract to document its effectiveness.
- For lighting at highway-rail grade crossings, it is suggested that MDOT work in partnership with local agencies to identify strategies to provide lighting at more highway-rail grade crossing on a systemic basis.

1 Introduction and Background

1.1 Research problem and motivation

By 2030, older adults – those with age 65 years and above (referred to as '65yrs-and-older' in this report) will represent approximately 20 percent of the population in Michigan and nationally. Studies have shown that older drivers (65yrs-and-older) are prone to an increased risk of crash involvement per vehicle-miles-traveled and are more likely to be severely injured or killed as a result of a crash (e.g., Lyman et al 2002). According to the *FHWA 2014 Handbook for Designing Roadways for the Aging Population* (FHWA, 2014), the effects of aging on people as drivers and pedestrians are highly individual. Challenges that may impact people as they age include declining vision, decreased flexibility and psychomotor performance, and changes in perceptual and cognitive performance. Furthermore, older drivers have more difficulty handling situations with a high driving work load as well as unfamiliar or novel situations. There are a number of studies that have examined medical factors associated with older adult crashes (e.g., Anstey et al 2005, Owsley et al 1998, etc.). However, studies linking older adult crashes with roadway design features are limited. As the population ages, the older adult segment has received more national attention and focus, and is starting to be considered in the design of roadway infrastructure, operations, and traffic engineering features. For this reason, it has become an important task to analyze the association of older adult crashes with roadway features. The *FHWA 2014 Handbook for Designing Roadways for the Aging Populatio*n presents a list of roadway features and their associated design elements that need to be considered when designing with the aging adults in mind. With such recommendations, there was a need to examine Michigan crash data to determine their association with these roadway design elements and to identify any revisions needed in the Michigan design guidelines.

1.2 Objectives of the study

The main purpose of this study was to analyze the association of older adult crashes with roadway features. An additional objective was to apply the results to provide guidance in roadway design to MDOT. To accomplish the objectives of this research, a number of tasks were undertaken. These tasks aimed and focused on:

- Identification of the scenarios in which older adults are over-represented in Michigan crashes: This was not a trivial task since the percentage of older adults crashes may be affected by exposure (e.g., older adults population, vehicle-miles-traveled by older drivers, etc.), time of day, weather conditions, in additional to roadway factors.

- Collection of a comprehensive list of Michigan roadway features: Statewide asset mapping was unavailable, therefore collecting roadway features such as roadway geometry, traffic control and operations factors, and traffic generator information was difficult. Field data collection and satellite imaging analysis (e.g., from Google Earth) was used to accomplish this need.
- Proper accounting for other factors affecting older adults crashes which are not associated with the roadway features, such as weather, time of day, and exposure.
- Providing clear guidance to make informed decisions for effective future deployments. This involved estimates of safety with and without an engineering design feature. Benefit-cost analysis of major recommendations was conducted and is documented.

1.3 Overview of research tasks

The research team examined the association between Michigan crashes involving the aging population and roadway features. A comprehensive literature review to uncover similar studies on roadway features and engineering improvements that benefit older adults was undertaken. After literature review, a review of Michigan crash data was conducted to identify locations, time of day, and weather conditions in which older drivers are disproportionately involved in crashes. Then, the team surveyed Michigan road users (with emphasis on the older adults) to obtain their opinions regarding the roadway features and potential improvements. A review of alternative transportation options available in all Michigan counties was performed. The team then collected data on roadway geometry and analyzed safety factors. Statistical analysis was conducted to study the significance of the roadway factors and identify the most effective engineering design solutions to improve traffic safety for the older adults. Lastly, the research team conducted a cost-benefit analysis of the engineering solutions and developed guidance in roadway design to address older drivers and prepared recommendations for revisions to the Michigan Department of Transportation (MDOT) standards and guides. The results from the research can be utilized by MDOT to determine the roadway features and engineering design countermeasures that can improve the public traffic safety, especially where the aging population is likely to have difficulty driving, or is over-represented in crashes. The results may also help MDOT make more informed decisions, such as where to invest resources to improve traffic safety of the older adults.

1.4 Scope of research and report organization

This research focused on analysis of crashes involving older adults (age 65 years and above) in Michigan to determine roadway features associated with them. Chapter 2 of this report presents the literature review focusing on factors associated with older adult crashes. It also introduces review of the *FHWA 2014 Handbook for Designing Roadways for the Aging Population* and Michigan roadway design guides. Chapter 3 presents a description of the intercept survey of Michigan road users and identification of alternative transportation options available in Michigan counties. Chapter 4 documents analysis of Michigan's five year (2010-2014) crash data to identify any associations with roadway features. Chapter 5 presents roadway design guidance for Michigan to better accommodate the aging population. Chapter 6 documents benefit-cost analysis results for selected countermeasures recommended in Chapter 5. Chapter 7 highlights important conclusions and recommendations from this research while Chapter 8 lists additional references relevant to this study. Lastly, Chapter 9 contains appendices with additional detailed information for selected report sections.

2 Literature Review

2.1 Physical issues associated with older adult drivers

Driving requires a number of psychological and physical abilities. These include cognitive, visual and psychomotor skills. Aging can produce declines in these abilities produced by medical conditions associated with aging and the medications used to treat these conditions but the degree will vary considerably across individuals (Charlton et al., 2004; Dobbs, 2005; Eby, Molnar, & Kartje, 2009). A number of studies show that older drivers are involved in different types of crashes than younger drivers. One major difference is the greater involvement in intersection crashes (Clark, Forsyth, & Wright, 1999; Hakamies-Bloomqvist, 2004; Oxley, Fildes, Corben & Langford, 2006. These studies show an increasing trend in fatal multivehicle crashes at intersections affecting older drivers with a marked increase after age 79 (IIHS, 2013). However, it is not clear what role increasing fragility plays in the increase of fatal crash. It is well documented that older drivers are more fragile and therefore more likely to sustain a serious injury in a high energy crash (Kent, 2010; Kent et al, 2009). In any case it can be concluded that busy intersection pose a significant safety risk for older drivers regardless of who is responsible for the crash. Other studies show that older drivers have a higher crash rate when merging onto inter-state highways with a large increase in crash involvement ratios after age 69 (Stutts et al, 2009). One study (Classen et.al. (2010) found that crash violation errors involving lane maintenance, yielding, and gap acceptance errors based on predicted crash-related injuries of older drivers with almost 50 percent probability.

Cognitive abilities are essential to safe driving. These include processing inputs, the ability to discriminate conditions accurately, situational awareness, and decision making. Key elements are processing complex stimuli, memory, and making decisions in a timely manner. (Eby, Molnar, & Kartje, 2009; Michon, 1985). Decline in these abilities varies greatly from individual to individual since not everyone ages at the same rate or suffers from the same diseases. Some of cognitive abilities that decline with aging are: the ability to deal with a high workload (Makishita, & Matsunaga, 2008); selective attention; decision making speed (French et al, 1993; spatial cognition (Salthouse, 1987); memory (e.g., Eby et al., 2012); and executive function (Anstey et al., 2005; Daigneault et al, 2002; Zelazo et al, 2004). These declines have the greatest impact on driving in heavy workloads such as busy traffic, negotiating busy intersections, and driving in unfamiliar areas.

Psychomotor abilities refer to a person’s ability to mover and orient parts of their body voluntarily (Kelso, 1982). Typically, older adults have slower reaction times, decreased physical flexibility, decreased coordination (Marottoli & Drickamer,1993; Malfetti, 1985; McPherson et al, 1988; Anshel, 1978; Marshall et al, 1985). These declines can affect the ability to check blind spots, and respond effectively in complex situations.

Visual abilities are key to safe driving. Declines in visual acuity may result in older drivers recognizing highway signs later than driver with normal vision. This places them at a greater disadvantage when combined with the average slower reaction time of older drivers. Declines in contrast sensitivity and glare recovery may impair the ability of some older drivers to drive at night. When exposure is taken into account, there is some evidence that older drivers have higher nighttime crash rates than drivers in the middle-aged group (Massie et al, 1995; Stutts & Martell, 1992). Since rod pathways are known to adapt more slowly than cone pathways, reaction time under the rapidly changing viewing conditions observed at night tend to be slower (Plainis et al, 2005). Plainis et al, (2006) provided a good explanation for slower reaction times at night. Processing information based on rod photoreceptors is relatively slow, and slower reaction times translate into longer stopping distances. It is also known that it is necessary to use offset rather than direct viewing when using rod photoreceptors.

Most drivers and pedestrians are not practiced at looking to the side to view the road ahead. Specifically, data show that adaptation rates are twice as fast for central compared with peripheral viewing (Plainis et al, 2005). In addition drivers may have a reduction in the visual field producing blind spots, and reduced sensitivity to motion which can make it difficult for older drivers to make temporal judgments of the size of gaps in traffic. This skill is critical for making turns at intersections (Anstey et al, 2005; Attebo et al, 1996; Ball et al, 1988; Birren & Shock, 1950; Burg, 1966; Heron & Chown, 1967; Long & Crambert, 1989; Owsley & Sloane, 1990; Schieber et al, 1992; Wolf, 1960). Of greatest concern is the decline at correctly estimating gaps based on vehicle speed. Staplin (1995) found a relative insensitivity to vehicle approach speed in left-turn situations by older drivers. This increases the risk for older drivers if there is an isolated speeder in the opposing traffic stream.

Older drivers also compensate for many of these declines. For example, older drivers maintain a longer headway and drive slower than younger drivers (Cotté, Meyer, & Coughlin, 2001; Kramer et al., 2007; Maltz & Shinar, 2004). Older drivers also have been documented to avoid night driving (Baldock et al., 2006; Charlton et al., 2006; Molnar et al., 2013).

Many problems frequently encountered by older drivers can also be mitigated by in-vehicle adaptations (see Eby et. al, 2015 for a complete review), such as mirrors that cover blind spots (Kessler et al., 2012; Jermakian, 2011). Back up cameras, auditory driving directions that provide ample warning of upcoming turns and exits. Technologies that assist drivers to see better at night using infrared cameras to detect pedestrians, signs, and roadway markings can be displayed on a screen (Rumar, 2002) and can provide a warning if an object is detected in the roadway (Brown et al, 2010). These systems are not in general use and there is little evidence available on whether they can assist older drivers.

A study of older drivers conducted in Michigan (LeBlanc et al., 2006) showed that a lane departure warning system decreased lane incursions and increased driving closer to the center lane and improved use of turn signals when changing lanes. Curve speed warning devices have also shown some promise. McElheny et al, (2006) found that older drivers tested at night showed improvements in speed with results similar to those of younger drivers with this type of in vehicle warning system. Forward collision warning systems have also been shown to improve the safety of older drivers (Ervin et al., 2005; LeBlanc et al, 2013; Sayer et al., 2010). Based on this review it appears clear that older drivers have problems with gap acceptance at intersections, and merging with high speed traffic and share attention.

2.2 Roadway features associated with older adult crashes

In addition to physical factors affecting the performance of older adults, there may be specific roadway features which increase the risk of older adults causing a crash. There has been a few studies focusing on identification of roadway features associated with older adult crashes. Stutts et al., (2009) performed a study identifying behaviors and situations associated with increased crash risk for older drivers. The Fatality Analysis Reporting System (FARS) and National Automotive Sampling System (NASS)/General Estimates System (GES) data from 2002 to 2006 was used for analysis. The study focused on identifying the association between older drivers' increased crash involvement and vehicle, driver and environmental/roadway features. Also, the aim of the study was to identify specific driving behaviors or performance errors common to older drivers. The methodology for analyzing data in this study involved two parts. The number of total crashes utilized from the FARS records was 109,937 out of which 72,847 were single-vehicle and 37,090 were two-vehicle crashes. The GES records utilized were 181,698 for total crashes, out of which 69,689 were single-vehicle and 112,009 were two-vehicle crashes. The roadway characteristics analyzed included route signing, rural/urban roadway, relation to junction, interchange-related, railroad crossing, number of lanes, speed limit, roadway alignment, traffic control, light condition, and weather. Calculated Crash Involvement Ratios (CIRs) revealed that drivers of age 70 and older had a higher risk of crash involvement (in a fatal two-vehicle crash) when driving on principal arterial roads. The study also found that the likelihood of older adults being involved in intersection-related crashes was strongly associated with age. Older drivers were less likely to cause a crash on curved roadways (perhaps because most of older adults may reduce their speeds more than their counterpart younger drivers when negotiating a curve). For drivers of age 80 years and older, non-signal controlled intersections (especially those with yield signs) presented the greatest risk of a fatal two-vehicle crash. For those among 60-69, the only situation that posed increased risk was when flashing signals where present. Flashing signals and stop and yield signs exhibited higher risks for drivers of age 70 to 79 years old.

A study by Stout et al. (2006) evaluated the safety impacts of road diet in Iowa. Analysis of the safety impacts on 15 urban sites where road diet was performed (from four lanes to three lanes) was conducted using monthly crash data. The authors implemented a before and after study approach with “yoked pair” control sites (15 treated sites and 15 comparison sites using 10 years of annual data), and a full Bayes method (using 30 selected sites for a period of 23 years (1982-2003). The results showed that there was a reduction of 21 percent and 29 percent in the number of crashes of those at higher risk (25 years and younger and the 65 years and older drivers), respectively.

Hallmark and Mueller (2004) evaluated the impacts of left-turn phasing on older and younger drivers at signalized intersection with high speed and their contribution to same crash type under certain left-turn phasing in Iowa. The Poisson regression was used to analyze crash rate per phasing (protected, permitted, and protected/permitted). The study used 101 urban-area intersections with an intersecting roadway of at least 45 mph. Crashes analyzed ranged from 2001-2003 and they were left-turn related crashes. Crash severity and rate for the left turn related crashes were calculated per age groups (young: 14-24 years old, middle-aged: 25-64 years old, older: 65 and above years old) using crashes per million entering (MEV) of the problematic approach since data for left turn volume was not available. It was found that protected left turn phasing are much safer than permitted and protected/permitted. The phasing with the highest crash rates (overall) was the protected/permissive left turn. This phasing also had the highest calculated average severity index of 21.0. The average severity index for using a protected/permissive left turn was higher for younger and older drivers than for the middle-aged; they were 25.6, 26.5, and 15.8 respectively. Due to the safety benefits obtained from protected left-turn phasing, the study recommended such phasing at high-speed intersections.

Khattak et al. (2002) analyzed 10-year crash data (1990-1999) in order to separate contributing factors of severer injuries in older drivers (65 years and older) in the state of Iowa. The study investigated vehicle, roadway, driver, crash, and environmental factors influencing crash injury severity for older drivers using 17,045 crashes involving older drivers. The results showed that older drivers driving under alcohol influence are more likely to be severely injured in a crash. From the vehicle factors, it was found that injuries sustained by older drivers’ driving farm vehicles were more severe when compared to those sustained by drivers of other vehicle types. Analysis of roadway features revealed that, among others, crashes occurring under poor lighting or dark conditions were more severe for older drivers. It was recommended to perform further studies uncovering differential impacts of factor in older and younger drivers

Rakotonirainy et al. (2012) performed a study on crashes involving older drivers in Australia. The main purpose of the study was to identify the relationship between crash severity and older driver’s crashes. A Chi -square test was used and crash data analysis covered drivers of all ages to relate the injury level sustained by the victims with traffic control measures and roadway features.

From results, it was observed that serious crashes are significantly different between age groups (e.g. 17-24, 25-39, 40-49, 50-59, 60-69, 70-79, and 80+) when analyzed as a function of crash severity, at fault levels, roadway condition, and traffic control measures. Compared to drivers aged 60 years or more, the drivers in the middle age-category (40-49 and 50-59) had the lowest proportion of crashes involving fatalities, hospitalization, failure to yield the right-of-way, and at uncontrolled intersection. However, for these drivers (middle-age) the highest proportion was found in the speed and alcohol-related crashes when compared to the older drivers. Within the older drivers group, drivers with age of 70-79 years were more likely to have accidents at stop and yield signs.

Alam (2005) performed an analysis of the relationship between the age-range of at-fault drivers and roadway, traffic, weather, and other factors in Florida. The results showed that older drivers (65 years and greater) are involved in intersection crashes more than non-intersection crashes. The opposite was true for the younger group (less than 24 years). There was an 18 percent of cases when older drivers at intersections misjudged the speeds of oncoming vehicles; 17 percent of cases in which older drivers failed to see vehicles (in all sides) before approaching the intersection. Other notable reasons for higher involvement of older drivers in intersection crashes included disregarding traffic signals (13.4 percent), and performing improper left turns (12.4 percent).

2.3 Review of MDOT roadway design guidelines

The MDOT guidelines for the design of roadway features were reviewed and compared with the 2014 Handbook for Designing Roadways for the Aging Population. The aim of this review was to identify any inconsistencies between the two guidelines. Five main locations were discussed which were intersection, roadway segments, interchange, construction area and highway-railway crossing. The review identified areas where MDOT has no guidance, has ambiguous guidance, has clear guidance which are inconsistent with the FHWA Handbook, has optional or similar guidance which are also consistent with the FHWA Handbook, as well as where MDOT is completely consistent with the 2014 Handbook for Designing Roadways for the Aging Population. Details of this comparison are provided in Chapter 5 and a full list of all roadway design features as discussed in the 2014 Handbook for Designing Roadways for the Aging Population and comparison with MDOT standard is provided in Appendix 9.3.2.

3 Survey of Michigan Drivers and Identification of Transportation Options

3.1 Introduction

This chapter presents a description of the intercept survey of Michigan road users and identification of alternative transportation options available in Michigan counties. By utilizing crash data, census data and the special elderly facilities in Michigan, different locations for conducting the intercept survey were identified. Locations identified include restaurants, libraries, rest areas, Secretary of State (SOS) branch offices and “welcome” centers. The intercept survey aimed at addressing the following objectives;

- To identify perspectives of road users (especially those age 65yrs-and-older) on roadway features and identify issues they face as road users.
- To identify the type of driving and maneuvers the 65yrs-and-older drivers tend to avoid.
- To identify alternative transportation modes available to Michigan residents, especially those 65yrs-and-older.
- To identify if age influences perspectives and performance (i.e., compare road users age 65yrs-and-older to those age 64yrs-and-younger).

To identify alternative transportation options available in Michigan counties, a detailed review of available information regarding public transportation was reviewed.

3.2 Survey design and administration

The research team developed a survey questionnaire that covered questions with an intent to respond to survey objectives. The following are eight steps followed by the research team to develop and conduct the survey:

1. Development of a draft questionnaire that took into consideration human factors issues that could be expected to influence older drivers.
2. Discussion with the RAP and potentially small focus group of 65yrs-and-older population.
3. Survey testing (using a pilot).
4. Finalization of the survey questionnaire.
5. Selection of the survey location.

6. Seeking approval by the Western Michigan University (WMU) Human Subjects Institutional Review Board (HSIRB).
7. Conducting the survey.
8. Survey results analysis.

As pointed earlier, different places were identified as location suitable to conduct the survey. Due to the fact that this research deals with Michigan as whole, locations were identified in such a way that they approximately covered different geographical locations (Kalamazoo, Detroit, Ann Arbor, Muskegon, Traverse City and Marquette). The survey was administered between May and July, 2016 and it was conducted by randomly interviewing people found at the identified locations.

3.3 Analysis of survey data

Data collected from the survey were processed and a descriptive statistics of the responses were developed. A chi-square test was utilized to test for any statistically significant differences derived from the descriptive statistics of the participants' responses. A total of 961 respondents were obtained at least a few from each of the 4 MI regions namely; South-East, South-West, North and Superior regions. The analysis of this survey was done by grouping the participants into three age groups; the less than 41years, 41-61 years and 65yrs-and-older. However, for the purpose of this report, the two groups (participants with less than 41 years and those between 41-64 years) were combined into one group that henceforth will be termed as 64year-and-younger. Detailed analysis of the two groups (65yrs-and-older and 64yrs-and-younger) is provided in this section while results with respect to the three age groups (less than 41 years, 41-64 years and 65yrs-and-older) are provided in Appendix 9.1.1. Figure 3.1 and Figure 3.2 show the distribution of the survey participants by age and location, respectively.

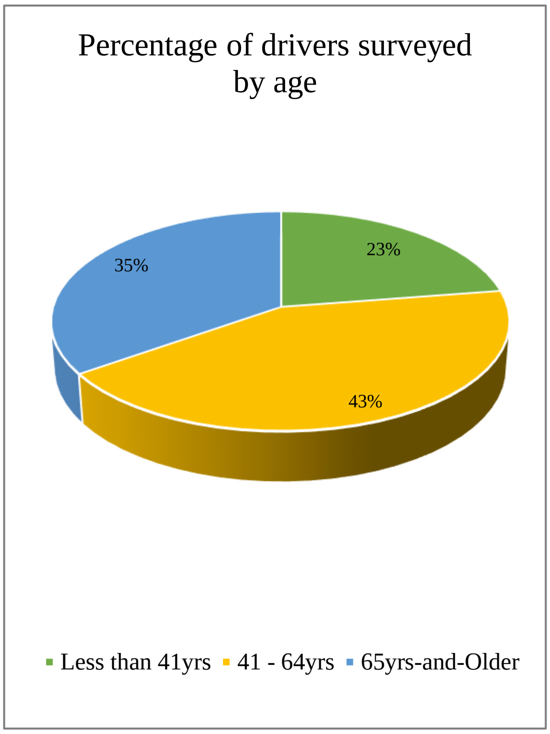

Figure 3.1 Distribution of survey participants by age

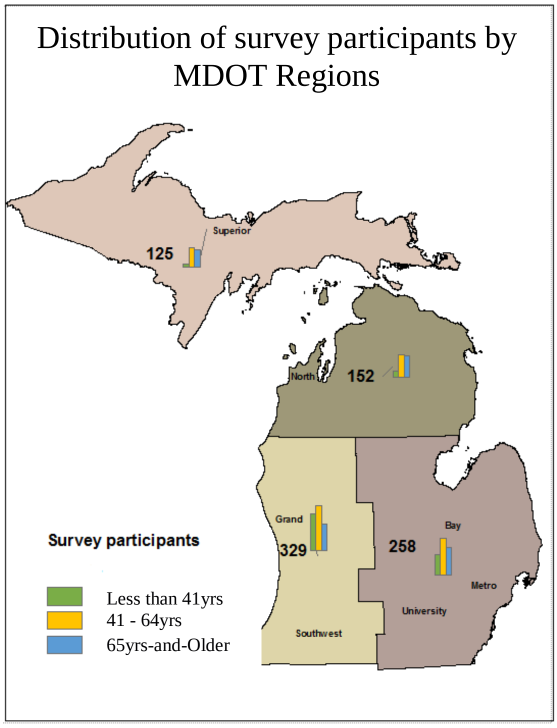

Figure 3.2 Distribution of survey participants by location

3.3.1 Transportation alternatives available to survey participants

Table 3.1 shows the availability of transportation alternatives by regions as reported by survey participants. This data should not be confused with the detailed information on transportation alternatives available in each county presented in Section 3.5 of this chapter. Availability of transportation alternatives reported here is a result of the intercept survey (i.e., reported by survey participants. Survey participants indicated that personal car as a driver and walking are the most available transportation alternatives and dial-a-ride transit is the least available. On average, more than 80 percent of participants reported the availability of personal car as a driver while 22 percent of participants reported dial-a-ride transit as an available transportation option alternative to them. The same ordering of options was observed region wise. In general, personal car as a driver, personal-car-as a passenger, bicycle and walking are the transportation alternatives which more than 50 percent of participants reported as being available to them.

Table 3.1 Transportation alternatives available to surveyed people by location

Transportation Alternative	Michigan Region				
	South East	South West	North	Superior	Statewide
Personal car as a driver	88%	81%	99%	97%	89%
Personal car as passenger	65%	62%	68%	78%	66%
Public Transit	50%	43%	43%	44%	45%
"Dial A. Ride" Transit	19%	14%	39%	26%	22%
Taxicab	40%	26%	43%	46%	36%
Bicycle	48%	44%	62%	64%	51%
Walking	84%	78%	80%	94%	82%

3.3.2 Frequency of use of the available transportation alternatives

Figure 3.3 shows the comparison of frequency of use for the available transportation alternatives by 65yrs-and-older participants and that observed 64yrs-and-younger participants. Personal car as a driver was reported to be the most frequently used mode of transportation for both the 65yrs-and-older and 64yrs-and-younger sample while public transit was reported to be used more by the 64yrs-and-younger than the 65yrs-and-older. About 9 percent of 65yrs-and-older use public transit most frequently while 19 percent of 64yrs-and-younger participants reported to use public transit most frequently. A largest difference between 65yrs-and-older and the 64yrs-and-younger participants was observed in the use of public transit. Appendices 3.1 shows the percentage frequency of use of available transportation alternatives by age.

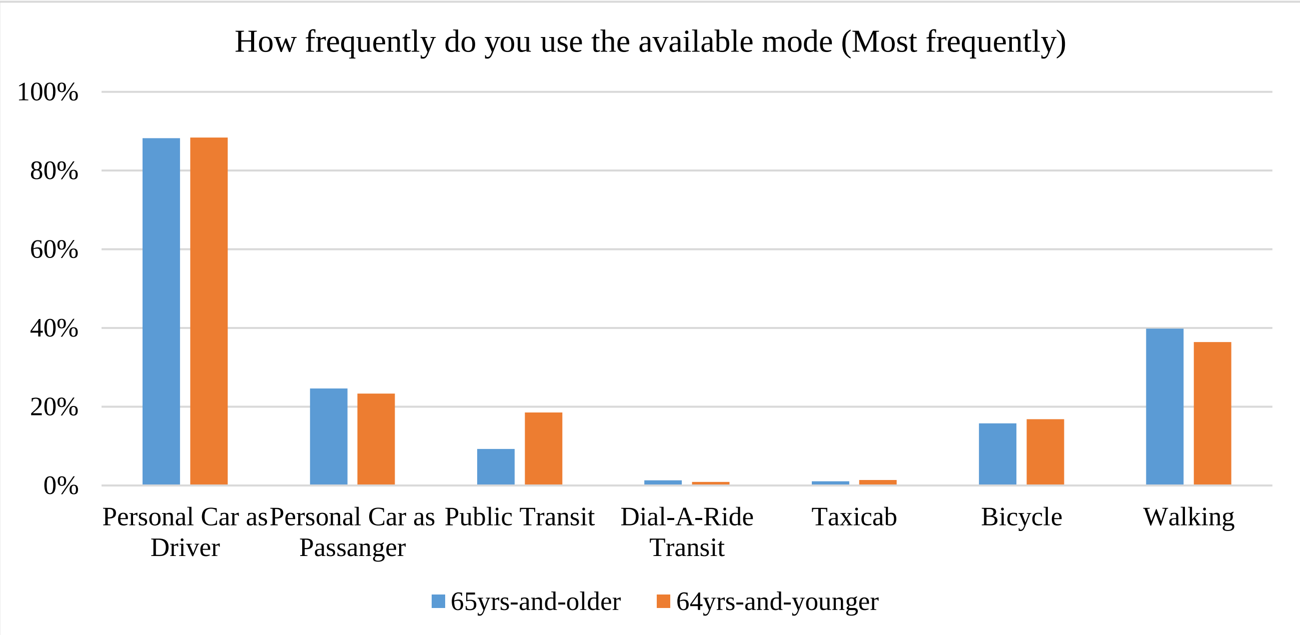

Figure 3.3 Transportation alternatives used most frequently

3.3.3 Concerns with driving in different conditions.

Avoiding driving is a decision that might be taken by a driver to reduce their driving frequency when they believe that certain conditions might interfere with their capability to safely operate their vehicle. In some cases, a decision not to drive might be a function of weather, roadway and/or traffic condition. It is assumed that older drivers have a tendency of avoiding certain driving conditions that they believe pose hazardous conditions to them. Different driving condition were provided: night-time, bad weather, on roadways with speed limits greater than 55mph, when a left turn would be needed, driving alone, during peak travel times or busy time of day (rush hour), and intersections in unfamiliar areas. Drivers 65yrs-and-older constitutes the highest percentage of drivers avoiding driving in every given condition, however, the highest percentage (53 percent) of 65yrs-and-older drivers avoid driving during bad weather.

Figure 3.4 shows percentage of 65yrs-and-older drivers avoiding driving as compared to the 64yrs-and-younger drivers. In all conditions 65yrs-and-older drivers had higher percentage of drivers avoiding driving than the percentage observed from all drivers. This is to say older drivers avoid driving more than the overall percentage. Driving during bad weather ranks the most frequently avoided by older drivers out of all given conditions and driving alone is the least. About 53 percent of 65yrs-and-older drivers said they avoid driving in bad weather while only 5 percent said they avoid driving alone. The largest difference between older drivers and all drivers is in the category of driving at night. There were statistically significant differences at the 0.05 significance level for drivers 65yrs-and-older and the 64yrs-and-younger for driving at night, during bad weather, during rush hour, on busy roads/intersections and at unfamiliar areas. There was also statistically significant difference at the 0.1 significance level for driving on roads with speed limits greater than 55mph.

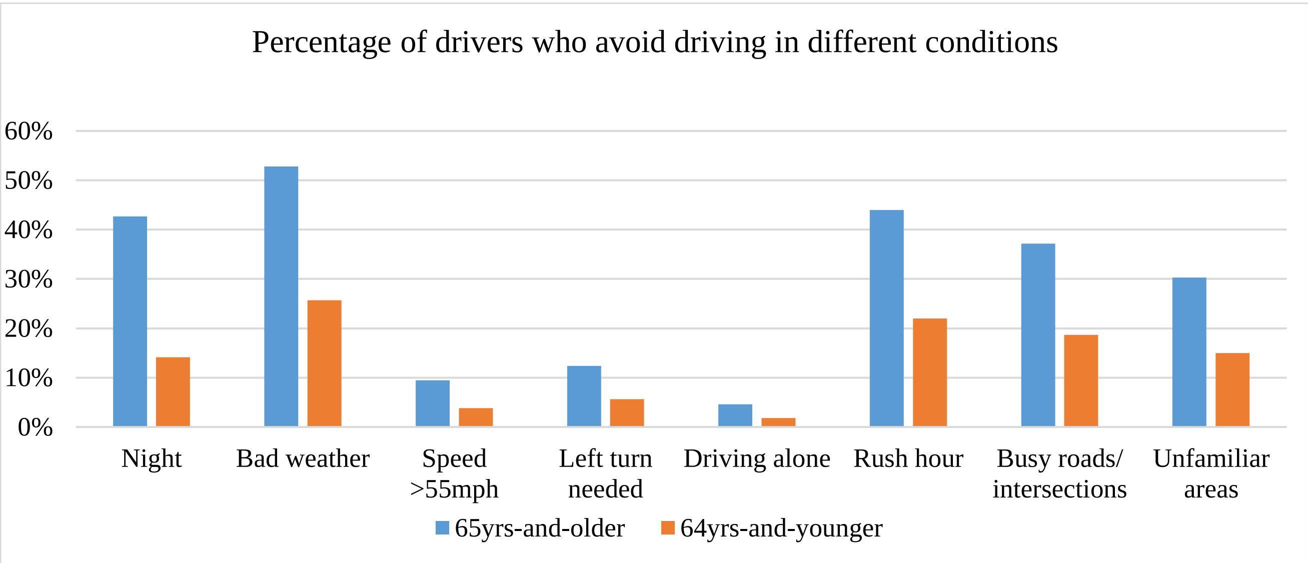

Figure 3.4 Percentage of drivers avoiding driving in different conditions

3.3.4 Concerns when making a turn at an intersection

Drivers were asked about concerns at intersections with sharp angles, turning into a narrow lane, insufficient visibility when turning, visibility of curbs and median islands and opposing vehicle blocking driver's visibility of oncoming traffic when they are making a left turn were queried. 65yrs-and-older comprised the highest percentage of drivers with concerns at intersections with sharp angle during daytime (8 percent), night-time (14 percent) and bad weather (16 percent). They also have concerns with insufficient visibility when turning. The respective percentage of 65yrs-and-older that had concerns with insufficient visibility in daytime, night-time and bad weather were 25 percent, 43 percent and 39 percent. Opposing vehicle blocking the visibility of oncoming traffic when making a left turn constituted the highest percentage of drivers with concern from the 65yrs-and-older drivers in which 42 percent having concern in night-time and 36 percent having concern in bad weather. There were an almost identical percentage of drivers with concerns in the visibility of curbs and median islands between drivers 65yrs-and-older and the 64yrs-and-younger. The respective percentage of 65yrs-and-older who had concerns with visibility of curbs and median islands in daytime, night-time and bad weather were 7 percent, 16 percent and 15 percent. Turning into a narrow lane was not more of a concern among the 65yrs-and-older drivers (Figure 3.5). There were statistically significant differences in concerns between 65yrs-and-older and 64yrs-and-younger drivers when making a turn at intersections with sharp angle in night-time (0.05 significance level), insufficient visibility when turning in night-time (0.1 significance level) and regarding opposing vehicle blocking their visibility of oncoming traffic when making a left turn in night-time (0.1 significance level).

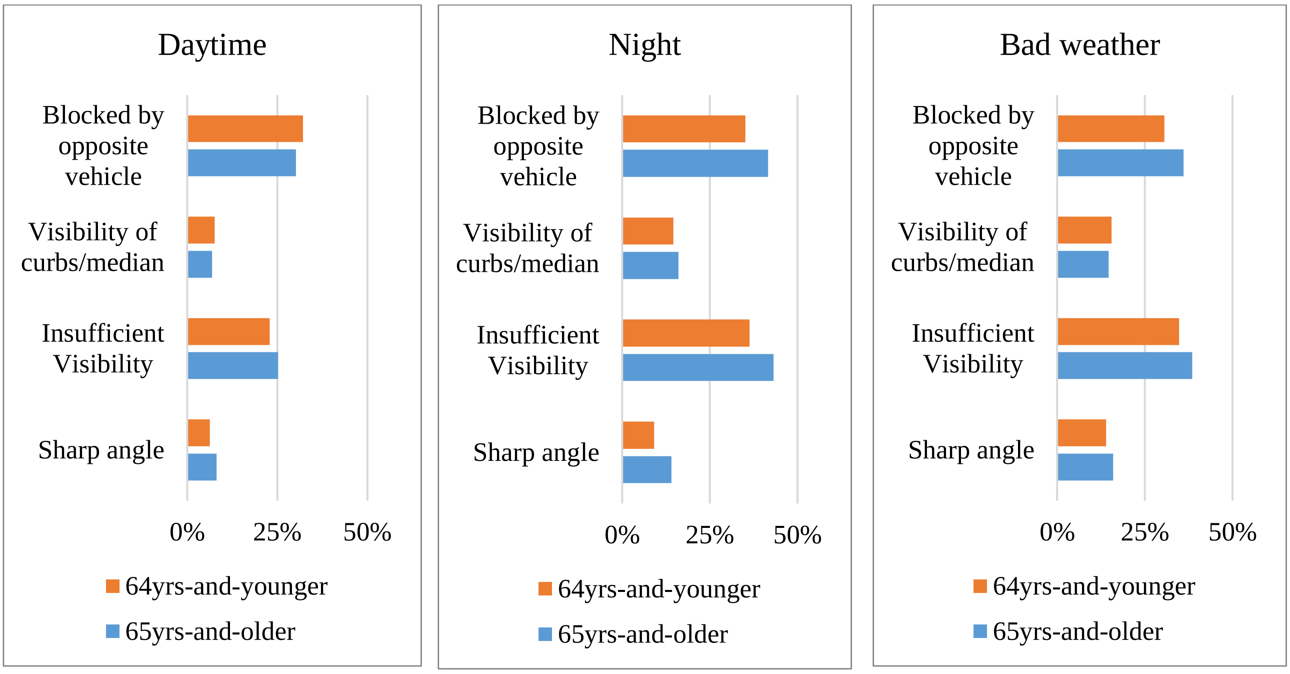

Figure 3.5 Drivers' concerns when making a turn at an intersection in the given conditions

Summary of concerns when making a turn at an intersection

65yrs-and-older drivers report having concerns with opposing vehicle blocking their visibility of oncoming traffic when making a left turn during night-time more than in daytime and bad weather. They also have concerns with insufficient visibility in night-time and bad weather more than in daytime. There were statistically significant differences in concerns by 65yrs-and-older in every concern except when turning into a narrow lane for which there was no statistically significant difference between 65yrs-and-older drivers and 64yrs-and-younger drivers.

3.3.5 Concerns with pavement markings/signs at intersections

Concerns on visibility and legibility of different markings on the pavements were examined next. These include; visibility of edge line, lane marking on the pavement, visibility and legibility of street name signs, visibility and legibility of pedestrian signs and visibility of crosswalks. Visibility and legibility of street name signs, and the visibility of edge lines and lane markings on the pavement were two areas at which 65yrs-and-older drivers showed concerns more than 64yrs-and-younger drivers (Figure 3.6).

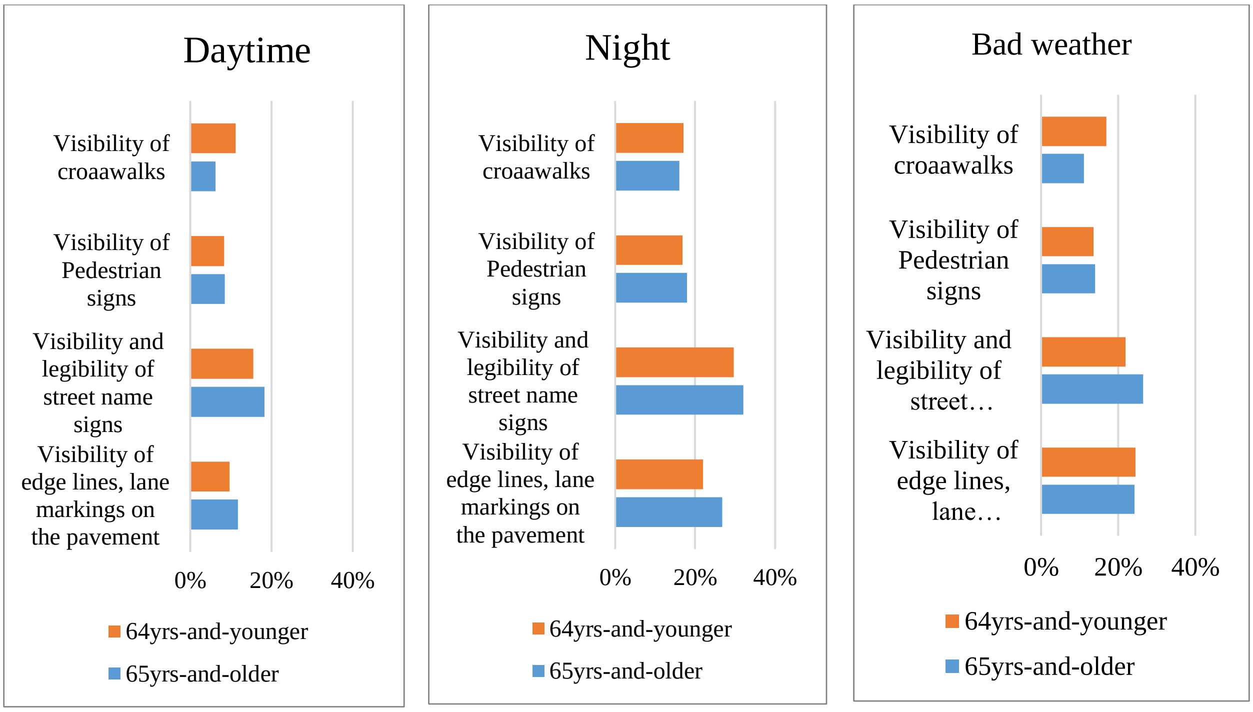

Figure 3.6 Drivers' concerns on pavement markings/signs at intersections in the given conditions

About 18 percent, 27 percent and 26 percent of 65yrs-and-older drivers had concerns on visibility and legibility of street name signs in daytime, night-time and bad weather respectively. With regards to visibility of edge lines, lane markings on the pavement, about 12 percent and 27 percent of 65yrs-and-older had concerns in daytime and night-time respectively. There were no statistically significant differences in concerns between 65yrs-and-older drivers and 64yrs-and-younger drivers.

Summary of concerns with pavement markings/signs at intersections

65yrs-and-older drivers reported that they have concerns with visibility of edge lines, lane markings on the pavement and the visibility and legibility of street name signs during night-time more than in daytime and bad weather. There were no statistically significant differences in any of the concerns.

3.3.6 Concerns when approaching freeway exit

Concerns on what to expect when approaching a freeway exit addressed; visibility of markings at the off ramp, visibility of signs and knowing where the exit goes. In daytime, 65yrs-and-older had more concerns in knowing where the exit goes (14 percent) than the 64yrs-and-younger drivers, they had approximately equal percentage of drivers with concerns in visibility of markings at the off ramp (9 percent) and the visibility of signs (10 percent) as the 64yrs-and-younger. In night-time, 65yrs-and-older had more concerns about the visibility of markings at the off ramp (18 percent) and visibility of signs (17 percent) than the 64yrs-and-younger drivers. They had approximately equal percentage of drivers with concerns in knowing where the exit goes (20 percent) as the 64yrs-and-younger drivers. In bad weather, 65yrs-and-older had approximately equal percentage of drivers with concerns in visibility of markings at the off ramp (15 percent), visibility of signs (14 percent) and knowing where the exit goes (17 percent) as the 64yrs-and-younger drivers. There were no statistically significant differences in concerns by drivers 65yrs-and-older and the 64yrs-and-younger drivers (Figure 3.7).

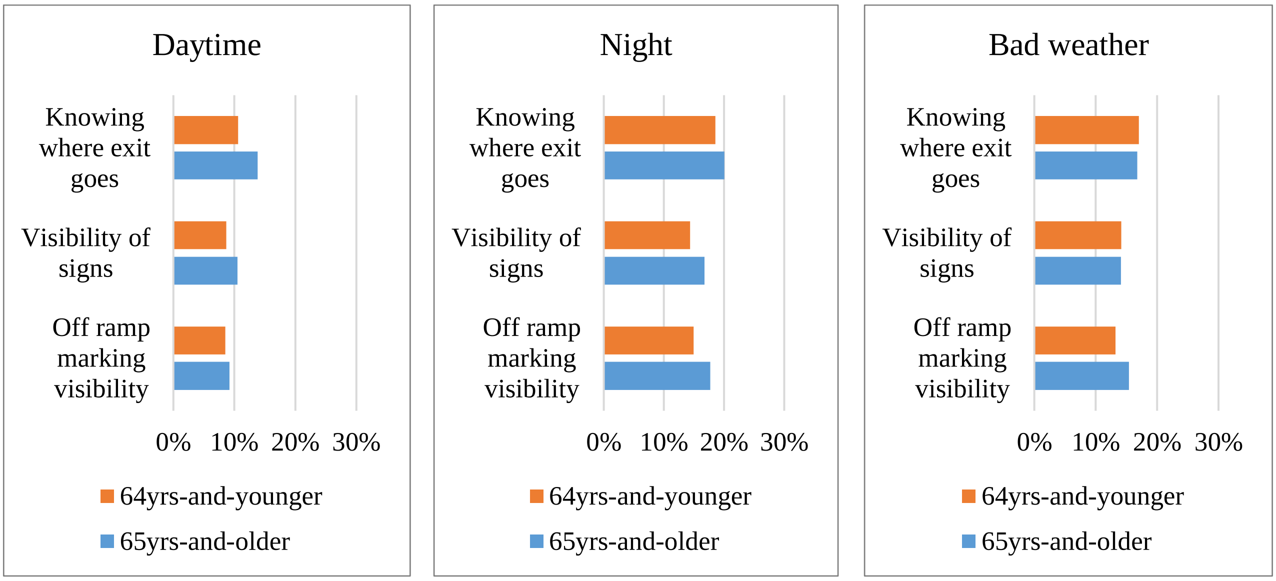

Figure 3.7 Drivers' concerns approaching freeway exit in different conditions

Summary of concerns when approaching freeway exit

65yrs-and-older drivers report having concerns with visibility of markings at the off-ramp, visibility of signs and knowing where the exit goes in night-time driving more than it is in daytime and bad weather. There were no statistically significant difference for any concern by 65yrs-and-older drivers and 64yrs-and-younger drivers.

3.3.7 Concerns when approaching or traversing construction/work zones

Concerns on what to expect when approaching or traversing construction/work zone were next explored. These included: pre-warning of lane closure at construction/work zones, visibility of control devices (e.g. cones) in construction/work zones and maneuvering through the construction/work zone. In daytime, 65yrs-and-older had approximately equal percentage of drivers with concerns in pre-warning of lane closure at construction/work zones (13 percent), visibility of control devices in construction/work zones (8 percent) and maneuvering through the construction/work zone (12 percent) as the 64yrs-and-younger drivers. In night-time, drivers 65yrs-and-older had more concerns in maneuvering through the construction/work zones (19 percent) than the 64yrs-and-younger drivers while there was approximately equal percentage of drivers with concerns in pre-warning of lane closure (19 percent) and the visibility of control devices (15 percent) as the 64yrs-and-younger drivers. In general, there were no statistically significant differences in concerns by 65yrs-and-older and the 64yrs-and-younger drivers for each type of concern examined (Figure 3.8).

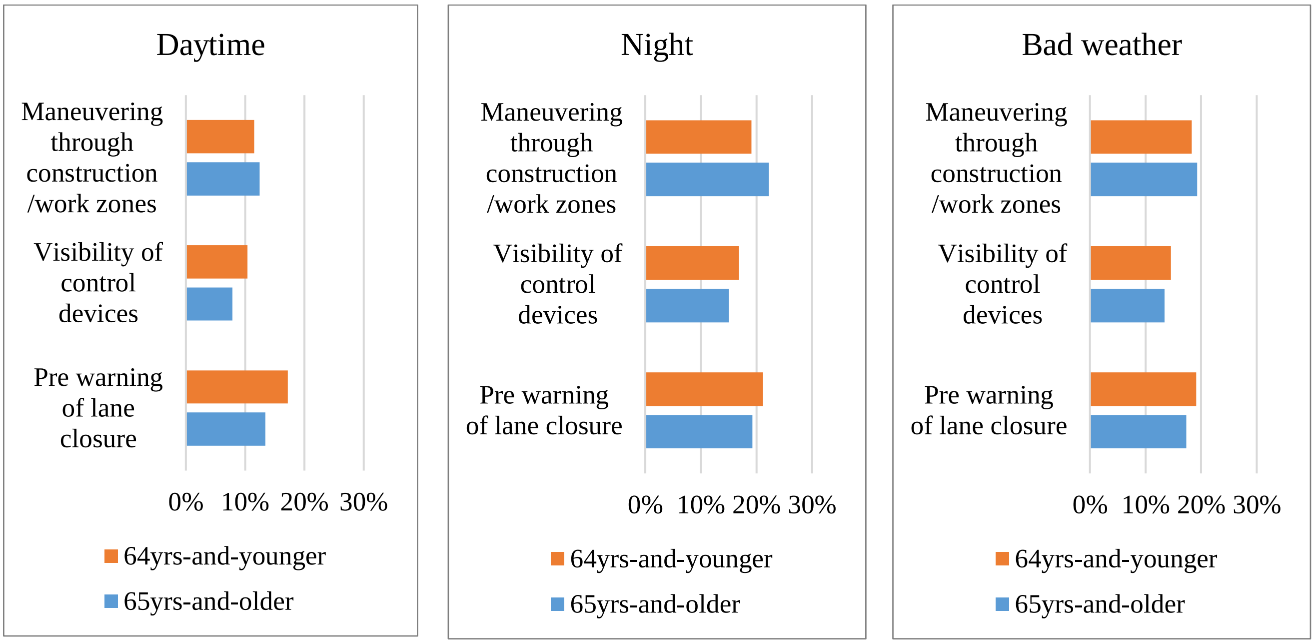

Figure 3.8 Drivers' concerns when approaching or traversing construction/work zones in the given conditions

3.3.8 Concerns when approaching or traversing highway-rail grade crossings

Concerns on what to expect when approaching or traversing highway-rail grade crossings were addressed next. These included; visibility of highway-rail crossing sign (e.g. crossbuck) and identification of a safe path at an unlighted highway-rail grade crossing in rural areas. In daytime, 65yrs-and-older had more concern in identification of a safe path at an unlighted highway-rail grade crossing in rural areas (10 percent) than the 64yrs-and-younger drivers. The visibility of highway-rail crossing sign has approximately equal percentage of drivers with concerns for 65yrs-and-older drivers (6 percent) as the 64yrs-and-younger drivers. In night-time 65yrs-and-older had more concern in identification of a safe path at an unlighted highway-rail grade crossing in rural areas (29 percent) than the 64yrs-and-younger drivers. Approximately equal percentage of drivers with concerns in the visibility of highway-rail crossing sign was observed in 65yrs-and-older drivers (11 percent) as in the 64yrs-and-younger drivers. Bad weather was more of a concern among 65yrs-and-older than the 64yrs-and-younger in identification of a safe path at an unlighted highway-rail grade crossing in rural areas (21 percent). There were only statistically significant differences at 0.05 significance level in concerns about identification of safe path at an unlighted highway-rail crossing in rural area by 65yrs-and-older and the 64yrs-and-younger drivers in night-time and bad weather (Figure 3.9).

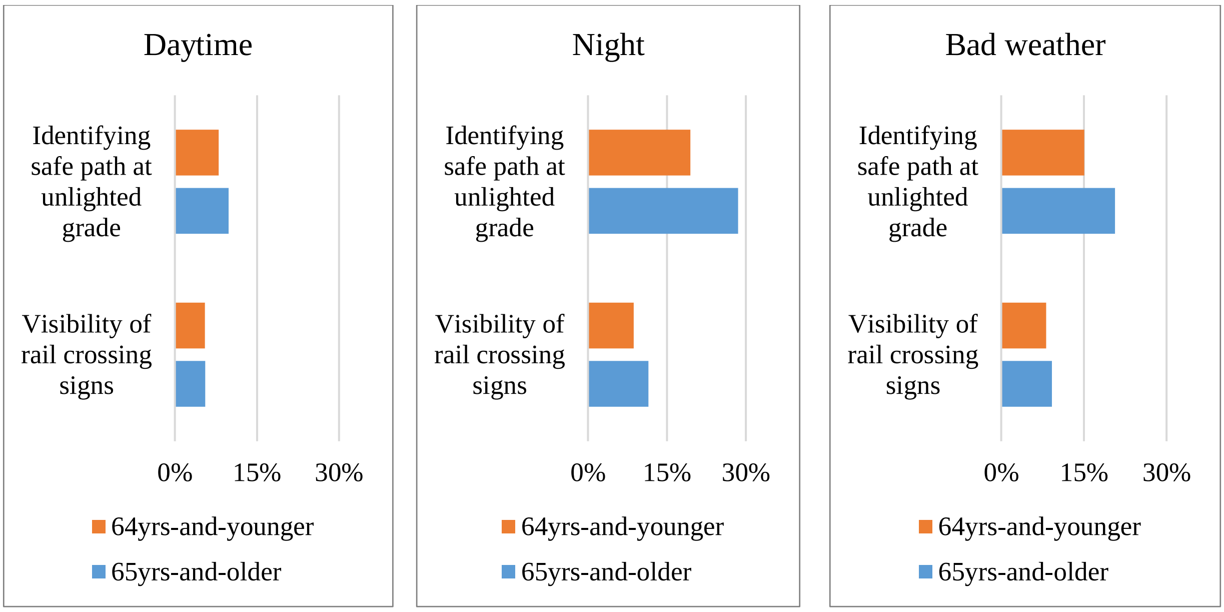

Figure 3.9 Drivers' concerns when approaching or traversing highway-rail grade crossing in the given conditions

Summary of concerns when approaching or traversing highway-rail grade crossing

65yrs-and-older drivers report having concerns with visibility of highway-rail sign and identification of a safe path at an unlighted-rail grade crossing in rural areas in night-time more than in daytime and bad weather. There were statistically significant differences in identification of a safe path at an unlighted-rail grade crossing by 65yrs-and-older and the 64yrs-and-younger drivers in rural areas in night-time and bad weather.

3.3.9 Concerns when making a turn at a traffic signal

Participants were asked if they have concerns when making a left turn at a traffic signal without a green left-turn arrow and visibility of traffic signals. In daytime there were similar percentages of 65yrs-and-older drivers with concerns in turning left at signals without a green left-turn arrow (11 percent) and the visibility of traffic signals (8 percent) as the 64yrs-and-younger. In night-time, 65yrs-and-older drivers were more concerned in turning left at signals without a green left-turn arrow (12 percent) than 64yrs-and-younger. In bad weather, there were similar percentages of drivers with concerns for both 65yrs-and-older and the 64yrs-and-younger drivers (Figure 3.10). There was no statistically significant difference in concerns between 65yrs-and-older drivers and the 64yrs-and-younger drivers for all concerns presented when making a turn at a traffic signal.

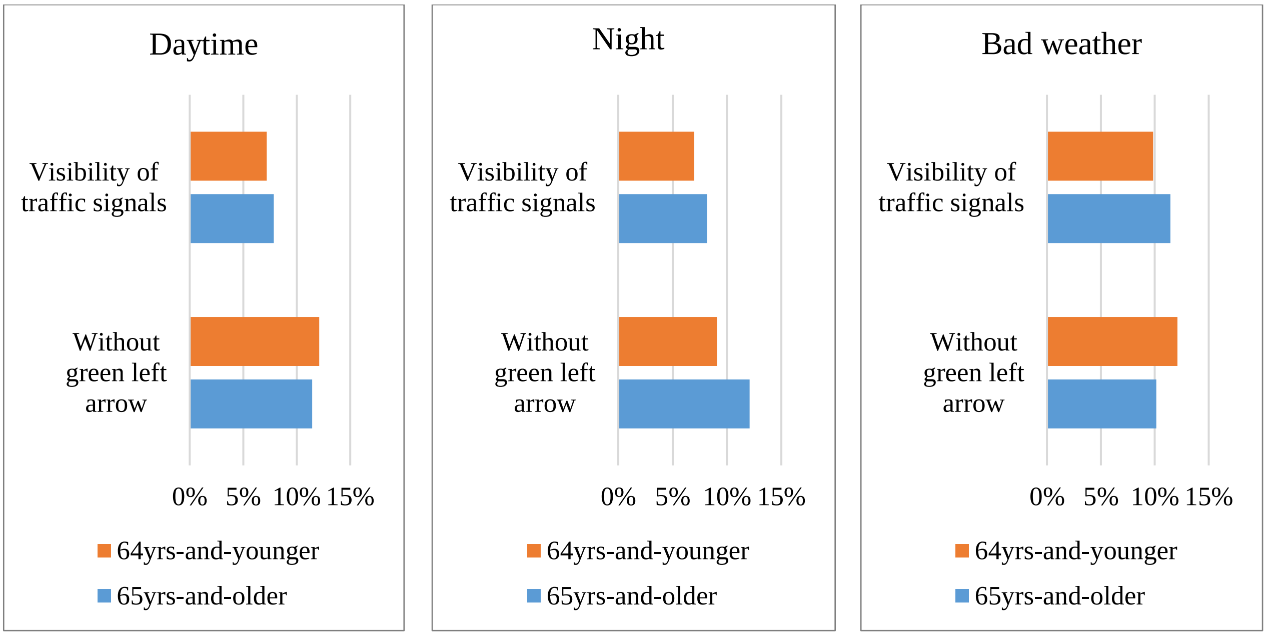

Figure 3.10 Drivers' concerns when turning at traffic signal in the given conditions

Summary of concerns when making a turn at a traffic signal

65yrs-and-older drivers reported to have concerns with turning left at signals without a green left-turn arrow in night-time more than in daytime and bad weather. They also reported having concerns with the visibility of traffic signs in bad weather more than in daytime and night-time. There were no statistically significant differences observed between drivers 65yrs-and-older and 64yrs-and-younger.

3.3.10 Concerns at intersections with a Yield/Stop Sign

With regards to concerns when at intersections with a yield/stop sign, three scenarios were examined: the visibility and/or legibility of the yield sign, visibility and/or legibility of the stop sign and difficulty in judging gaps. Difficulty in judging gap was a concern more in 65yrs-and-older than all drivers in other age group in daytime (7 percent), night-time (10 percent) and bad weather (11 percent). Visibility and/or legibility of the yield sign and visibility and/or legibility of the stop sign were not reported to be much of concerns among the 65yrs-and-older drivers. There were similar percentages of drivers with concerns about visibility and/or legibility of the yield sign and visibility and/or legibility of the stop sign between 65yrs-and-older and the 64yrs-and-younger drivers. The respective percentages of 65yrs-and-older drivers with concerns in visibility and/or legibility of the yield sign in daytime, night-time and bad weather are 8, 9 and 12 percent while for visibility and/or legibility of the stop sign are 8, 8 and 11 percent. This shows that drivers 65yrs-and-older have problem in judging gaps and the problem might be higher during bad weather (Figure 3.11).

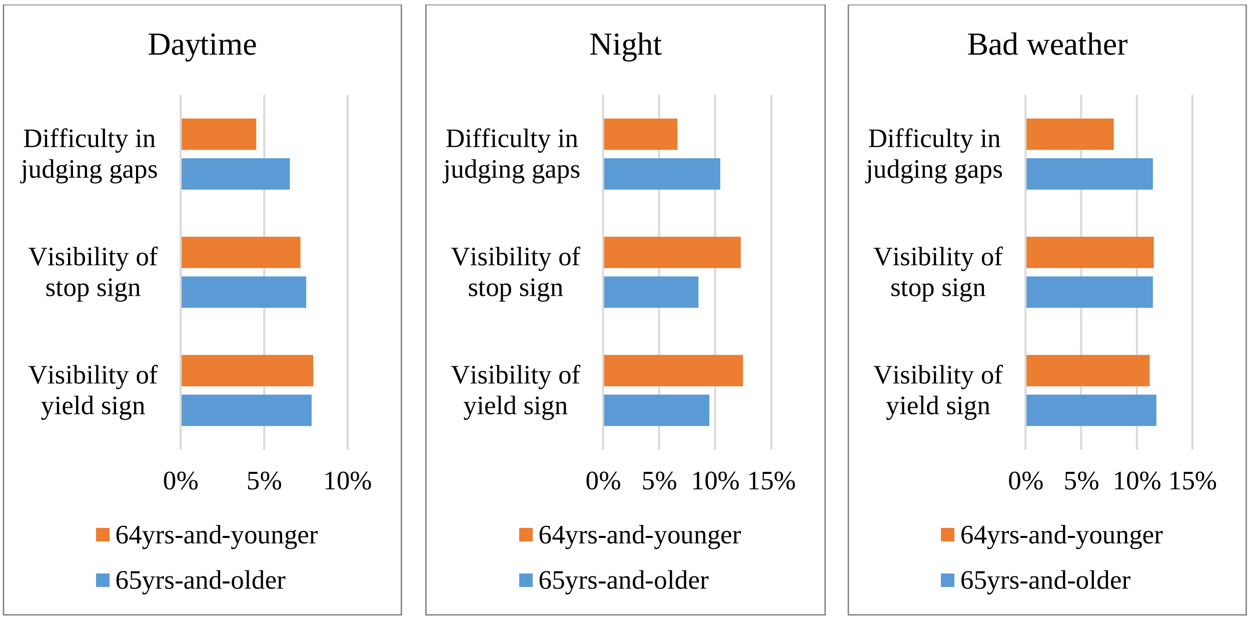

Figure 3.11 Drivers' concerns when turning at traffic signal in the given conditions

There were only statistically significant differences in concerns about difficulty in judging gaps between 65yrs-and-older and the 64yrs-and-younger drivers in night-time (at 0.05 significance level) and bad weather (at the 0.1 significance level).

Summary of concerns at intersections with a Yield/Stop sign

65yrs-and-older drivers reported that they have concerns regarding difficulty in judging gaps. The concerns are higher in bad weather followed by night-time. There were statistically significant differences between drivers 65yrs-and-older and drivers 64yrs-and-younger in concerns about difficulty in judging gaps in night-time and bad weather.

3.3.11 Concern in choosing the proper lane at multilane roundabouts.

Figure 3.12 presents of percentage of drivers with concerns in choosing a proper lane at multilane roundabouts. The graphs show that, the percentage of drivers with concerns is higher among drivers 65yrs-and-older (33 percent) than among the 64yrs-and-younger (17 percent). There was statistically significant difference at 0.05 significance level in concern between drivers 65yrs-and-older and drivers 65yrs-and-younger. This is to say 65yrs-and-older have more concerns in choosing the proper lane at multilane roundabouts than 64yrs-and-younger.

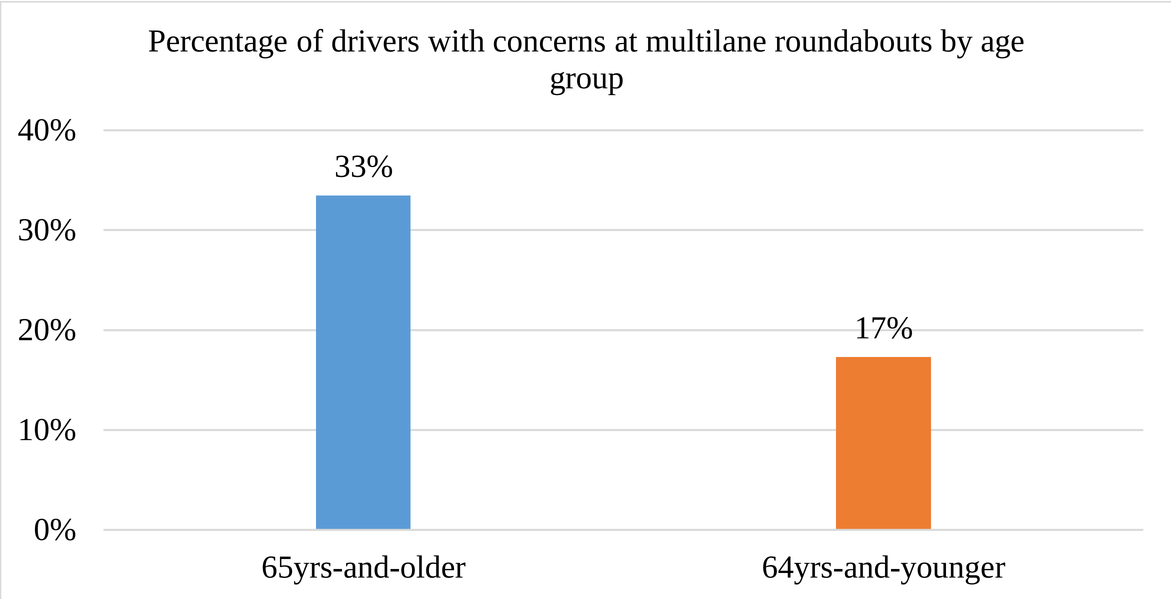

Figure 3.12 Drivers' concerns on multilane roundabout

3.3.12 Road users with physical issues

Figure 3.13 shows percentage of 65yrs-and-older drivers reported to have ever had at least one of the physical issues mentioned. Hearing was the leading problem reported by drivers 65yrs-and-older of all the physical issues interviewed. In addition, drivers 65yrs-and-older reported to have physical issues in head/neck mobility more than 64yrs-and-younger drivers while an approximately equal percentage of drivers was observed between 65yrs-and-older and the 64yrs-and-younger drivers with physical issues in vision and focused attention.

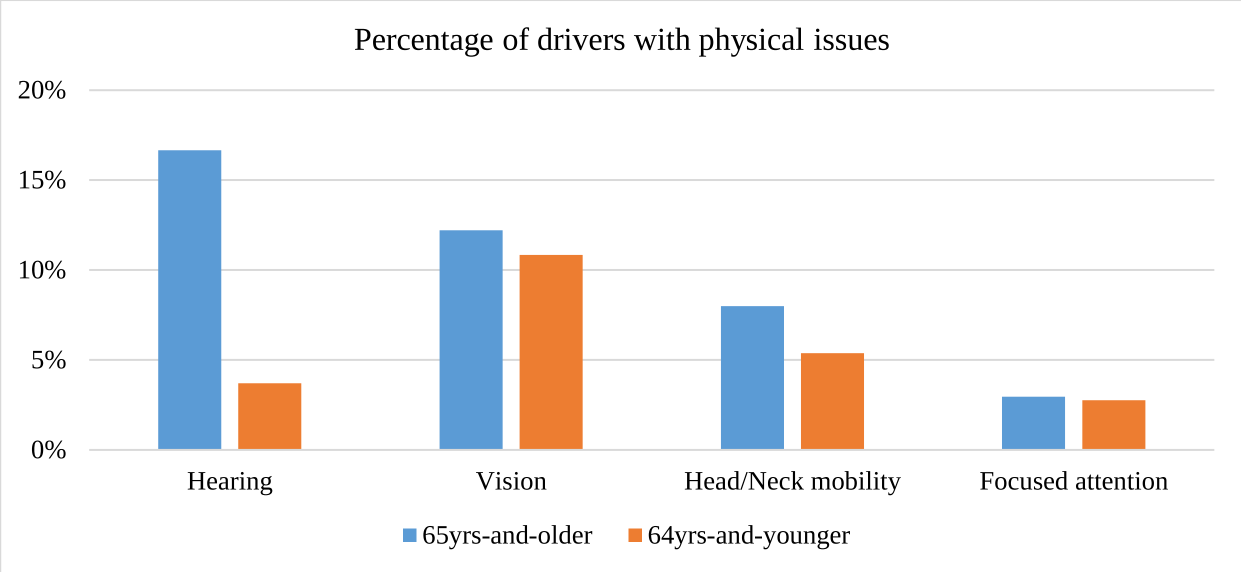

Figure 3.13 Drivers who have had physical issues

3.3.13 Concerns by pedestrian road users

When participants were asked on different concerns related to when they use roadways as pedestrians. Findings on pedestrian-related concerns are important because it has been reported earlier in this chapter to be among the most common and available transportation alternatives in different regions. Questions related to pedestrian as a road user were asked and their results are documented below:

How often do you run out of time when crossing an intersection?

Due to their age, 65yrs-and-older may have a lower walking speed than other drivers, thus they are vulnerable to non-motorized crashes at any roadway section however, intersection was an area of concentration for this question. Running out of time when crossing was not reported to be more of a concern to 65yrs-and-older than among people 64yrs-and-younger. About 5 percent of 65yrs-and-older (compared to 9 percent of people 64yrs-and-younger) reported to always run out of time when crossing an intersection, 39 percent of people 65yrs-and-older (compared to 44 percent of people 64yrs-and-younger) reported to sometimes run out of time and about equal percentage (44 percent) of people 65yrs-and-older and 64yrs-and-younger people reported to never run out of time when crossing an intersection.

How often does a yielding vehicle at a roundabout block your crosswalk?

Roundabouts are said to reduce severe crashes due to their nature of reducing vehicle speed for effective maneuvering. However, these facilities are also said to impose difficulties in how lanes are to be properly used when entering, navigating through, and exiting the roundabout. Yielding is a key maneuver when entering and exiting a roundabout, thus the driver's consideration to pedestrian is of important. As it was for the crossing at the roundabout, 65yrs-and-older did not report to have much of the problems as compared people 64yrs-and-younger. About 2 percent of people 65yrs-and-older (compared to 9 percent of 64yrs-and-younger) reported to always have their crosswalk blocked by a yielding vehicle; 22 percent of 65yrs-and-older (compared to 28 percent of 64yrs-and-younger) reported to sometimes have their crosswalk blocked by a yielding vehicle; and 23 percent of 65yrs-and-older (compared to 27 percent of 64yrs-and-younger) reported to never had their crosswalk blocked by a yielding vehicle.

How important is the presence of a pedestrian refuge island when crossing wider streets?

As expected, more than 60 percent of every participants' age groups reported the presence of pedestrian refuge island to be very important, about 25 percent said slightly important and about 10 percent said it is not important. Appendix 9.1.1 provides responses by age group.

3.4 Summary of the survey of road users

In conclusion, drivers age 65yrs-and-older reported personal car as a driver, personal car as a passenger, bicycle and walking as the most frequently used modes of transportation. In addition, these drivers tend to avoid driving in many conditions more than any other age group. They also have concerns in different sections of the roadway with different features at different time of the day and condition, from drivers of other age groups. However, night-time poses a dangerous condition to them in every situation queried.

3.5 Identification of alternative transportation options

According to the 2010 US Census, Michigan has nearly 14 percent of the residents being age of 65 or older. Like the rest of the country the reality is the population is getting older due to advances in medicine and lifestyle, as well as the demographics of the baby boomer phenomenon, the number of older drivers are expected to increase every year. There are several statewide groups that work together such as Senior Mobility Work Group under the Governor's Traffic Safety Advisory Commission, Area Agency on Aging, Regional Elder Mobility Alliance–(REMA) to meet the challenges of older population by trying to improve safety and mobility of older drivers.

Michigan has an extensive senior transportation network. Every county has some form of senior transportation service which includes public transit providers, specialized service agencies, or volunteer driver services, all focused on keeping Michigan's aging population mobile. There also are a number of very innovative programs across the state demonstrating daily that senior transportation can be successfully delivered. Details can be found in the Michigan Senior Mobility and Safety Action Plan for 2016-2018 (available at http://www.michigan.gov/documents/msp/Action_Plan-SMWG-7-15-15-final_495134_7.pdf).

As a part of this research survey was conducted asking older adults of available transportation alternatives and what modes they use and how frequent. According to the results of this survey driving a personal car as a driver, personal car passenger, public transit, walking or biking are the major modes used by surveyed older adults. Furthermore, an inventory of transit transportation options available in Michigan was established. Figure 3.14, compiled by MDOT, shows various types of local transit options available in each county. As mentioned earlier every county has some form of senior transportation options that provides mobility to senior population, which includes:

- Fixed routes services in heavy populated counties
- Flexible schedules
- Dial-a-ride at city level
- Demand response for county services
- Intercity buses
- Train
- Other hire services
- Ferry

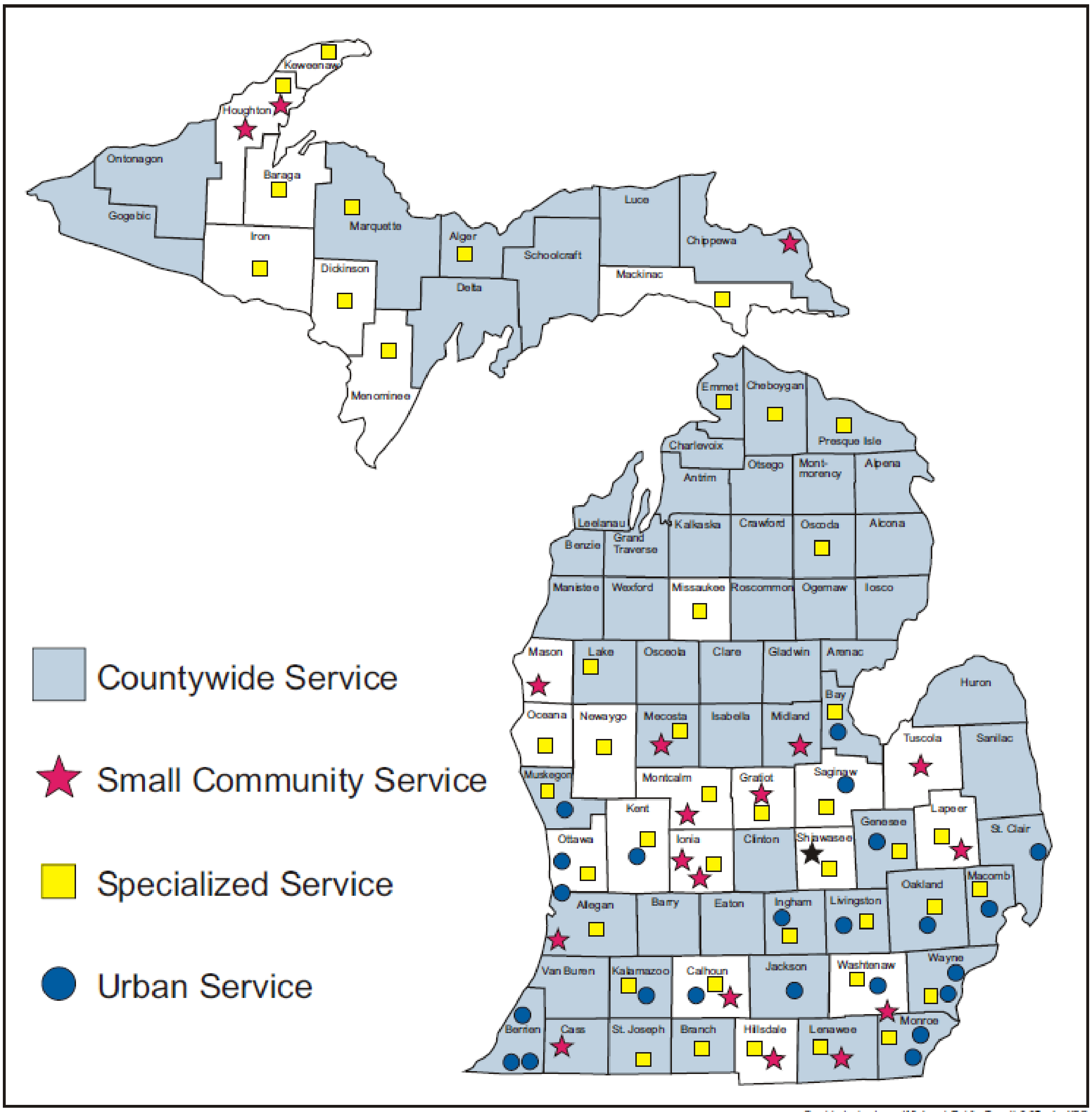

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Figure 3.14 Local transit options available in each county in Michigan

According to MDOT, there are around 79 transportation agencies serving Michigan residents, including 21 urbanized transit organizations. This list can be found at http://www.michigan.gov/mdot/0,1607,7-151-9625_21607-31837--,00.html. All counties in Michigan have at least one form of public transit available. Many of the counties have specialized services. The "Specialized Services" program provides operating assistance to private, nonprofit agencies, and public agencies providing transportation services primarily to seniors and individuals with disabilities. Some counties offer service with specific bus stops, while others offer dial-a-ride service for community level or demand-response at county level. Additionally, an intercity bus map is also available on MDOT website (http://www.michigan.gov/mdot/0,4616,7-151-11056---,00.html).

Other for hire services such as taxis or web-based services such as Uber or Lyft are also available in many parts of the state. In some cases, such as in the Escanaba area, taxi services are being actively coordinated and integrated with local transit. Whereas in other parts of the state, services such Uber and Lyft as well as traditional taxi services provide enhanced mobility options for senior drivers where transit may not be a feasible option. As the market penetration for these other hire services continues to increase, enhanced travel options for seniors will also increase.

MDOT has also developed a new website, Mi Commute (http://www.michigan.gov/micommute) which provides detailed statewide information, links, and options to many local organizations that provide various resources for travel in various areas. MDOT and its partners also created various multi-county regional road and trail bicycling maps (http://www.michigan.gov/mdot/0,4616,7-151-9615_11223-146053--,00.html) that shows road surface type, traffic volume range, condition of shared use paths, recreational facilities, points of interest, amenities and other facilities for residents. In addition to that walking maps are also available on MDOT website (http://www.michigan.gov/mdot/0,4616,7-151-11151---,00.html).

In addition to options outlined in the map in Figure 3.14, other services are also available for older adults as listed below:

- Charter services: http://www.michigan.gov/micommute/0,4623,7-214-53572_53755---,00.html
- Taxi
- Ridesharing: http://www.michigan.gov/mdot/0,4616,7-151-9615_11228---,00.html
- Transitapp (https://transitapp.com): Transit is simplifying commute in three major cities in Michigan, Ann Arbor, Detroit and Grand Rapids. It helps commuters to navigate cities by providing nearby transit options, and step-by-step navigation. You can also plan a trip and set reminders through their app. They work with various partners such as transit agencies, Bikeshare, Carshare and On-Demand.
- Uber app: https://www.uber.com/ride/
- Lyft app: https://www.lyft.com/app

4 Analysis of Michigan's Older Adult Crashes

4.1 Introduction

This chapter documents analysis of Michigan's five year (2010-2014) crash data to identify any associations with roadway features. The 65yrs-and-older-related crashes were sorted out from total crashes using driver's age information provided in the crash data. The 65yrs-and-older-related crashes and the rest of the crashes were compared based on different roadway attributes such as weather condition, lighting condition, roadway condition, roadway type, speed limit, number of lanes, access control and traffic control. For all these attributes, multiple-vehicle crashes and single-vehicle crashes were analyzed separately. The analysis was then expanded to individual drivers who were involved in those crashes. Driver's attributes such as injury severity, driving while intoxicated with alcohol or drugs and their actions prior to crash occurrence were investigated for single-vehicle and multiple-vehicle crashes involving drivers 65yrs-and-older.

A more in-depth analysis using crashes which involved one 65yrs-and-older driver and one 64yrs-and-younger driver was conducted to discern locations and their respective roadway features that are more problematic to the 65yrs-and-older drivers. Under normal circumstances each driver has a 50 percent chance of being responsible for the crash (i.e., committing hazardous action) when two vehicles are involved. The location under the study was considered problematic to 65yrs-and-older drivers if the chances of the 65yrs-and-older drivers to commit hazardous action was greater than 50 percent. This analysis provided an additional advantage of controlling for exposure measure as we do not necessarily need to know how many 65yrs-and-older drivers or other drivers were on a given facility at the time of crash.

Figure 4.1 shows the percentage of crashes involving drivers 65yrs-and-older and the percentage of 65yrs-and-older population over the past ten years in Michigan. Crashes involving drivers 65yrs-and-older increased from 11.4 percent in 2005 to 16.4 percent in 2014. During the same period, the percentage of 65yrs-and-older population increased from 12 percent to 15.5 percent. Interestingly, after 2009 the percentage of these crashes was increasing at higher rate compared to its population.

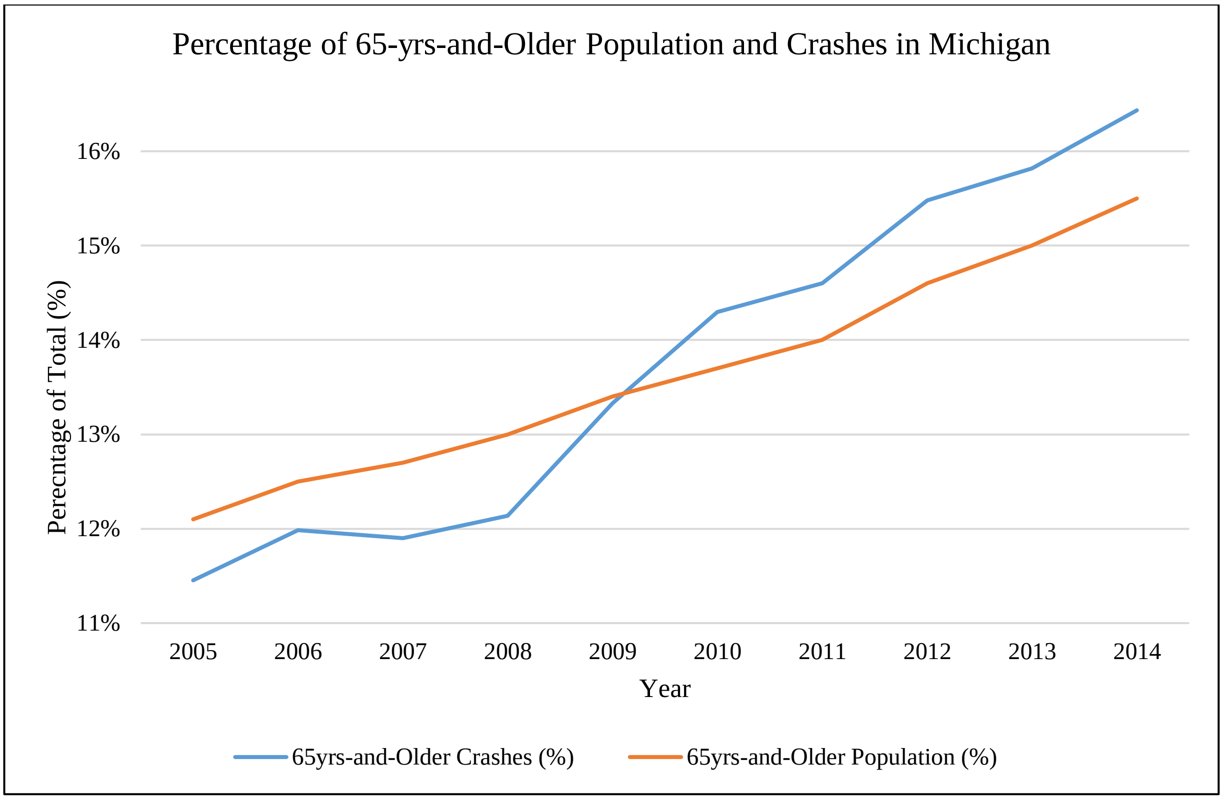


Figure 4.1 Trend of 65yrs-and-older driver-related crashes over the past ten years

4.2 Effect of lighting condition

Table 4.1 shows the distribution of crashes by age group by different lighting condition. Overall, more 65yrs-and-older-related crashes occurred during the daylight (76 percent) compared to the rest of the crashes (58 percent). This is correlated to the results obtained from the survey that shows 65yrs-and-older drivers had a higher tendency of avoiding driving at night compared to the 64yrs-and-younger drivers. Majority of single-vehicle crashes occurred in dark-unlighted crashes with 64yrs-and-younger drivers having a higher proportion (43 percent) compared to 65yrs-and-older drivers (37 percent).

Table 4.1 Distribution of crashes by lighting condition

	Multiple vehicles crashes		**Single vehicle crashes**		**All crashes**	
	Older-related crashes	*Non-older related crashes*	*Older-related crashes*	*Non-older related crashes*	*Older-related crashes*	*Non-older related crashes*
Dark-Lighted	8%	15%	5%	9%	7%	13%
Dark-Unlighted	4%	7%	37%	43%	11%	22%
Dawn	1%	2%	5%	6%	2%	4%
Daylight	85%	72%	48%	37%	76%	58%
Dusk	2%	2%	5%	3%	2%	3%
Other/unknown	0%	1%	1%	1%	1%	1%

4.3 Roadway characteristics

Table 4.2 shows the distribution of both crashes involving drivers 65yrs-and-older and the rest of the crashes by different roadway attributes. The following can be learned from the results:

- The 65yrs-and-older drivers were more likely to have issues when using multilane roadway compared to other drivers. About 22 percent of the 65yrs-and-older drivers-related crashes occurred on roadway with more than 4 lanes (2 lanes in each direction), compared to 16 percent for crashes that did not involve drivers 65yrs-and-older.
- Divided highway with barrier may have safety benefits to the 65yrs-and-older drivers as there were slightly fewer 65yrs-and-older-related crashes (7 percent) compared to the rest of the crashes (10 percent).
- The 65yrs-and-older drivers were more likely to have more problems on roadway with no access control (83 percent) compared to the 64yrs-and-younger drivers (79 percent).

Table 4.2 Crash distribution by different roadway attributes

		Multiple vehicles crashes		**Single-vehicle crashes**		**All crashes**	
Attribute	Element	*Older-related crashes*	*Non-older related crashes*	*Older-related crashes*	*Non-older related crashes*	*Older-related crashes*	*Non-older related crashes*
Number of lanes	1 lane	2%	3%	2%	3%	2%	3%
	2 lanes	38%	41%	82%	79%	48%	57%
	3 lanes	15%	16%	6%	7%	13%	12%
	4 lanes	18%	17%	6%	6%	15%	13%
	>4 lanes	28%	24%	4%	4%	22%	16%
Posted speed limit	15-25mph	18%	23%	6%	7%	15%	17%
	30-40mph	35%	31%	8%	8%	29%	22%
	45-55mph	41%	37%	72%	68%	48%	49%
	>55mph	6%	9%	13%	17%	8%	12%
Roadway type	Divided Hwy with Barrier	8%	10%	7%	10%	7%	10%
	Divided Hwy without Barrier	9%	9%	9%	9%	9%	9%
	Non-Traffic	1%	2%	2%	2%	1%	2%
	Not Physically Divided	78%	73%	82%	77%	79%	75%
	One-Way Traffic	4%	5%	1%	2%	4%	4%
Access control	Full access control (only ramp entry/exit)	11%	14%	14%	18%	12%	16%
	No access control	83%	79%	83%	79%	83%	79%
	Non-traffic area	1%	2%	2%	2%	1%	2%
	Partial access control	4%	4%	1%	1%	4%	3%

4.4 Driver characteristics

Table 4.3 provides a comparison of drivers who were involved in crashes in Michigan over a period of five years (2010-2014). The results suggest that:

- The 65yrs-and-older drivers are more likely to sustain higher injury severity when a crash occurred compared to the 64yrs-and-younger drivers for both single-vehicle and multiple vehicles crashes.
- The 64yrs-and-younger drivers are more likely to be intoxicated with alcohol or drugs compared to the 65yrs-and-older drivers, especially in single-vehicle crashes.
- More 65yrs-and-older drivers (14 percent) were found to be turning left prior to crash occurrence compared to the rest of the drivers (10 percent). This suggests that turning left may be difficult for 65yrs-and-older drivers.

Table 4.3 Distribution of crashes by different driver characteristics

		Multiple vehicles crashes		**Single vehicle crashes**		**All crashes**	
Attribute	Element	*65yrs-and-older*	*Less-than-65yrs*	*65yrs-and-older*	*Less-than-65yrs*	*65yrs-and-Older*	*Less-than-65yrs*
Injury severity	Fatal	0%	0%	0%	0%	0%	0%
	Suspected serious	1%	1%	1%	1%	1%	1%
	Suspected minor injury	3%	2%	3%	4%	3%	3%
	Possible injury	9%	8%	6%	7%	8%	8%
	No injury	87%	89%	88%	87%	87%	88%
Alcohol involvement	Alcohol/Drug	1%	2%	2%	6%	1%	3%
	No-Alcohol/Drug	99%	98%	98%	94%	99%	97%
Driver action prior to crash	Going Straight Ahead	43%	46%	76%	76%	45%	49%
	Turning Left	14%	10%	8%	7%	14%	10%
	Turning Right	5%	4%	6%	6%	5%	4%
	Other	39%	40%	11%	12%	36%	37%

4.5 Injury severity sustained by the 65yrs-and-older drivers in rural and urban areas

Injury severity of 65yrs-and-older drivers in rural and urban areas were compared. There was no difference observed for no injury (PDO) crashes whereby both locations had 87 percent of 65yrs-and-older-related crashes as PDO. The 65yrs-and-older drivers who sustained fatal, serious and minor injury were more in rural areas compared to urban areas as shown in Figure 4.2.

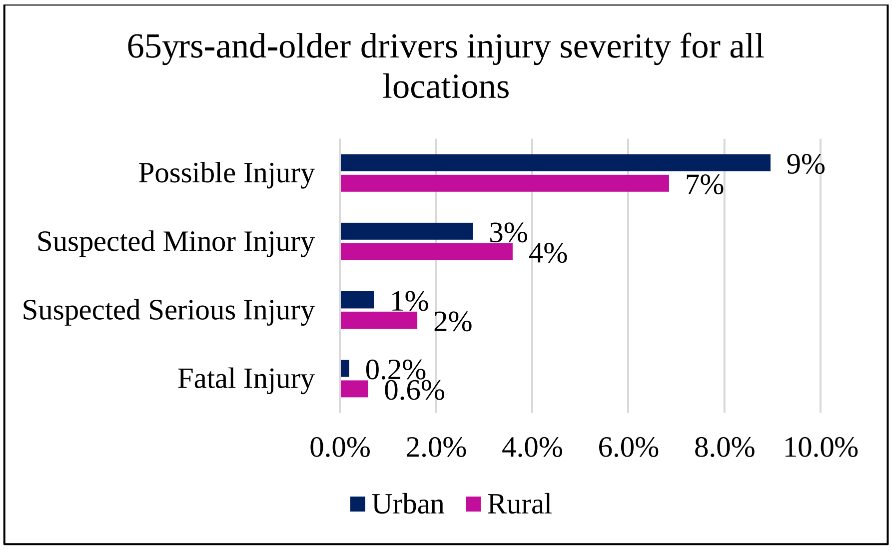


Figure 4.2 65yrs-and-older driver injury severity in rural and urban area

4.6 Crash distribution by locations defined by MDOT

Comparison was made on the distribution of the 65yrs-and-older-related crashes at different locations as defined by MDOT as shown in Figure 4.3. Intersections were the leading location with higher percentage of the crashes involving drivers 65yrs-and-older. About 56 percent of these crashes were at intersections. Interchanges were the lowest, with only 9 percent. The lower percent of interchange crashes involving drivers 65yrs-and-older may be related to the fact that the 65yrs-and-older drivers are more likely to avoid driving on higher speed roads.

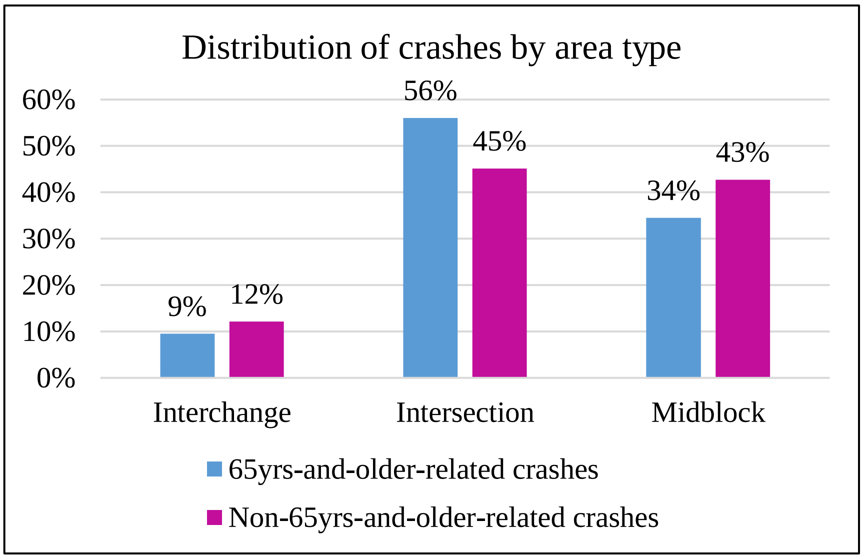


Figure 4.3 Distribution of crashes by location as defined by MDOT

4.7 Distribution of crashes involving 65yrs-and-older driver by number of units

Table 4.4 presents proportion of 65yrs-and-older-related crashes by number of drivers who were involved in a crash. For all crashes involving drivers 65yrs-and-older, 60 percent involved one 65yrs-and-older driver and one 64yrs-and-younger driver. About 28 percent were single-vehicle crashes. The rest were combination of multiple number of 65yrs-and-older drivers and 64yrs-and-younger drivers.

Table 4.4 Percentage of 65yrs-and-older-related crashes by number of involved parties

		Number of 64yrs-and-younger drivers			
		0	**1**	**2**	**3**
Number of 65yrs-and-older drivers	**1**	28%	60%	5%	1%
	2	5%	1%	0%	0%

Subsequent analyses focused on two-vehicle crashes and compared the percentage of 65yrs-and-older drivers and 64yrs-and-younger drivers who were responsible for the crash (i.e., committed hazardous action) at different locations. Table 4.5 provides locations where the 65yrs-and-older-related crashes were investigated in relation to roadway features. Locations where the 65yrs-and-older drivers were more likely to commit hazardous action as compared to 64yrs-and-younger drivers, were determined. Further descriptive analysis was then conducted to discern specific hazardous actions that were committed for those locations where drivers 65yrs-and-older were overrepresented.

Table 4.5 Design elements at different roadway location

Location	Design elements
Intersection	Intersection skewness
	Left turn offset
	Raised Median
Midblock	Driveways away from intersection
	Median crossover
	Transition areas (lane drop or addition)
	Curved segments
	Parking areas along the roadside
	Auxiliary passing lane
Interchange	Freeway entrance or exits

4.7.1 Analysis of driver responsibility for a crash by locations defined by MDOT

For all locations, the 65yrs-and-older drivers were more likely to commit hazardous action as compared to other drivers when only two vehicle were involved as shown in Figure 4.4. The difference was higher at intersection where 54 percent of the time, the 65yrs-and-older drivers were responsible for the crash they were involved in.

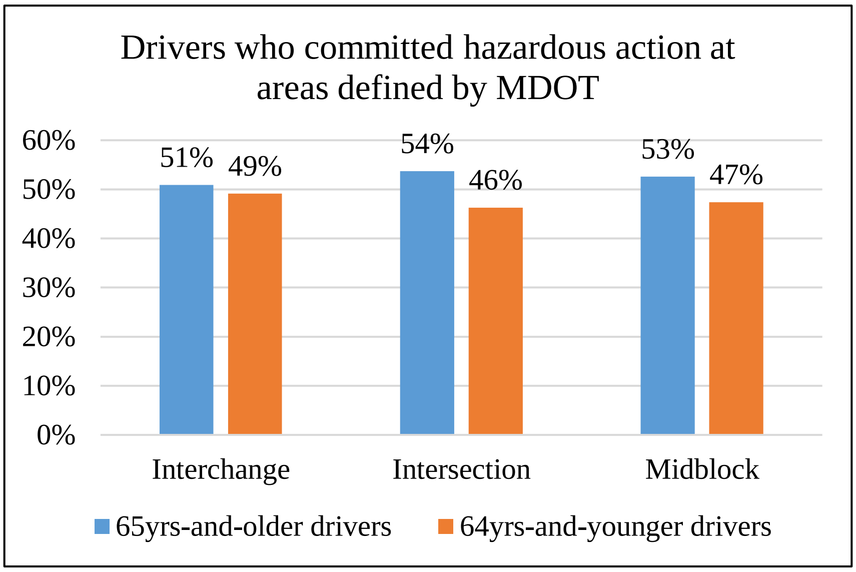


Figure 4.4 Percent of drivers who committed hazardous action for two-vehicle crashes involving one 65yrs-and-older driver and one 64yrs-and-younger driver

4.7.2 Analysis of driver responsibility for a crash in rural and urban areas

The percentage of drivers 65yrs-and-older who committed hazardous actions were compared with respect to rural and urban environment as shown in Figure 4.5. For each location, the 65yrs-and-older drivers had more than 50 percent chance of being responsible for crash compared to the 64yrs-and-younger. However, the percentage of the 65yrs-and-older drivers who were at fault was slightly higher in rural areas compared to urban areas.

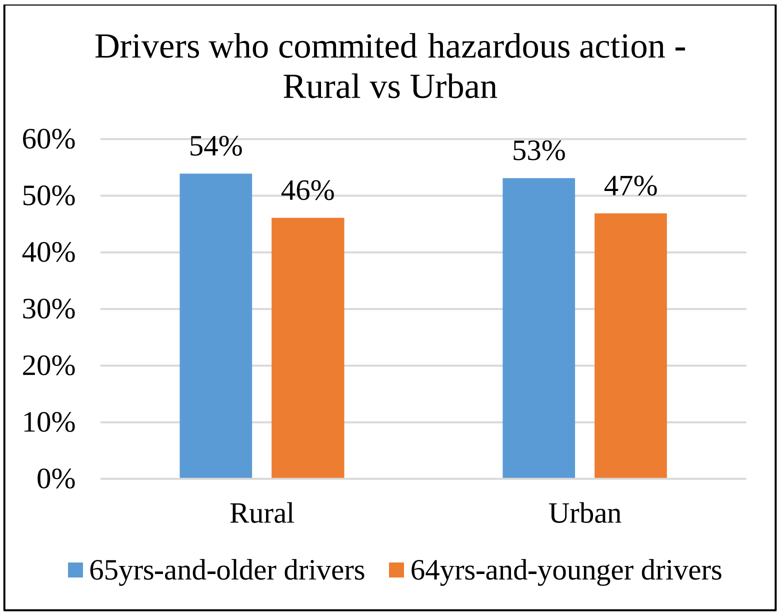
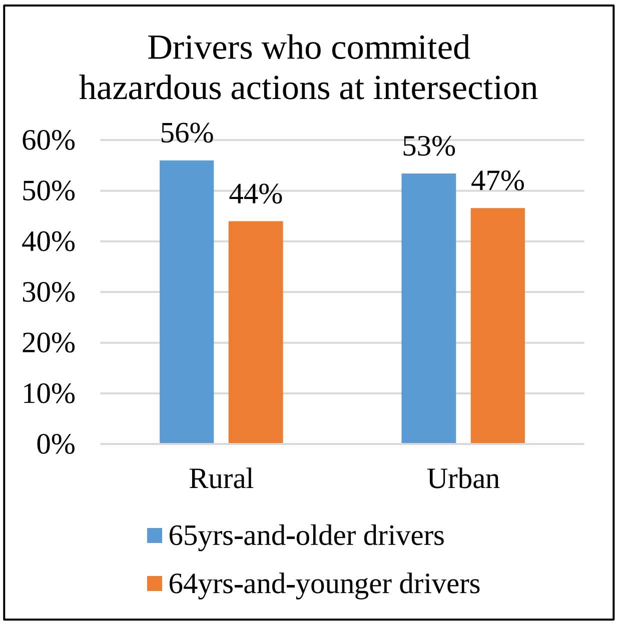


Figure 4.5 Drivers who committed hazardous action in rural and urban areas

The 65yrs-and-older-related crashes in rural and urban areas were then analyzed by specific locations as shown in Figure 4.6. Rural intersections had more 65yrs-and-older drivers who committed hazardous actions than urban intersections when compared to 64yrs-and-younger drivers. At rural midblock locations, drivers involved in 65yrs-and-older-related crash had equal chance of being responsible for a crash. In urban midblock locations more than 50% of 65yrs-and-older drivers committed hazardous actions.



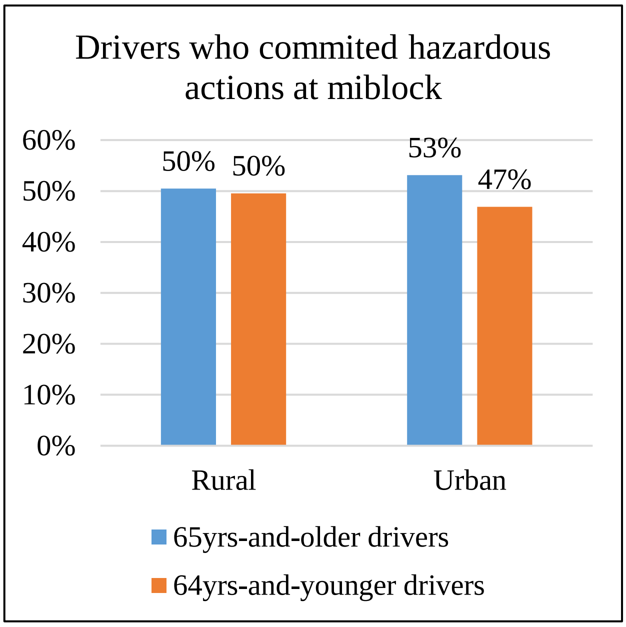


Figure 4.6 Drivers who committed hazardous action in rural and urban areas by location

4.8 Analysis of Intersection Crashes Involving Drivers 65yrs-and-older

Five-year 65yrs-and-older-related crashes that occurred at intersection were analyzed based on the crash type, driver's movement prior to the crash and driver's hazardous actions. Crash types that involved multiple vehicles and were overrepresented at intersections include angle crashes, rear end crashes, and sideswipe same direction. Figure 4.7 shows percentage of drivers who committed hazardous actions at intersection by crash type while crash type with 65yrs-and-older drivers having more than 50 percent chance of committing hazardous actions at intersection includes angle crashes, head-on-left turn, sideswipe-opposite direction and sideswipe-same direction. Higher percentage was observed for head-on left turn with about 64 percent of 65yrs-and-older drivers who committed hazardous actions as compared to the 64yrs-and-younger drivers. Appendix 9.2.1 shows hazardous actions committed by 65years-and-older drivers by action prior to a crash at intersections.

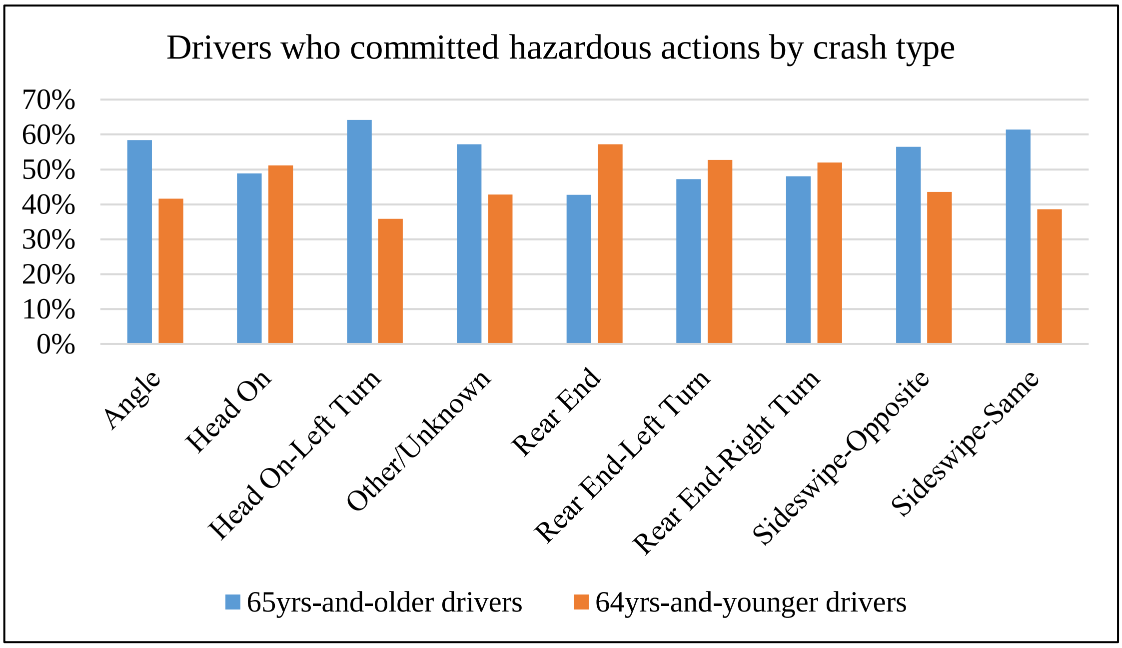


Figure 4.7 Percentage of drivers who committed hazardous action by crash type at intersection

4.8.1 Intersection-related crashes by traffic control

The analysis was further subdivided by intersection traffic control. The 65yrs-and-older drivers who committed hazardous action were more than 50 percent for both STOP-controlled intersections and signal-controlled intersections. By comparing the two traffic controls, analysis showed that the 65yrs-and-older drivers were more likely to be responsible for crashes that occurred at STOP-controlled intersections as shown in Figure 4.8.

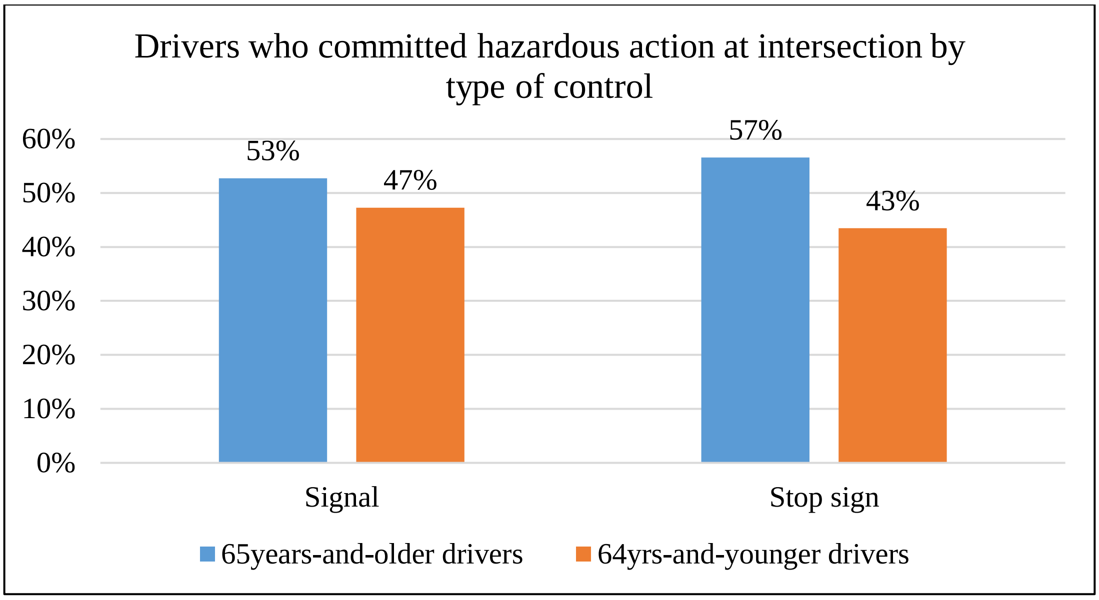


Figure 4.8 Percentage of drivers who committed hazardous action by traffic control

4.8.2 Analysis of the 65yrs-and-older-related crashes at STOP-controlled intersections

At STOP-controlled intersections, turning maneuver was the problem for 65yrs-and-older drivers as indicated in Figure 4.9. Majority of the 65yrs-and-older drivers had issues when turning left, with 65 percent committing hazardous action as compared to the 64yrs-and-younger drivers. Failure to yield was overrepresented for 65yrs-and-older drivers who were turning left.

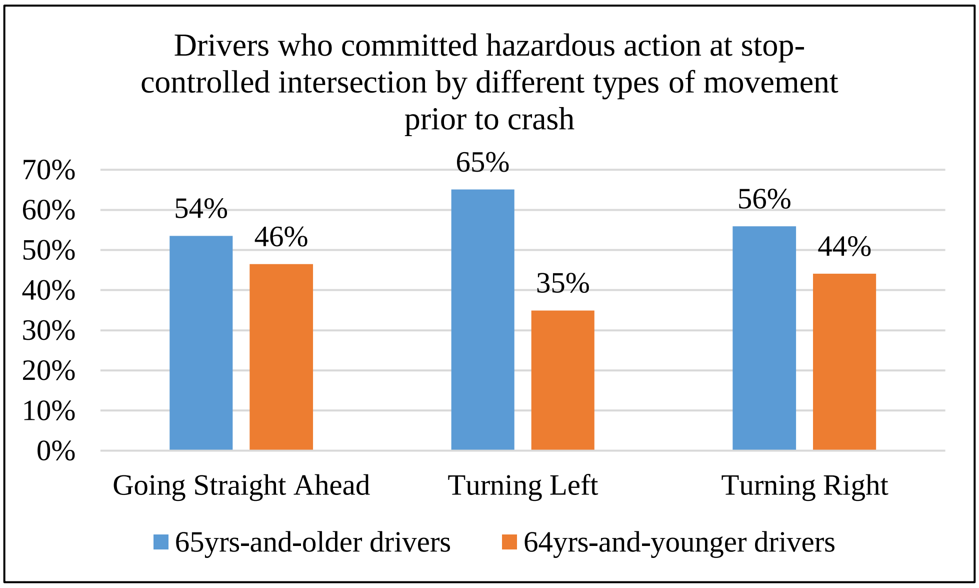


Figure 4.9 Percent of drivers who committed hazardous action at stop-controlled intersection

4.8.3 Analysis of the 65yrs-and-older-related crashes at signal-controlled intersections

Figure 4.10 presents a comparison of the 65yrs-and-older drivers and the 64yrs-and-younger drivers by their respective movements prior to a crash at signal-controlled intersections. Both turning right and turning left had higher proportion of the 65yrs-and-older driver being responsible for a crash as compared to the 64yrs-and-younger drivers. Specific hazardous action that was overrepresented for both turning movements was failure to yield. The problem might be largely associated with relatively higher amount of traffic at signalized intersection, thus making it difficult for the 65yrs-and-older drivers to judge the gap when making a permitted turn. In addition to making a permitted left turn, failure to yield can also be associated with the tendency of drivers to make a turn during the amber time.

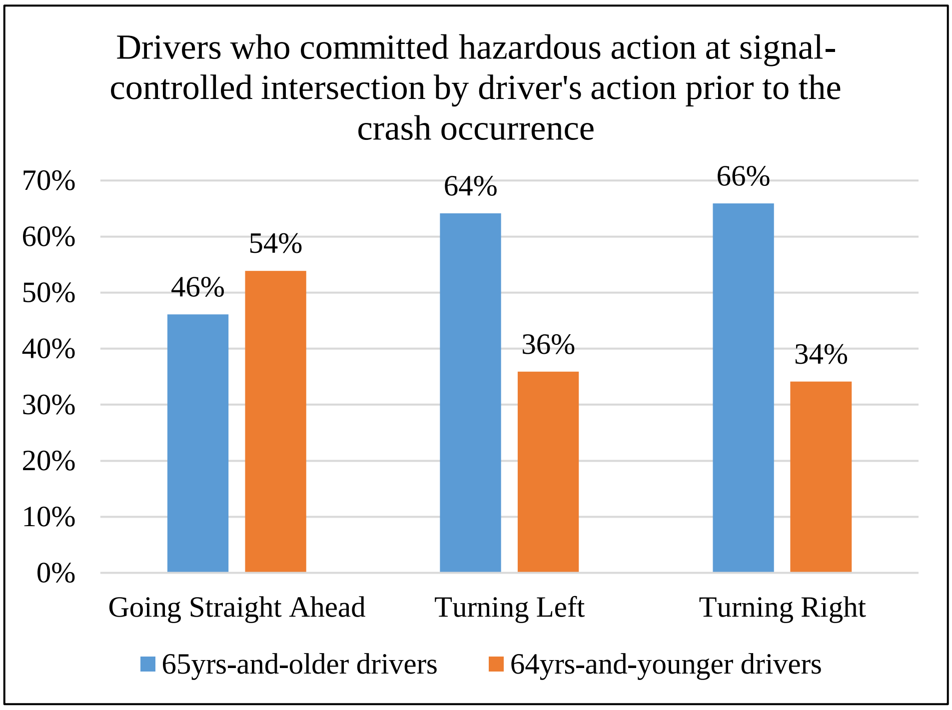


Figure 4.10 Percent of drivers who committed hazardous action at signal-controlled intersection

4.8.4 Analysis of skewed intersections

Intersection skewness was one among important intersection elements analyzed. As intersection angle becomes more acute, it presents several operation and sight distance problems to drivers. These problems are more pronounced to the 65yrs-and-older drivers as they may have difficulty in turning their neck. Operational problems arise from difficulties that are experienced by the 65yrs-and-older drivers in making a proper turn without encroaching into the opposing lane.

Currently, the MDOT design manual allows a minimum intersection skewness of 60 degrees when there is a restriction of right-of-way, although it states that a minimum skewness of 75 degrees is desirable. Contrary to this, the *FHWA 2014 Handbook for Designing Roadways for the Aging Population* recommends a minimum angle of 75 degrees to accommodate the declined head and neck mobility of the 65yrs-and-older drivers. Therefore 65yrs-and-older-related crashes were analyzed with respect to intersection skewness. Intersection angles for all major intersections joining arterial and collector roads in Michigan were automatically measured using ArcGIS. Visual verification was done for some intersections. Intersections with angle 60-75 degrees and intersection with angle 75-90 degrees were analyzed compared for both STOP-controlled intersections and signal-controlled intersections.

A notable result was observed for crash scenarios involving 65yrs-and-older drivers who were turning left and involved in an angle, head-on or head-on left turn crashes. At STOP-controlled intersection (see Figure 4.11), the proportion of the 65yrs-and-older drivers who committed hazardous action while turning left diminished as the intersection angle increases.

At signal-controlled intersections, the 65yrs-and-older drivers who committed hazardous action when making a left turn were disproportionally higher as compared to other drivers within each intersection angle group. Slight difference was observed across the intersection angle group as depicted in Figure 4.12. This indicates little effect of intersection skewness at signalized intersection when the 65yrs-and-older drivers were making a left turn.

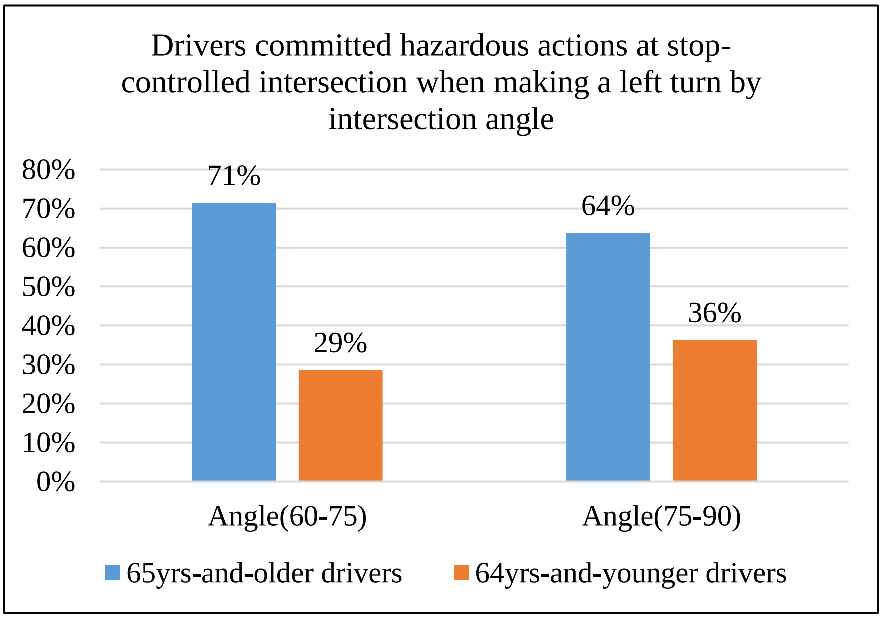


Figure 4.11 Drivers who committed hazardous action by intersection angle at Stop-controlled intersection

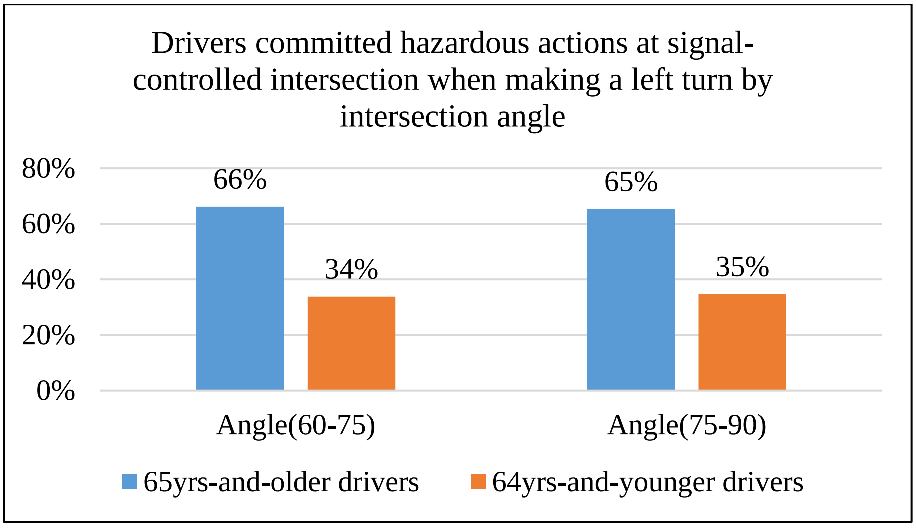


Figure 4.12 Drivers who committed hazardous action by intersection angle at Signal-controlled intersection

Specific hazardous actions were studied so as to discern possible reasons for the observed trend. A hazardous action that was directly related to intersection skewness was improper turning. Percentage of 65yrs-and-older drivers who performed an improper turn maneuver while making a left turn was computed out of all hazardous actions committed. Regardless of intersection control type, intersection with angle of 60-75 degrees had higher percentage of improper left turn (12 percent) compared to intersection with angle 75-90 degrees (10percent). Figure 4.13 illustrates typical case of crash that occurred as the result of improper left turn at skewed intersection. 65yrs-and-older driver attempted to cut diagonally instead of making a proper left turn.

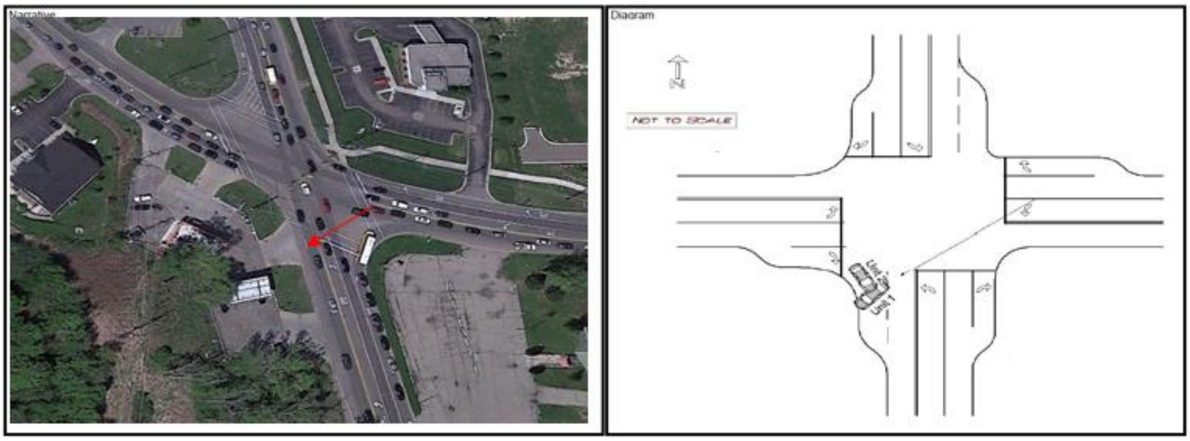


Figure 4.13 Example of improper left turn maneuver at skewed intersection which resulted to a crash

4.8.5 Analysis of intersections with raised median

The FHWA's 2014 Handbook for Designing Roadways for the Aging Population recommends the use of raised medians with sloping curbs. Raised medians may reduce sideswipe-opposite crashes if properly implemented. Figure 4.14 shows typical sideswipe-opposite crashes that can be reduced when raised median is present.

Figure 4.14 Example of sideswipe 65yrs-and-older related crashes that can be avoided by using raised median

The analysis of crashes was carried out by comparing intersections with raised median and intersections without raised median. A total of 285 intersections connecting state roads were identified using ArcGIS. Out of those 25 intersections had a raised median. Crash analysis showed a reduction in total 65yrs-and-older-related drivers who committed hazardous action regardless of crash type when a raised median was present as shown in Figure 4.15. The 65yrs-and-older drivers had a 59 percent chance of committing a hazardous action at intersections with no raised median, compared to the 64yrs-and-younger drivers. This was reduced to 52 percent at intersections with a raised median.

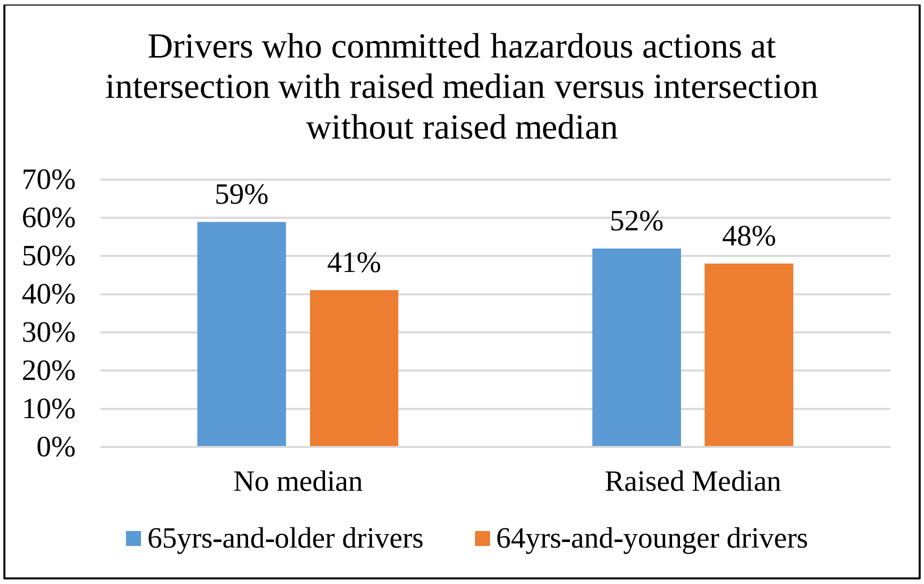


Figure 4.15 Drivers who committed hazardous actions at intersection based on presence or absence of raised median

4.8.6 Analysis of intersections with Offset Left-Turn lane

Providing a left turn offset for the intersections with left turn bay may enhance sight distance for the vehicle turning left. Drivers can have a direct view of opposing through vehicles before making a permitted left turn. Figure 4.16 demonstrates typical crashes types that can be avoided by providing left-turn offset. 65yrs older driver was turning left unaware of through vehicle from the opposite lane.

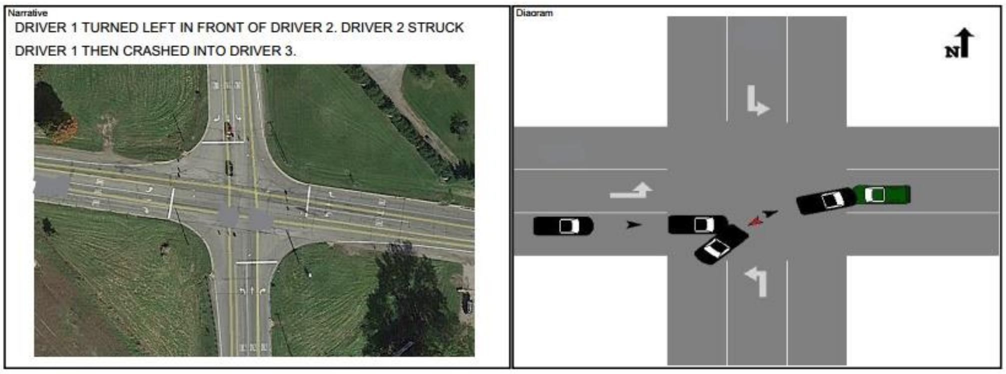


Figure 4.16 Example of crash type that can be avoided by providing left-turn offset

Intersections with left turn offsets were identified from all state-road intersections. Since providing offset is not a common practice in Michigan only six intersections were found to have offset out of 285 trunk-line intersections. Only intersections with a left turn bay were considered in the analysis. Similar crash analysis was performed by comparing the percentage of 65yrs-and-older drivers who committed hazardous action at intersections with offset and those which had no offset as shown in Figure 4.17. The results indicated a reduction in the number of 65yrs-and-older drivers who committed hazardous action from 58 percent to 55 percent when offset was present.

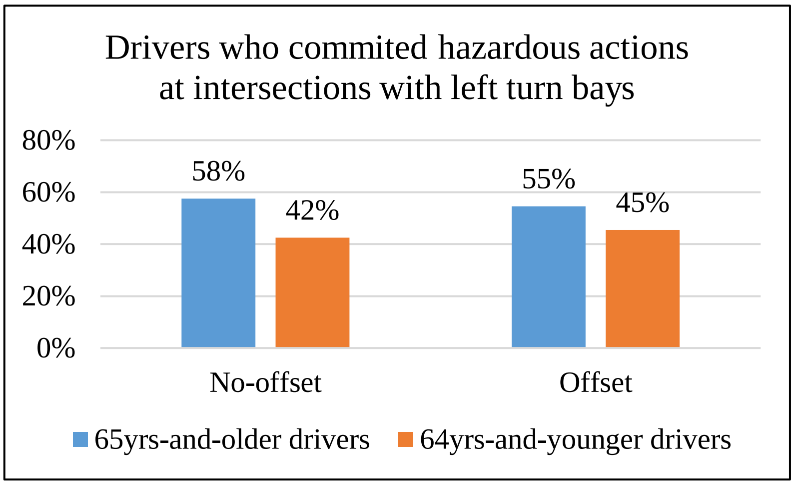


Figure 4.17 Drivers who committed hazardous actions at intersection based on presence or absence of left turn offset

4.8.7 Intersection lighting

Intersection lighting is one of the essential intersection design elements. It enhances night time visibility for drivers and other road users at the intersection. The 65yrs-and-older-related crashes that occurred at intersection were analyzed based on the three lighting condition namely; daytime, dark-lighted and dark-unlighted. Figure 4.18 shows how the percentage of 65yrs-and-older drivers varies by lighting condition at intersection. Analysis was carried out for rural and urban areas separately so as to be able to control for area-specific factors and driver's exposure. For rural intersections, about 63 percent of 65yrs-and-older drivers were responsible for 65yrs-and-older-related crashes that occurred at dark-unlighted conditions. This was reduced to 57% for dark-lighted conditions. For urban intersection, slight improvement was observed when comparing percentage of 65yrs-and-older drivers who committed hazardous action at dark-unlighted conditions relative to dark-lighted conditions.

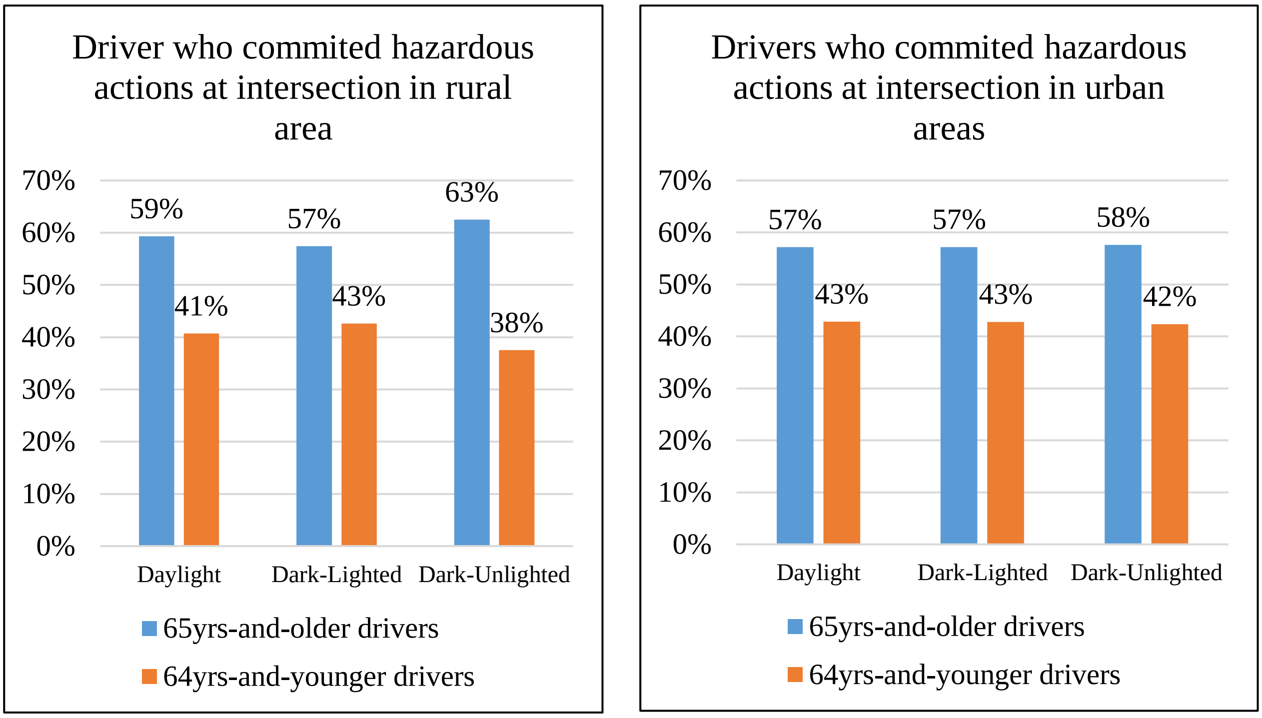


Figure 4.18 65yrs-and-older drivers who committed hazardous action by different intersection lighting condition

4.9 Modeling of intersection crashes related with the 65yrs-and-older drivers

The binary logistic regression was used to establish the association between 65yrs-and-older drivers being responsible for crash with the roadway features at intersection. Binary logistic regression was selected as it is appropriate for binary response variable given a set of explanatory variables. A binary variable was created indicating whether the 65yrs-and-older driver was responsible for a crash or not based on driver's hazardous action information as suggested in the crash report.

Suppose Y is the binary response variable, then Y=1 if the 65yrs-and-older driver committed a hazardous action otherwise Y=0. The probability (π_i) that the 65yrs-and-older driver committed a hazardous action given a set of explanatory variables is computed as

$$\pi_i = \Pr(Y_i = 1 | X_i = x_i) = \frac{\exp(\beta_o + \beta_i x_i)}{1 + \exp(\beta_o + \beta_i x_i)}$$

Whereby

β_i – Coefficient of explanatory variable *i*

x_i –Explanatory variable *i*

Table 4.6 Results from binary logistic regression

Variables	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
Gender: Male	-0.151	0.018	-8.18	0	-0.19	-0.12
Alcohol involvement	2.676	0.228	11.73	0	2.23	3.12
Left turn Maneuver	1.865	0.033	56.63	0	1.80	1.93
Right turn Maneuver	1.620	0.048	33.81	0	1.53	1.71
Going straight ahead	0.265	0.020	13.32	0	0.23	0.30
Dark-lighted condition	-0.070	0.034	-2.06	0.039	-0.14	0.00
Number of lanes	0.014	0.007	1.9	0.058	0.00	0.03
Posted speed limit	-0.004	0.001	-3.88	0	-0.01	0.00
Intersection angle	-0.001	0.001	-1.22	0.222	0.00	0.00
Four legged intersection	0.064	0.025	2.52	0.012	0.01	0.11
Partial access control	0.221	0.048	4.56	0	0.13	0.32
Traffic control: Signal	-0.150	0.027	-5.54	0	-0.20	-0.10
Constant	-0.146	0.067	-2.18	0.029	-0.28	-0.01

The following can be observed from Table 4.6.

- Male are less likely to be responsible for a crash compared to female
- 65yrs-and-older drivers who were driving while intoxicated were more likely to be responsible for a crash.
- All maneuvers prior to crash were associated with 65yrs-and-older driver being responsible for the crash. 65yrs-and-older drivers who were turning left were more likely to be at fault compared to other movements
- The 65yrs-and-older drivers were less likely to be responsible for 65yrs-older-related crashes that occurred at dark-lighted condition.
- As the posted speed limit increases, it is less likely for 65yrs-and-older driver to be responsible for a crash.
- The 65yrs-and-older drivers were less likely to be responsible for crash as the intersection angle increases i.e. approaching to 90 degrees
- The 65yrs-and-older drivers were more likely to be responsible for a crash in four-legged intersection as compared to three-legged intersection
- Lack of access control close to intersection was associated with high likelihood of 65yrs-and-older drivers being responsible for crash.
- The 65yrs-and-older drivers were less likely to be responsible for a crash at signal-controlled intersection compared to stop-controlled intersection

4.10 Analysis of older-related crashes at midblock locations

Midblock areas are the second after intersections for having a high proportion of the 65yrs-and-older-related crashes. Similar to intersections, they are also associated with higher proportion of the 65yrs-and-older drivers who committed hazardous actions as compared to the 64yrs-and-younger drivers, although slightly less than at intersections. Distribution of the 65yrs-and-older-related crashes by crash type indicated single-vehicle crashes to be overrepresented (25 percent) followed by rear end crashes (11 percent) and angle crashes (8 percent) as show in Figure 4.19.

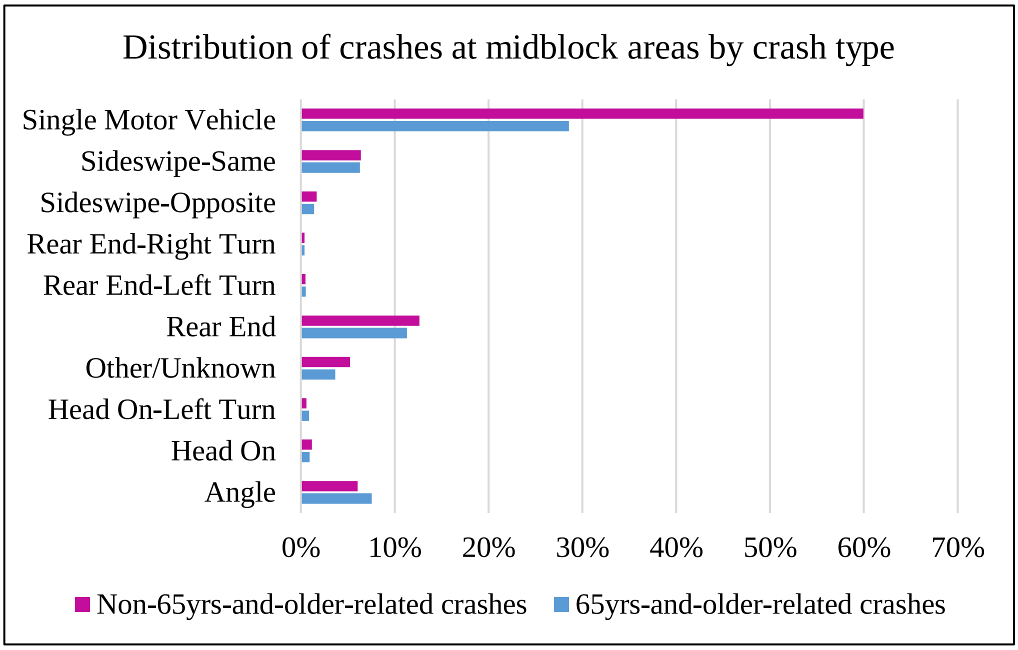


Figure 4.19 Distribution of crashes at midblock areas by crash type

The analysis of crashes was then carried out at various midblock locations by combining the information from the crash data and state road sufficiency file. Midblock locations that were studied include:

- Driveway away from intersection
- Median crossover
- Transition area
- Non-freeway curved roadway segment
- Parking areas along the roadside

Appendix 9.2.2 presents crash type distribution at various locations in midblock areas while Appendix 9.2.4 shows hazardous actions committed by drivers involved in two-vehicle crashes involving drivers 65yrs-and-older at midblock locations. Appendix 9.2.5 shows hazardous actions committed by 65yrs-and-older drivers in single-vehicle crashes at midblock locations.

Figure 4.20 provides the distribution of the 65yrs-and-older-related crashes that occurred at various midblock locations. By comparing only these five locations, the 65yrs-and-older-related crashes were higher at driveways away from intersections (35 percent) and at curved segments (33 percent). Parking areas had 23 percent of the 65yrs-and-older-related crashes over the five years (2010-2014) analyzed.

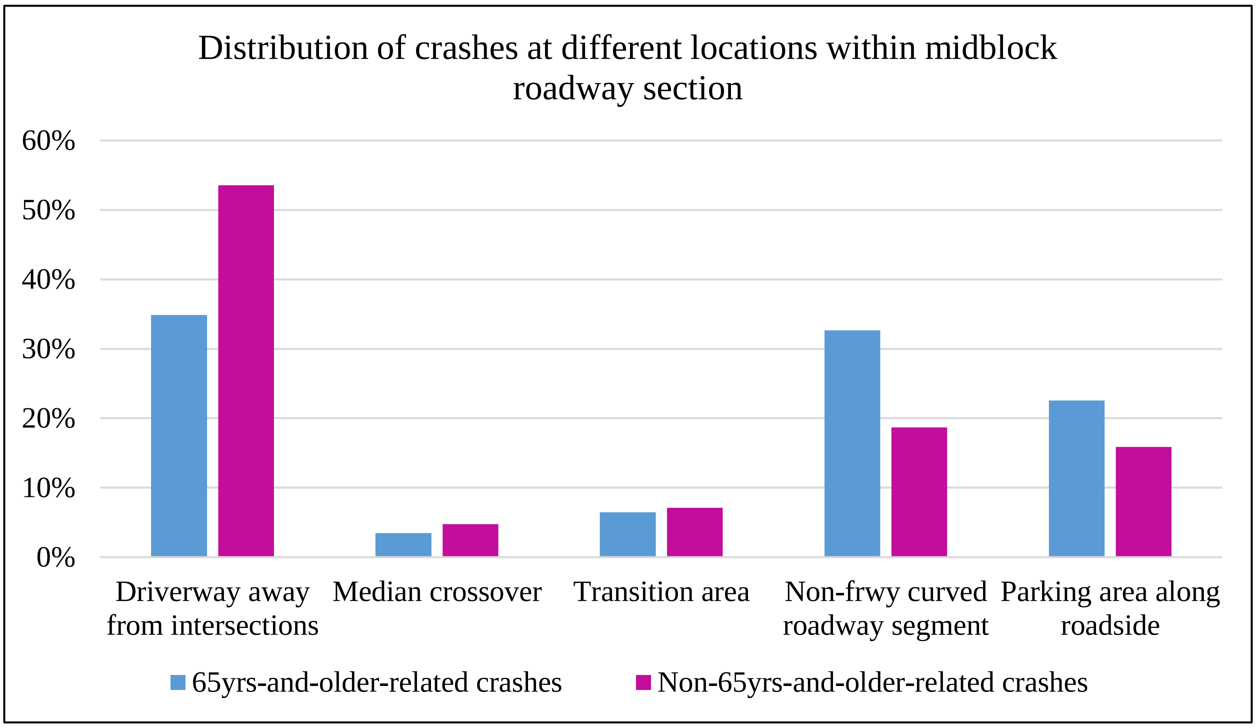


Figure 4.20 Distribution of crashes at different midblock locations

The list below shows midblock locations with more than 50 percent of the 65yrs-and-older drivers who committed hazardous action as compared to the 64yrs-and-younger drivers when only two vehicles were involved.

- Driveways away from intersections-57 percent
- Median crossovers-62 percent
- Transition areas-58 percent
- Parking areas-57 percent

Analysis was performed for the 65-years-and-older-related crashes by crash type at each midblock location. The matrix showing crash type by percentage for each specific midblock location is attached in appendices. Summary provided hereafter is for crash types that were overrepresented.

- At driveways away from intersection, most of the crash types were angle (51 percent), rear-end (11 percent) and sideswipe same direction (10 percent).
- At median crossovers, crash types that were overrepresented include angle (34 percent), rear-end (19 percent), sideswipe-same (19 percent).
- At transition areas, crash types that were overrepresented include sideswipe same direction (27 percent) rear-end (26 percent) and angle crashes (17 percent)
- At curved segments about 64 percent of the 65yrs-and-older-related crashes were single-vehicle crashes. Other minor crash types include sideswipe-opposite direction (9 percent) and rear-end (6 percent)
- For parking areas sideswipe-same direction was the common crash type (24 percent)

Specific hazardous actions that the 65yrs-and-older drivers committed for each location were analyzed. Notable results are summarized hereafter. A table that shows distribution of hazardous actions for each midblock location is attached in Appendix 9.2.4.

For two vehicle 65yrs-and-older-related crashes the following results were obtained

- At driveways away from intersection, failure to yield had about 39 percent
- At median crossover majority of drivers committed hazardous action as the result of failing to yield (28 percent).
- 23 percent of 65yrs-and-older drivers involved in a crash at parking area alongside the road were doing improper backing
- At transition areas, most of the 65yrs-and-older drivers failed to yield (21 percent) and had improper lane use (8 percent).

The following are the most common hazardous actions that were observed for single-vehicle 65yrs-and-older-related crashes at various midblock locations. A table with all the details is provided in the Appendix 9.2.5.

- Drive away from intersection: Failure to yield (11 percent) and careless driving (10 percent)
- Median crossovers: Careless driving (9 percent) and improper turn (7 percent)
- Curved segment: Speeding too fast (40 percent) and careless driving (10 percent).
- Parking areas along the road: Careless driving (20 percent) and unable to stop (14 percent).
- Transition areas: Speeding too fast (22 percent) and careless driving (8 percent)

4.10.1 Analysis of single-vehicle crashes at curved segments

Overrepresentation of single-vehicle crashes at curved section (see Appendix 9.2.2) prompted a more detailed analysis. Most of these crashes occurred because the drivers were speeding too fast, according to the crash investigating officer. A notable result was obtained when the single-vehicle crashes were related to roadway conditions for the case of the 65yrs-and-older drivers who were speeding too fast. About 57 percent of this crash type occurred when the roadway was icy or snowy for 64yrs-and-younger drivers, whereby for 65yrs-and-older it was 49% as shown in Figure 4.21 below. This may suggest that the drivers were driving too fast for the condition, not necessarily exceeding the speed limit.

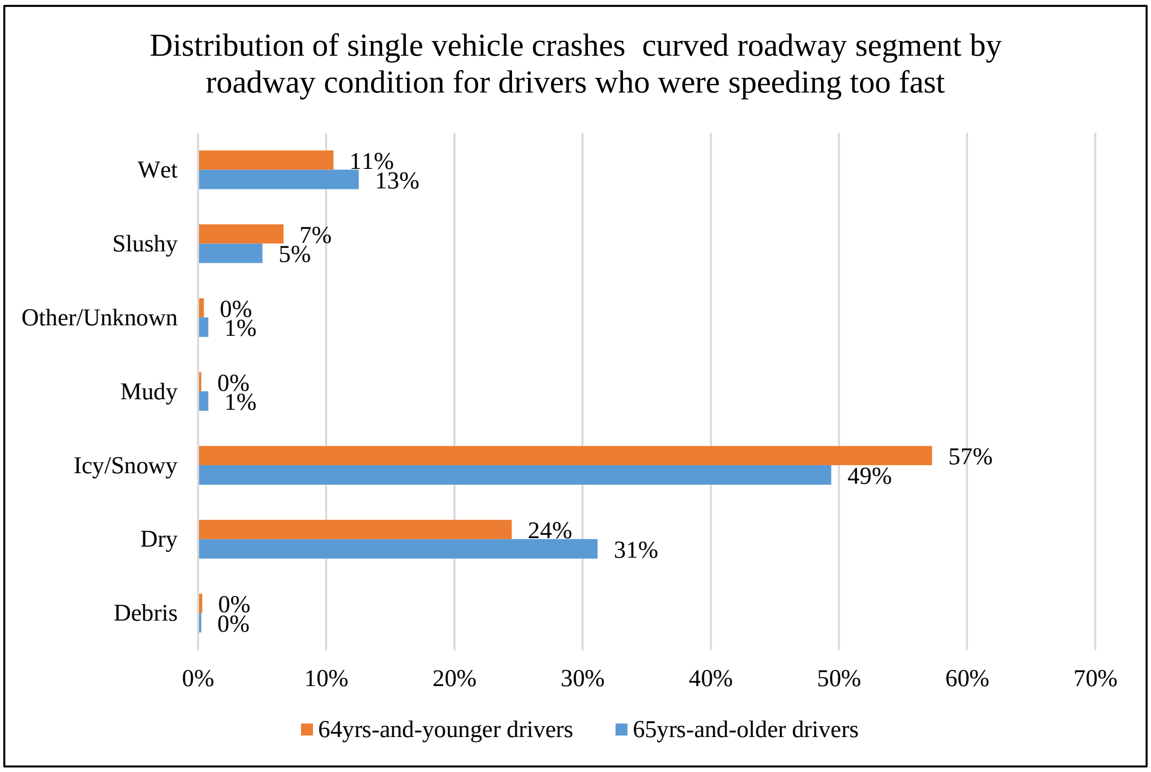


Figure 4.21 Single-vehicle crashes by weather condition at curved sections

4.10.2 Analysis of two-vehicle crashes involving older drivers at auxiliary passing lanes

Crash analysis for auxiliary passing lanes was conducted only for two-way undivided state road segments because such information was available in the state road sufficiency file. The comparison of the 65yrs-and-older-related crashes was made for undivided two-way roadway segment with and without auxiliary passing lanes. Only crashes which involved drivers making passing maneuvers were considered in the analysis. Figure 4.22 shows the reduction of 65yrs-and-older drivers who committed hazardous action when making passing maneuvers in locations where there was auxiliary passing lane. Improper passing was the most common hazardous action committed by the 65yrs-and-older driver at locations where there was no auxiliary passing lane as depicted in Figure 4.23. Also at the auxiliary passing lane, the 65yrs-and-older drivers were found to be speeding too fast before the crash occurrence.

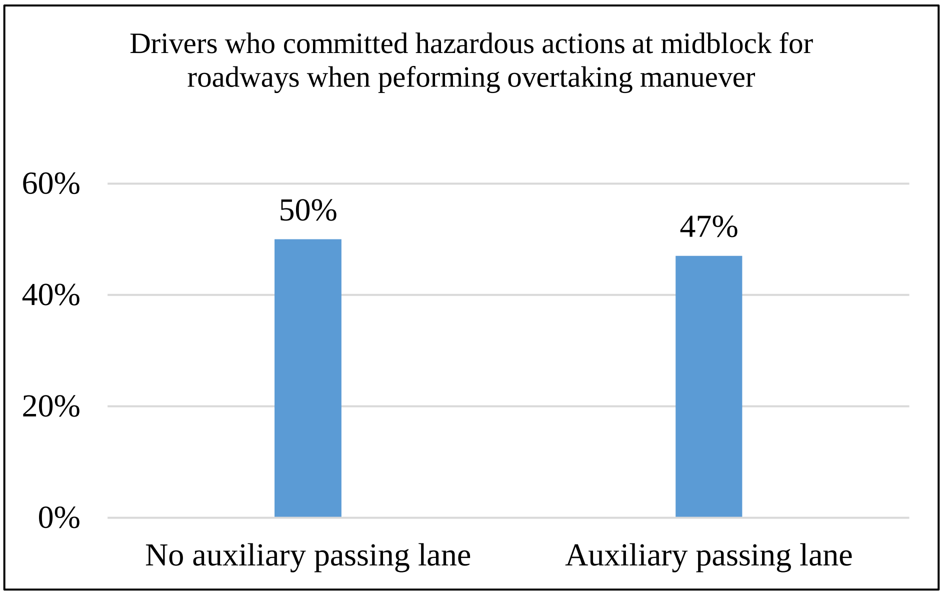


Figure 4.22 Percentage of 65yrs-and-older drivers who committed hazardous action when performing passing maneuver

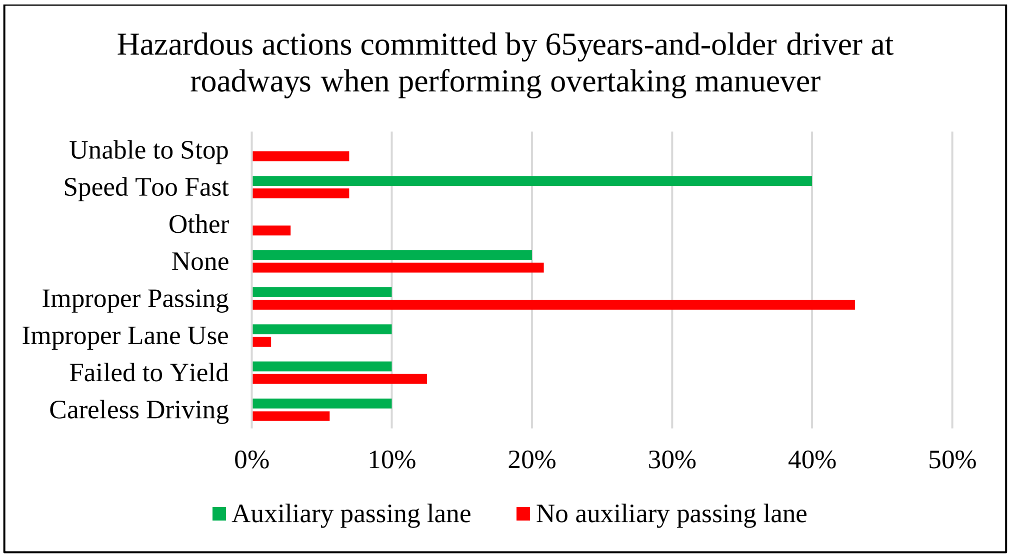


Figure 4.23 Hazardous actions committed by 65yrs-and-older drivers when performing overtaking maneuver

4.11 Analysis of two-vehicle crashes related with older drivers at freeway entrance or exits

Crash type for the 65yrs-and-older-related crashes that were overrepresented at freeway entrance and exits include rear-end (42 percent), sideswipe same direction (18 percent), angle (8 percent) and single motor vehicle crashes (19 percent) as shown in Appendix 9.2.3. The percent of the 65yrs-and-older drivers who committed hazardous actions for angle and sideswipe same direction crash type was higher than 50 percent compared to the 64yrs-and-younger drivers. Head-on left turn crashes had a 68 percent chance of 65yrs-and-older drivers committing hazardous action. This was the highest for all crash types as shown in Figure 4.24.

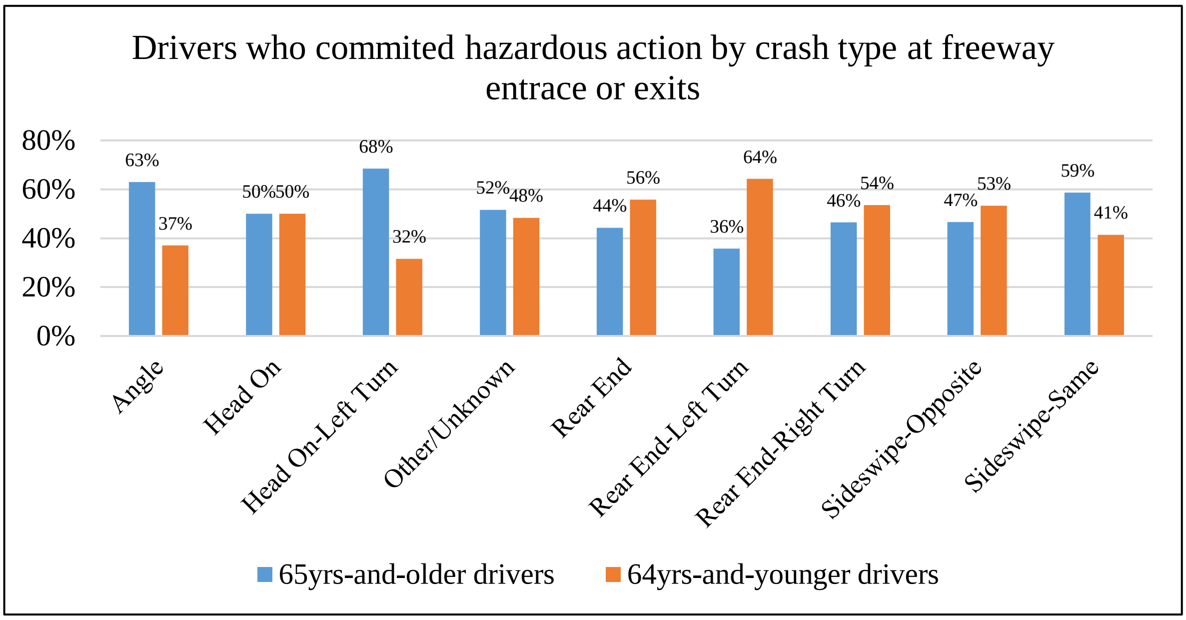


Figure 4.24 Drivers who committed hazardous actions at freeway entrance or exits

4.12 Summary of crash analysis

This chapter aimed at associating crashes involving drivers 65yrs-and-older with roadway features. Systematic crash analysis was performed starting from general analysis of the data which help to have a general understanding of environmental, roadway and drivers attributes of 65yrs-and-older-related crashes. A more in-depth analysis using crash data and UD-10 reports was conducted. The 65yrs-and-older driver's movements and their respective hazardous actions were studied in relation to different roadways features.

General analysis of the 65yrs-and-older-related crashes suggested that the 65yrs-and-older drivers might have problems when using multilane roadways, particularly those with more than four lanes. Presence of median with barriers on highway was likely to improve safety of the 65yrs-and-older drivers compared to the rest of the drivers. When analyzing specific maneuvers, turning left movement was found to be overrepresented for the 65yrs-and-older drivers. However, the 64yrs-and-younger drivers were more likely to be intoxicated while driving, especially on single-vehicle crashes compared to 65yrs-and-older drivers.

Distribution of crashes that involved the 65yrs-and-older drivers were examined based on the locations as defined by MDOT. Intersection locations had more 65yrs-and-older-related crashes compared to midblock areas and interchanges. Interchanges had the lowest percentage of 65yrs-and-older-related crashes. This suggested that 65yrs-and-older drivers were likely to avoid high speed roads compared to 64yrs-and-younger drivers. Analysis of two-vehicle crashes involving one 65yrs-and-older driver and one 64yrs-and-younger driver was conducted to discern which areas were more problematic to 65yrs-and-older drivers. For all locations as defined by MDOT, police reports for crashes analyzed indicated that drivers 65yrs-and-older had more than 50 percent chance of committing a hazardous action.

Detailed analysis of the 65yrs-and-older-related crashes was extended to each area. At intersections, specific roadway elements that were investigated include intersection skewness, raised medians, offset left turn lane and intersection lighting. Analysis of intersections showed that the 65yrs-and-older drivers have more problems at Stop-controlled intersections compared to signal-controlled intersections. Most of the 65yrs-and-older driver were responsible for a crash occurrence when they were making turning maneuver, especially left turn maneuver. Intersection skewness was found to have an impact on angle, head-on and head-on left turn 65yrs-and-older-related crashes especially when the 65yrs-and-older drivers were making a left turn. Crash diagrams from UD-10 reports showed that the 65yrs-and-older-related drivers at skewed intersections were likely to fail to yield when other vehicles were coming from the acute angle approach. In addition, the 65yrs-and-older drivers had issues in making proper left turn maneuvers, as in some cases they were found to encroach into opposing vehicle lane.

The 65yrs-and-older-related crashes which occurred at intersections with raised median were compared with those that occurred at intersections with no raised median. Fewer 65yrs-and-older drivers were found to commit hazardous actions at intersections with raised median. Similar results were obtained when intersections with offset left turn lane were compared with intersection with no offset left turn lane.

Possible safety benefits of intersection lighting were investigated by using the 65yrs-and-older-related crashes which occurred at dark condition. The 65yrs-and-older drivers were found to be less responsible for crashes in dark-lighted conditions compared to dark-unlighted conditions. The difference was more pronounced at rural intersections compared to urban intersections.

At midblock locations, five midblock areas were analyzed, namely: driveways away from intersection, median crossing, transition areas, parking areas alongside the road, and curved segments. At driveways, most of the crash types involving drivers 65 years-and-older were angle crashes, rear end and sideswipe-same direction crashes. The 65yrs-and-older drivers had 57 percent chance of committing hazardous actions for a crash involving two vehicles only. Most of the 65yrs-and-older drivers failed to yield when they were turning left and entering the roadway from the driveways. This may be associated with potential difficulty for the 65yrs-and-older drivers to correctly judge the gap before making a proper left turn from either main road or driveways.

Median crossings are common in Michigan due to the presence of Michigan Left Turns. These locations had 62 percent chance for the 65yrs-and-older driver being the one who committed a hazardous action when only two vehicles were involved in a crash. Most common crash types observed at these locations include angle crashes, rear-end and sideswipe same direction. Failed to yield was overrepresented at median crossing and majority of the 65yrs-and-older drivers were turning left prior to a crash.

Transition areas that were investigated includes construction areas with lane closure, lane drop after the intersection and lane drop at freeway ramps. Common crash types observed at these locations include sideswipe same direction, angle and rear-end. The 65yrs-and-older drivers had a 58 percent chance of committing hazardous actions at these locations when the crash occurred and involved one 64yrs-and-younger driver and one 65yrs-and-older driver. Specific hazardous actions for the 65yrs-and-older drivers that were overrepresented includes failure to yield and improper lane use.

The 65yrs-and-older-related single-vehicle crashes were overrepresented at midblock curved segments. Most of the 65yrs-and-older drivers were reported to be speeding too fast as suggested by the police officer when the crash occurred. Distribution of these single-vehicle crashes with respect to roadway condition showed that the majority of these crashes occurred when the road was icy or snowy. Therefore providing curve warning markings only might have a little effect because during snow periods, roadway markings may not be clearly visible. Supplementing the curve warning markings with curve warning signs may considerably have an impact on the 65yrs-and-older-related single-vehicle crashes at curved segments. For the parking areas, 65yrs-and-older drivers had a 57 percent chance of committing hazardous action in crashes involving one 65yrs-and-older driver and one 64yrs-and-younger driver. Improper backing and failure to yield were the most common hazardous actions reported by investigating officers.

5 Guidance in Roadway Design for Michigan

A key to implementing effective treatments to improve the safety of the transportation system for the aging population in Michigan is providing appropriate guidance related to the use of such treatments. In addition to the evaluation of existing facilities and safety treatments with respect to older drivers, it was also necessary to compare MDOT's existing design guidance with the resources identified as a part of this evaluation.

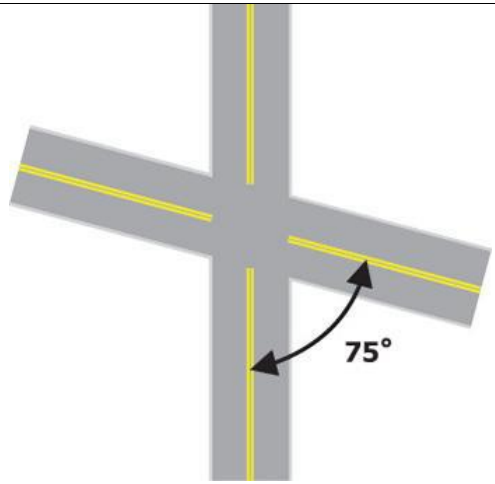
In 2004 and 2014 the Michigan Department of Transportation (MDOT) hosted North American Conference on Elderly Mobility (NACEM). As part of this effort MDOT partnered with FHWA to develop a showcase roadway. This involved 7.4 miles of roadway in Detroit where various safety countermeasures which targeted older drivers such as traffic signal backplates with retroreflective borders, pedestrian countdown signals, arrow-per-lane signing, and upgraded sign sheeting for warning signs. While MDOT has placed an increased focus on implementing engineering countermeasures specifically targeted for older drivers since 2004, there are additional opportunities to improve design guidance in accordance with the FHWA Handbook for Designing Roadways for the Aging Population, as well as other published best practice resources (FHWA 2014).

In order to assess the current state of MDOT's design guidance with respect to older drivers, a detailed comparison was completed with the FHWA Handbook for Designing Roadways for the Aging Population. Each aspect of the guidance provided in the handbook was compared with MDOT's existing guidance and rated using the following scale:

1. No guidance from MDOT on this topic
2. Ambiguous guidance from MDOT
3. Clear guidance from MDOT but inconsistent with the handbook
4. Optional or similar guidance from MDOT consistent with the handbook
5. Guidance from MDOT consistent with the handbook

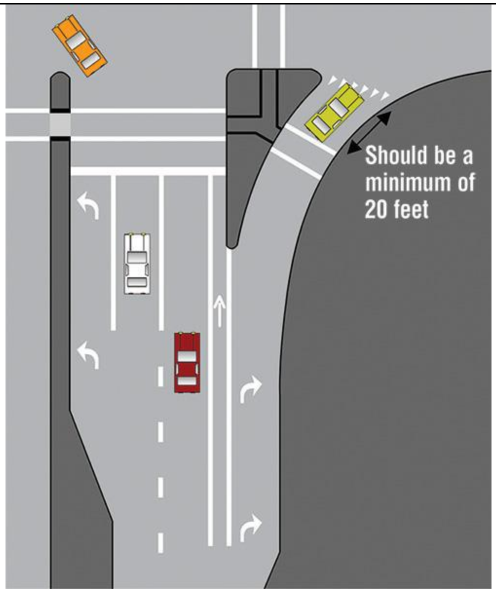
The results of the comprehensive comparison are provided in Appendix 9.3.2. Additionally, based upon the results of the comparison of the handbook, the countermeasures which are already implemented with clear design guidance from MDOT are summarized in Appendix 9.3.1. Finally, the countermeasures and strategies identified in the handbook or in other publications which currently do not have specific guidance from MDOT, or those which currently have ambiguous guidance, are summarized below in Table 5.1. The treatments listed within Table 5.1 represent opportunities for potential enhancements to MDOT's design guidance to better consider leading practices in the area of older drivers.

Table 5.1 **Proven Countermeasures and Strategies without Existing or Ambiguous Design Guidance**

Description	**Recommendation**	**Details**
Intersections		
Intersection skew	Skew intersections pose particular issues for older driver due to their decreasing head and neck mobility resulting in reduced perception reaction times. The physical capabilities of older drivers may affect their performance at intersections designed with sharp angles by requiring them to turn neck and heads more than would be required at a right-angle intersection. The FHWA guidelines for intersections suggest a minimum skew of 75 degrees for older drivers. MDOT's guidelines suggest a minimum skew of 60 degrees and a desirable skew of 75 degrees. Improving intersection skew angle can be expensive as significant amounts of right-of-way are typically required to implement these improvements. When constructing new facilities or making geometric changes to skewed intersections MDOT should consider: • Providing FHWA recommended intersection geometry between 75-105 degrees for new construction where feasible. • Installing a roundabout as opposed to a conventional intersection at stop-controlled skewed intersection	

Description	**Recommendation**	**Details**
	MDOT should also consider the following treatments at skewed intersections: • Eliminating permissive left turns • Providing No Right On Red signs if the skew angle is less than 75 and more than 105 degrees • Ensuring adequate intersection sight distance • Enhancing signal visibility by providing signal backplates • Providing retroreflective pavement markings to increase night-time visibility • Working with local agencies to provide intersection lighting	
Channelization	Raised channelization is used to separate turning movements from through movements. Channelization provides safety benefits for older driver better delineating the intersection approaches and to keep drivers on the roadway. Channelization also plays a key role in preventing drivers from turning across congested left-turn lanes. It is suggested that MDOT consider pilot testing locations for raised channelization. Certain types of five lane roadways or wider intersection locations can benefit from the presence of raised channelization. A possible pilot to consider would be to add a four foot raised median to a lower speed urban five lane road by narrowing the lane widths from 12 to	

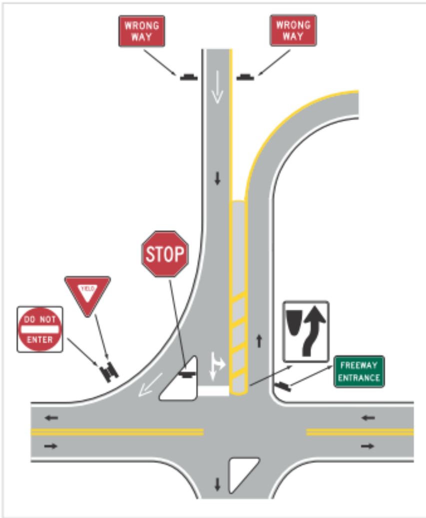
Description	Recommendation	Details
	11 feet. Raised channelization medians may also help to prevent access related crashes in urban and suburban areas. Retroreflective pavement markings should be used for curbs to improve the conspicuity However, there could be some limitations to the implementation of raised channelization such as: • Widening may be required and might be an expensive fix due to geometric changes and acquiring right-of-way. • Winter maintenance needs to be considered. These raised channelization islands are similar to those installed near roundabouts and for pedestrian refuges. • Negative offset can impact sight distance for left turn movements.	

Description	Recommendation	Details
Right-Turn Channelization Design	Right-turn channelization can be applicable for intersections with a high volume of right-turning vehicles that experience excessive delays due to traffic signal. Right-turn channelization helps with reducing pedestrian exposure and also moves right turn traffic ahead of the through traffic. They also provide improved sight distance for right-turn traffic that especially helps older drivers. FHWA suggests the use of channelized right-turn lanes, similar to the concept illustrated to the right. In some cases this design requires more right of way than an intersection with a conventional right-turn lane. This additional right-of-way is typically required to accommodate larger turning radii. A potential issue with this design is that larger radii can increase speeds, thus increasing risk for pedestrians. Visibility of the channelized islands is important especially at night and inclement weather. Therefore, if channelized islands are provided, delineation and retroreflective markings should be used on the curbs.	
Intersection sight distance	FHWA suggests eight second intersection sight distance, while MDOT's guidelines suggest 7.5 seconds with 0.5 seconds for each additional lane. To enhance intersection sight distance for older drivers, a gap of no less than 8 seconds plus 0.5 seconds for each additional lane crossed should be	

Description	Recommendation	Details
	considered. This will help to further accommodate the slower reaction times for older drivers by increasing the sight distance.	
Offset Left-Turn Lanes	Currently MDOT utilizes positive offset left-turn lanes at several intersections with divided highways. It is suggested that MDOT consider the use of positive offset left-turn lane using pavement markings on lower speed undivided highways. For example, on a five lane undivided roadway this could be applied by reducing the lane widths from 12 to 11 feet to accommodate five feet of space which would be used to create positive offset.	

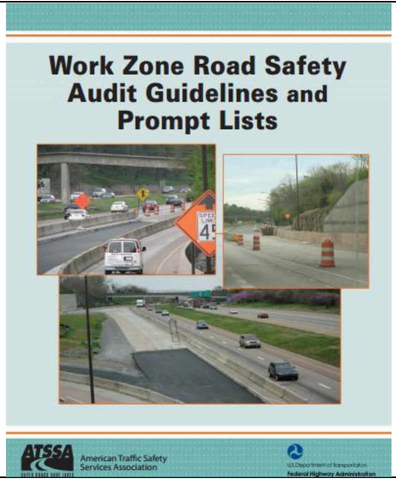
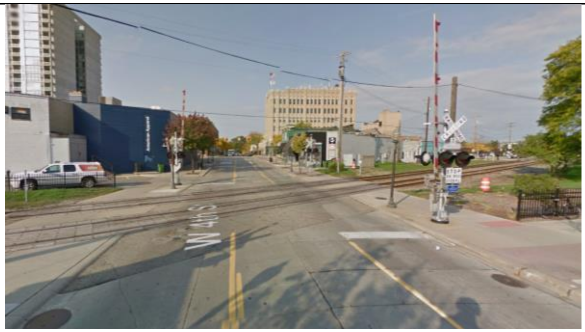
Description	Recommendation	Details
Delineation of Edge Lines and Curbs	To enhance the conspicuity of curbs and raised medians, it is proposed that delineation be provided on raised medians. Specifically, edge lines and retroreflective pavement markings and/or delineators on the faces of the medians be considered.	 Source FHWA
Additional ground mounted signal	Protected-permissive left-turn (PPLT) signals increase the likelihood of older drivers being involved in a crash (Hallmark and Mueller, 2004). It is suggested that MDOT consider providing an additional ground mounted signal head in the far left corner of multi-lane approaches with PPLTs. This is especially beneficial where sight distance restrictions are present, such as on approaches to intersections on curves and at skewed intersections.	

Description	**Recommendation**	**Details**
Street Name Signs	Overhead street name signs are extremely effective in reducing sudden braking and weaving at intersections, particularly for older drivers. As result, it is suggested that MDOT partner with local agencies to develop a plan for providing overhead street name signs at signalized intersections. This approach is applied on a systemic basis in more than 40 other states. These signs can either be retroreflective or internally illuminated. Many states have developed effective standards for attaching retroreflective street name signs to span wire. Several other states attach them to the poles located in the corner of the intersection. As local agencies are responsible for street name signs in Michigan, MDOT should partner with the County Road Association of Michigan (CRA) and the American Public Works Association (APWA) to develop an approach to implementing this countermeasure. This may require modifying the current cost sharing agreements with local agencies for trunkline signals. This countermeasure is recommended for all signalized intersections in Michigan.	  

Description	**Recommendation**	**Details**
Interchanges		
Freeway Entrance Ramp Traffic Control Devices	To enhance guidance around ramp terminals, it is suggested that the following signing be considered. • Freeway Entrance Signing – Several states utilize "Freeway Entrance" signing to enhance driver awareness that they are entering a freeway. • Diagrammatic signs – The use of diagrammatic signing near ramps to enhance driver awareness of entrance ramp turn locations have been found to be effective. These can reduce the risk of weaving by older drivers in congested ramp areas.	  Source: FHWA

Description	Recommendation	Details
Interchange Lighting	According to the literature review conducted for this study, older adults have higher rate of crashes when merging onto interstate highways. Presence of lighting helps with improved safety, for all users, especially older drivers, to recognize the geometry and interchange lane assignments at extended distances and therefore simplifying their task at night. This also may help with avoiding wrong-way crashes. The *FHWA 2014 Handbook for Designing Roadways for the Aging Population* suggests a general practice towards freeway lighting which should be considered by MDOT.	
Roadway segments		

Description	Recommendation	Details
Horizontal Curves	The FHWA Aging Driver Guidelines suggests using a pavement marking pattern which combines the message slow with an arrow in advance of a horizontal curve. This countermeasure was originally implemented by the Pennsylvania Department of Transportation and has been found to be effective in preventing lane departure crashes in horizontal curves. It is suggested that MDOT consider applying this countermeasures in addition to other delineation on horizontal curves. One issue with this countermeasure is it is not visible in snowy conditions. That being said, the effectiveness documented from Pennsylvania also considers snowy conditions.	 Chevron and curve delineation
Construction/work zone		
Portable changeable message signs, device spacing and letter height	The handbook suggests some enhanced guidance for portable changeable message signs. These enhancements have been suggested by the National Committee on Uniform Traffic Control Devices to FHWA for inclusion in the next Manual of Uniform Traffic Control Devices.	 FHWA, handbook

Description	Recommendation	Details
Work zone Road Safety Audit (RSA)	Several states have begun conducting Work Zone Road Safety Audits on large-scale projects or within complex work zones. It is suggested that MDOT consider conducting a pilot Work Zone RSA as part of its RSA contract to study its effectiveness.	
Highway-Rail Grade Crossings		
Lighting	Presence of lighting has been found to reduce the risk for crashes for older drivers. In most cases providing lighting is the responsibility of local agencies. It is suggested that MDOT work in partnership with local agencies to identify strategies to provide lighting at more highway-rail grade crossings on a systemic basis.	

Given the ambiguous or lack of existing guidance related to the proven countermeasures and strategies outlined above, it is recommended that MDOT incorporate such guidance into their existing design resources. This will represent a significant improvement in designing transportation facilities which accommodate the aging population in Michigan, both at the state and local levels. Specifically, MDOT should incorporate these results in existing guides and standards where appropriate, including (but not limited to) resources such as:

- MDOT's Standard Plans (http://mdotcf.state.mi.us/public/design/englishstandardplans/)
- MDOT's 2012 Standards and Specifications for Construction (http://mdotcf.state.mi.us/public/specbook/2012/)
- MDOT's Road Design Manual (http://mdotcf.state.mi.us/public/design/englishroadmanual/)
- MDOT Work Zone Safety and Mobility Manual (http://www.michigan.gov/documents/mdot/MDOT_WorkZoneSafetyAndMobilityManual_233891_7.pdf)

It is also recommended to integrate the proposed application guidelines into following existing MDOT guidebooks and standards:

- MI guide for aging drivers: https://www.michigan.gov/documents/mdot/MDOT_OlderDriverGuide_455323_7.pdf
- Evaluation of MI Engineering Countermeasures: https://www.michigan.gov/documents/mdot/RC1636_501939_7.pdf
- http://safety.fhwa.dot.gov/older_users/noteworthy/elderlymobilitynpg.pdf
- http://mutcd.fhwa.dot.gov/pdfs/PocketGuide0404.pdf

6 Benefit-Cost Analysis of Potential Countermeasures

6.1 Introduction

Cost-benefit analyses were performed for individual countermeasures recommended in the previous chapter. In this study, some of countermeasures were not included due to the lack of necessary data. For purposes of cost-benefit analysis, the base year was assumed to be 2015. The analysis period extends to the life span of each countermeasure, while applying a corresponding discount rate over the duration. All calculations are based on present value as of 2015 by applying the discount rate as below:

$$PV = \sum_{t=1}^{N} \frac{FV}{(1+i)^t}$$

Where:

PV= Total Present Value

FV = Future Value in year *t*

i = Discount rate applied

t = Years in the future (where base year of analysis is *t* = 0)

A benefit-cost ratio (BCR) is used in determining return-on-investment of each countermeasure.

$$\text{Benefit-Cost ratio (BCR)} = \frac{\text{Total Present Value of Benefits}}{\text{Total Present Value of Costs}}$$

6.2 Summary of Costs

Costs for individual countermeasures are classified into two parts: construction costs and maintenance and operation costs. These data were obtained from the Michigan Department of Transportation. Table 6.1 summarizes lifespan, construction costs, and maintenance and operation costs for individual countermeasures.

Table 6.1 List of potential countermeasures and their respective costs

Countermeasure	Life Span	Cost	
		Construction	Annual Maintenance & Operation
Physical channelization of right turn lane on major road	15 years	$ 5,000	
Pavement marking for left turn lane buffer/channelization	1 year	$ 1,500	
Physical channelization on both roads	15 years	$ 100,000	
Street Name Sign (LED) mounted on mast arms	7 years	$ 3,000	$ 175
Adding retro-reflectivity of stop signs	7 years	$ 500	
Installing street lights (52.8 lights per mile)	15 years	$ 500,000	$ 2,829
Installing Intersection lights (8 per intersection)	15 years	$ 75,000	$ 429
Installing 15 lights at Diamond interchange	15 years	$ 150,000	$ 804
Installing 30 lights at Par-Clo interchange	15 years	$ 300,000	$ 1,608
Installing 50 lights at Full Cloverleaf interchange	15 years	$ 500,000	$ 2,679
Curve warning markings	1 year	$ 1,500	

6.3 Methodology for Benefit Estimation

Benefits of individual countermeasures were estimated by applying unit crash costs to the estimated number of crashes reduced by the corresponding countermeasures. This section explains how these unit crash costs were estimated and how the number of crashes reduced were estimated. Even though countermeasures in this study are to help older drivers, the benefits estimated here are for all drivers as these countermeasures are not only beneficial to older drivers but also the other age groups.

6.3.1 Unit Crash Cost

Kostyniuk *et al.* (2011) documented crash costs by crash type in Michigan, and estimated an average crash cost of $19,999 as of 2009. Their estimates were based on monetary costs combining medical care, emergency responses, and quality-of-life. Based on the unit costs in the report, inflation rate during the period, and the number crashes in 2015, the crash costs by type for 2015 were estimated as shown in Table 6.2. The average cost for a crash was estimated as $33,235.

Table 6.2 Number of injuries per crash type and corresponding comprehensive costs

Type	**2009** (Kostyniuk *et al.*, 2011)	**2015**	
	Cost per person injured / vehicle damaged	**Cost per person injured / vehicle damaged**	**Cost per Crash**
Fatal	$3,611,958	$3,926,035	$4,080,640
Serious	$229,646	$249,615	$290,533
Moderate	$68,431	$74,381	$90,267
Possible Injury	$39,910	$43,380	$60,265
Property Damage Only (PDO)	$3,690	$4,011	$6,409
Average cost per unit	$19,999	$21,120	$33,235

6.3.2 Estimation of Crash Reduction

Due to the lack of experience in Michigan on those countermeasures, this study adopted previous study results available in the Crash Modification Factor (CMF) Clearinghouse (http://www.cmfclearinghouse.org/) in estimating the number of crashes to be reduced by those countermeasures. Table 6.3 summarizes available CMFs for the proposed countermeasures.

Table 6.3 List of countermeasures and corresponding CMFs

Countermeasure	CMF Value	Crash Severity Type
Physical channelization of right turn lane on major road	0.87	Injury
	0.81	PDO
Painted left turn channelization	0.67	All
Physical channelization on both roads	0.73	Fatal/Injury
	0.87	PDO
Street Name Sign (LED) mounted on mast arms	0.984	All
Adding retro-reflectivity of stop signs)	0.909	All
Street lighting/per mile (assuming LED lighting and 100ft spacing)	0.8	All
Installation of Intersection lighting (7 -8 per intersection, each $10k)		All
Installing lighting on Diamond interchange	0.5	All
Installing lighting Par-Clo interchange		All
Installing lighting Full Cloverleaf interchange		All
Curve warning markings	0.81	Injury

Source: Crash Modification Factor (CMF) Clearinghouse (http://www.cmfclearinghouse.org/)

6.3.3 Estimation of Benefits

An annual monetary benefit of each countermeasure is estimated as follow:

$$B = \sum NC_i \times CRF_i \times UC_i$$

where

B = Annual Monetary Benefit (Crash Saving)

NC_i = Number of Crashes for Type i

CRF_i = Crash Reduction Factor for Crash Type i = 1 - CMF_i

UC_i = Unit Crash Cost for Crash Type i

6.4 Benefit-Cost Ratio

As this study aims to develop a general equation for estimating benefit for each countermeasure, a unit benefit (that assumes one crash per year at the analysis site) for each countermeasure is estimated. In this way, the actual annual benefit can be estimated by multiplying the number of crashes per year at the analysis site. Table 6.4 summarizes unit benefits, costs, and corresponding BCRs. A BCR for each countermeasure is represented as a function of the number of crashes at the study site. Of course, those sites with more crashes will result in greater BCRs. Details on cost-benefit analyses are available in Appendices.

Table 6.4 Summary of cost-benefit analyses

Countermeasure	Unit Benefit		Cost	BCR[3)]
	Annual Crash Cost Saving	Total Present Value	Total Present Value	
Physical channelization of right turn lane on major road [1)]	$3,194	$41,060	$5,000	8.21 *N*
Painted left lane channelization	$ 10,967	$ 10,848	$ 1,500	7.23 *N*
Physical channelization on both roads [1)]	$8,860	$111,333	$ 100,000	1.11 *N*
Street Name Sign (LED) mounted on mast arms	$ 532	$ 3,455	$ 31,137	0.83 *N*
Adding retro-reflectivity of stop signs	$ 3,024	$ 19,649	$ 500	39.30 *N*
Installing street lights (52.8 lights per mile)	$ 6,647	$ 83,522	$ 535,548	0.16 *N*
Installing Intersection lights (8 per intersection)	$ 3,955	$ 49,696	$ 80,391	0.62 *N*
Installing 15 lights at Diamond interchange	$ 16,617	$ 208,805	$ 160,103	1.30 *N*
Installing 30 lights at Par-Clo interchange	$ 16,617	$ 208,805	$ 320,205	1.30 *N*
Installing 50 lights at Full Cloverleaf interchange	$ 16,617	$ 208,805	$ 533,663	0.65 *N*
Curve warning markings[2)]	$ 16,224	$ 16,047	$ 1500	10.70 *N*

1) Assumed that 80% of crashes are PDO crashes.
2) Based on injury crashes
3) *N* represents the number of crashes at the study site.

The charts presented in Appendix 9.4 can be used by MDOT when selecting a countermeasure to apply at a given location. The charts utilize the results presented in Table 6.6 to allow the user to look up the potential benefit-cost ratio (BCR) for a given site based on the number of crashes observed at that site. It should be noted that specific CMFs for older adults only are limited. Therefore, specific types of crashes for which the CMPF is applicable, are identified. These should be the type of crashes counted at a given site to apply these charts.

7 Conclusions and Recommendations

The main objective of this study was to analyze the association of Michigan's older adult crashes with roadway features and provide guidance in roadway design to MDOT. Detailed crash analyses and survey of road users were among the tasks performed to accomplish the objectives. A review of the *FHWA 2014 Handbook for Designing Roadways for the Aging Population* and Michigan design guidance revealed where MDOT has opportunities to improve design guidance, and to better address issues facing the state's aging population.

Key findings from the survey includes:

- Drivers age 65 years-and-older avoid driving in many conditions more than any other age group. These conditions included night-time, bad weather, when a left turn would be needed, driving alone, during peak travel times or busy time of day (rush hour), and intersections in unfamiliar areas. Driving during bad weather was stated to be the most avoided action by older drivers out of all given conditions while driving alone is the least avoided.
- At intersections, the 65yrs-and-older drivers reported concerns with opposing vehicle blocking their visibility of oncoming traffic when making a left turn, especially during night-time. They also have concerns with insufficient visibility in night-time and bad weather more than in daytime.
- For pavement markings/signs at intersections, the 65yrs-and-older drivers reported issues with visibility of edge lines, lane markings on the pavement and the visibility and legibility of street name signs during night-time.
- When approaching a freeway exit, the 65yrs-and-older drivers reported concerns with visibility of markings at the off-ramp, visibility of signs and knowing where the exit goes in night-time driving more than it is in daytime and bad weather.
- For traversing highway-rail grade crossings, the 65yrs-and-older drivers reported concerns with visibility of highway-rail sign and identification of a safe path at an unlighted-rail grade crossing, especially in rural areas.
- For Yield/Stop signs, the 65yrs-and-older drivers reported concerns on difficulty in judging gaps. The concerns are higher in bad weather followed by night-time.

- Multilane roundabouts pose challenges to drivers, especially older adults. The survey indicated that a higher proportion of 65yrs-and-older drivers have concerns in choosing the proper lane at multilane roundabouts than any other age group.

The Michigan's five year (2010-2014) crash data were analyzed to identify any associations with roadway features. General analysis of crashes involving drivers 65yrs-and-older suggested that:

- The 65yrs-and-older drivers face challenges when using multilane roadways, particularly those with more than four lanes.
- Presence of median with barriers on highway was likely to improve safety of the 65yrs-and-older drivers compared to the rest of drivers.
- Crashes related with left turning movements were overrepresented for the 65yrs-and-older drivers.
- The drivers 64yrs-and-younger were more likely to be intoxicated while driving especially on single-vehicle crashes compared to 65yrs-and-older drivers.

Distribution of crashes that involved the 65yrs-and-older drivers were examined based on the locations as defined by (MDOT). Intersection locations had more 65yrs-and-older-related crashes compared to midblock areas and interchanges. Analysis of two-vehicle crashes involving one 65yrs-and-older driver and one 64yrs-and-younger driver was conducted to discern which areas were more problematic to 65yrs-and-older drivers. At intersections, specific roadway elements that were investigated include intersection skewness, raised medians, offset left turn lane and intersection lighting. Analysis of intersection crashes showed that:

- The 65yrs-and-older drivers have more problems at Stop-controlled intersections compared to signal-controlled intersections.
- Most of the 65yrs-and-older drivers were responsible for a crash occurrence when they were making turning maneuvers, especially left turns.

- Intersection skewness was found to be associated with angle, head-on and head-on left turn 65yrs-and-older-related crashes especially when the 65yrs-and-older drivers were making a left turn.
- Fewer 65yrs-and-older drivers were found to commit hazardous actions at intersections with raised median.
- Intersections with offset left turn lane may have increased safety for older drivers when compared with intersection with no offset left turn lane.
- Intersection lighting, especially in rural areas, may be associated with reduced chance of older drivers committing hazardous actions.

For midblock locations, five midblock areas were analyzed, namely: driveways away from intersection, median crossing, transition areas, parking areas alongside the road, and curved segments. From the analyses, it can be concluded that:

- Drivers 65yrs-and-older drivers have a relatively higher chance of committing hazardous actions for a crash involving two vehicles only when they are turning left to enter a roadway from the driveways. This may be associated with a potential inability by the 65yrs-and-older drivers to correctly judge the gap before making a proper left turn from either the main road or driveways. Ensuring sufficient sight distance is very important to mitigate such crashes.
- Median crossings pose greater challenges to the 65yrs-and-older drivers than other drivers when only two vehicles are involved in a crash.
- For construction areas with lane closure, lane drop after the intersection and lane drop at freeway ramps, the 65yrs-and-older drivers have an increased risk of being responsible for the crash which involved one 64yrs-and-younger driver and one 65yrs-and-older driver.

From a detailed comparison of the current state of MDOT's design guidance with the *FHWA Handbook for Designing Roadways for the Aging Population* with respect to older drivers, and from crash analyses and survey results, the following design areas have opportunities for potential enhancements to MDOT's design guidance to better consider leading practices in the area of older drivers were identified. These include, but are not limited to:

- Intersection skew, including providing the FHWA recommended intersection geometry between 75-105 degrees for new construction where feasible.
- Channelization, especially right-turn channelization design,
- Intersection sight distance, by considering a gap of no less than 8 seconds plus 0.5 seconds for each additional lane crossed.
- Offset left-turn lanes, by considering the use of positive offset left-turn lane using pavement markings on lower speed undivided highways.
- Delineation of edge lines and curbs, by considering edge lines and retroreflective pavement markings on the faces of the medians.
- Additional ground mounted signals (i.e., consider providing an additional ground mounted signal head in the far left corner of multi-lane approaches with permissive left-turns).
- Street name signs, by partnering with local agencies to develop a plan for applying overhead street name signs at signalized intersections.
- At construction/work zones, consider the use of some enhanced guidance for portable changeable message signs as being suggested by the National Committee on Uniform Traffic Control Devices.
- MDOT should consider conducting a pilot Work Zone Road Safety Audit (RSA) as part of its RSA contract to document its effectiveness.
- For lighting at highway-rail grade crossings, it is suggested that MDOT work in partnership with local agencies to identify strategies to provide lighting at more highway-rail grade crossings on a systemic basis.

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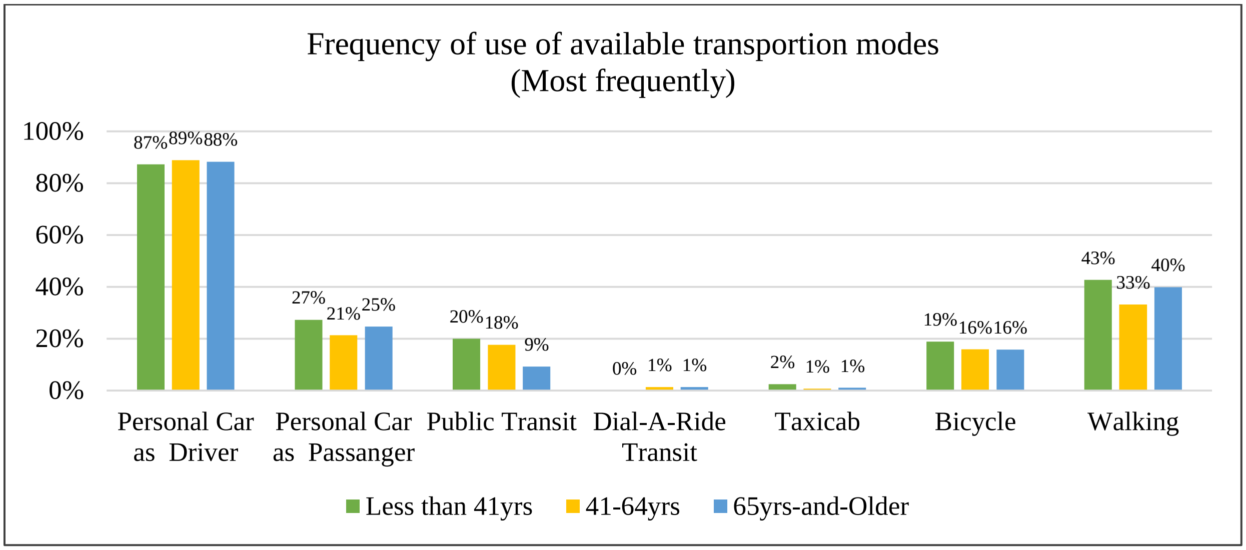
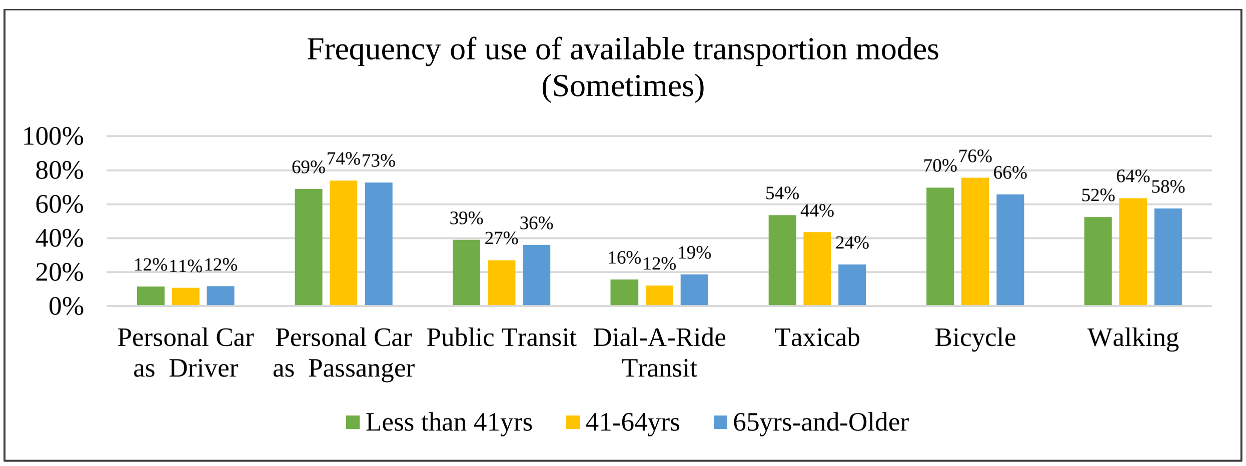
9 Appendices

9.1 Appendices for Chapter 3: Survey of Michigan Drivers and Identification of Alternative Transportation Options

9.1.1 Survey Questionnaire and Full Survey Responses

1. What transportation alternatives are available to you and how frequent do you use them for your regular trips (e.g shopping, work, recreational, etc.)





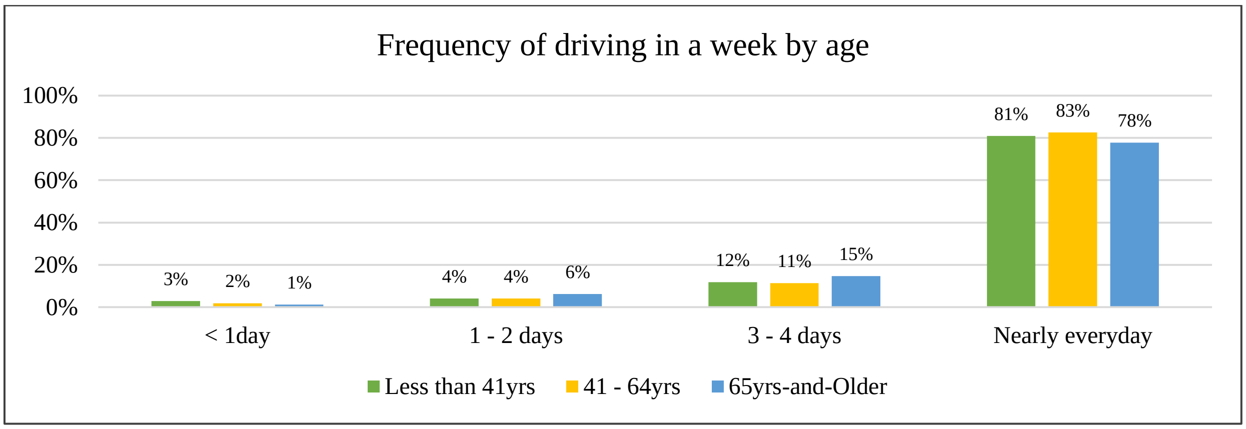
2. Do you currently hold a valid driver's license?

Status	Frequency	Percentage
Yes	873	91
No	90	9
Total	963	100

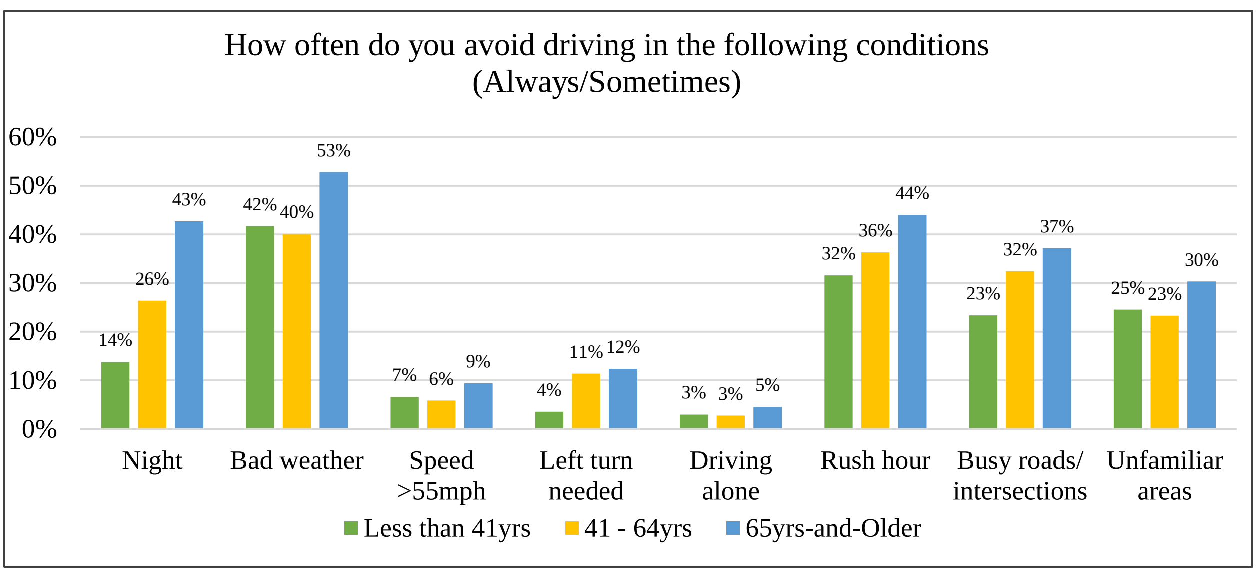
3. Do you drive in Michigan?

Status	Frequency	Percentage
Yes	836	96
No	37	4
Total	963	100

4 How often do you drive in a week?

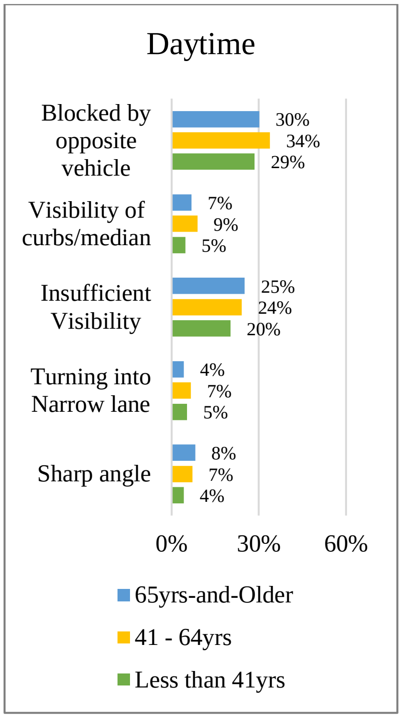


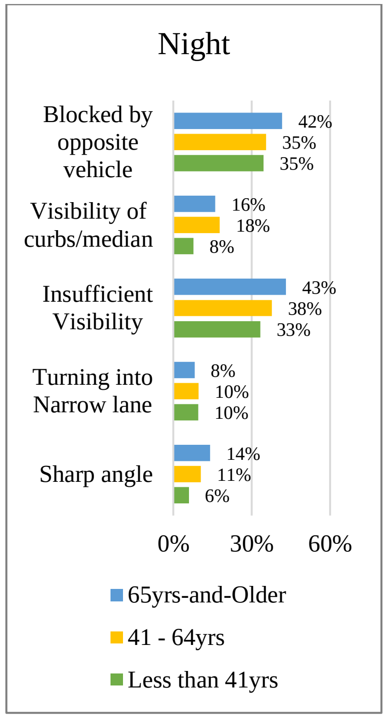
5 How often do you avoid driving in the following conditions?

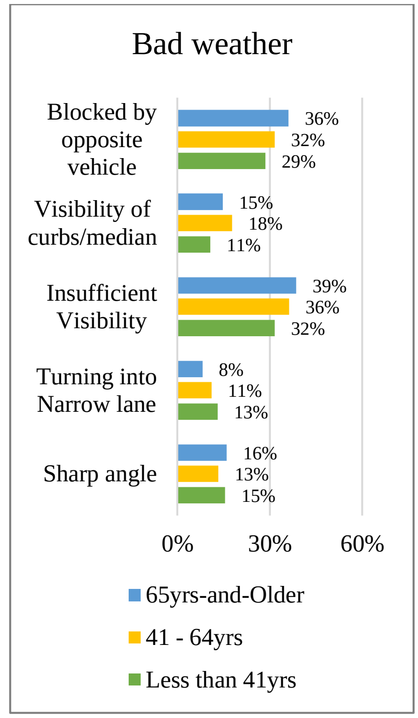


6 Do you have any of the following concerns when driving in Michigan?

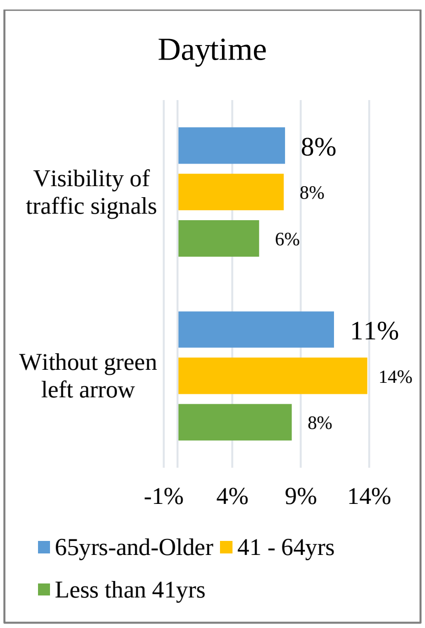
6a. When making a turn at an intersection

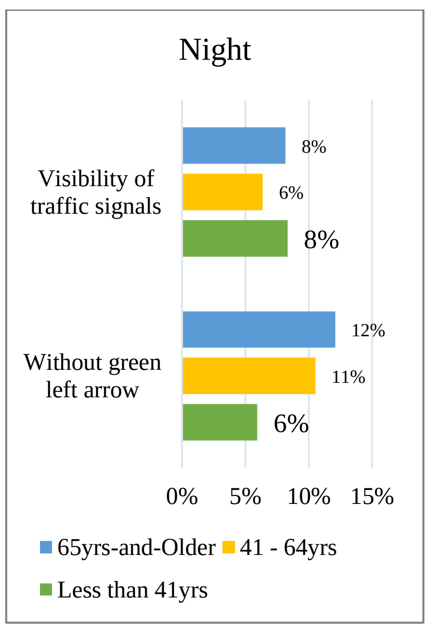


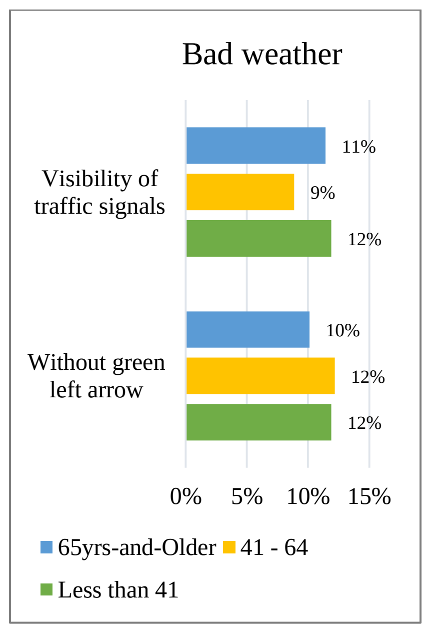




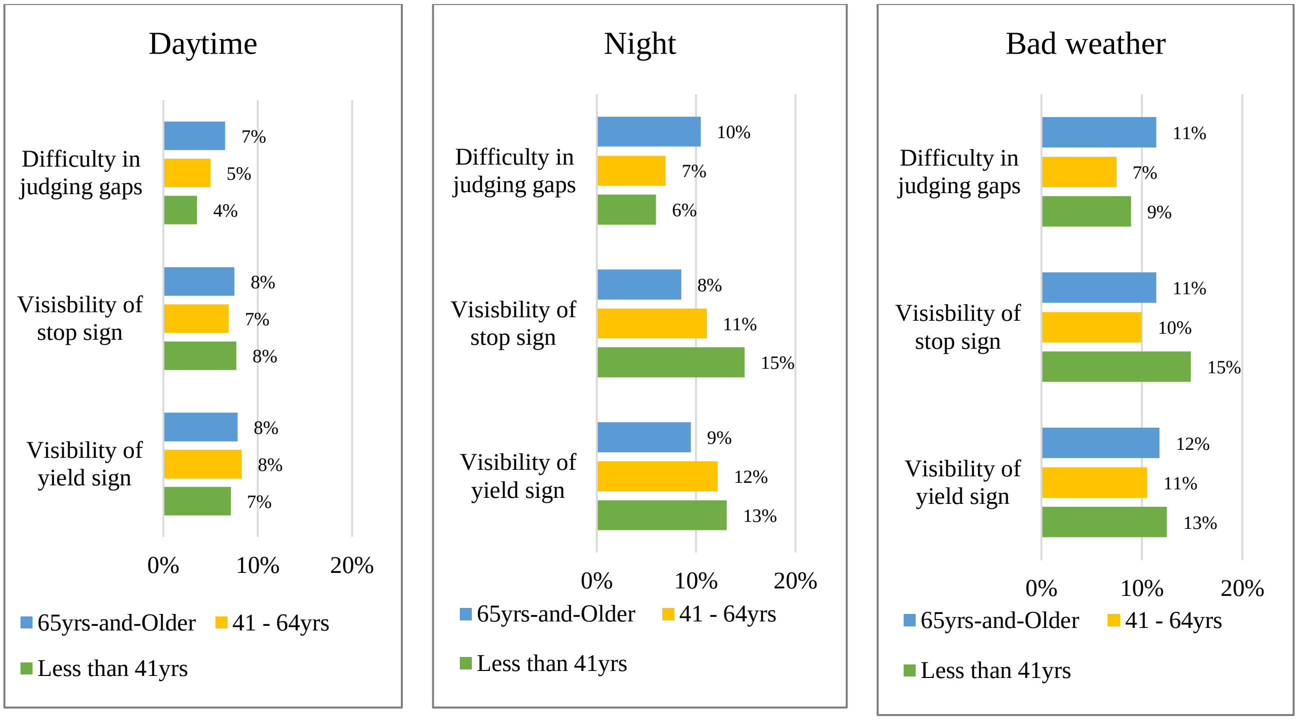
6b. When making a turn at a traffic signal



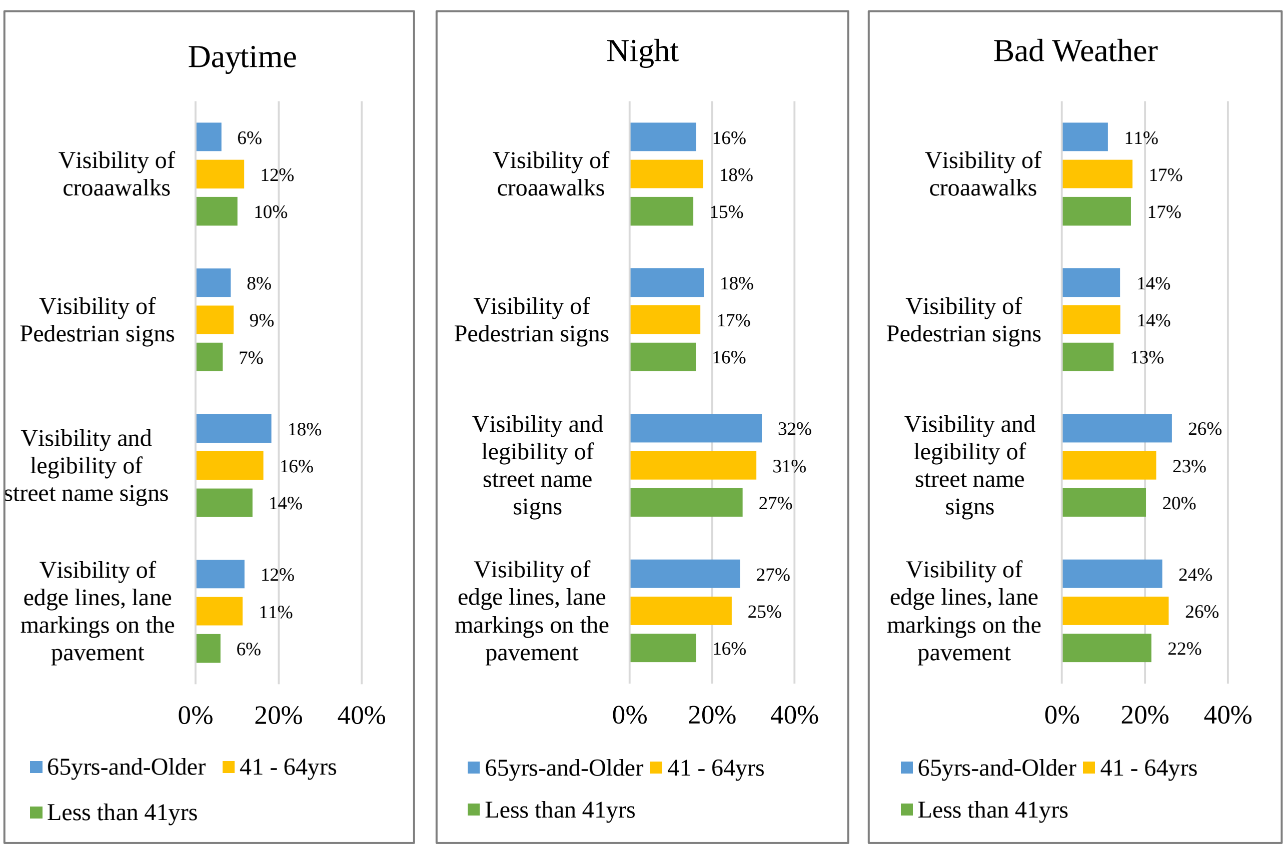




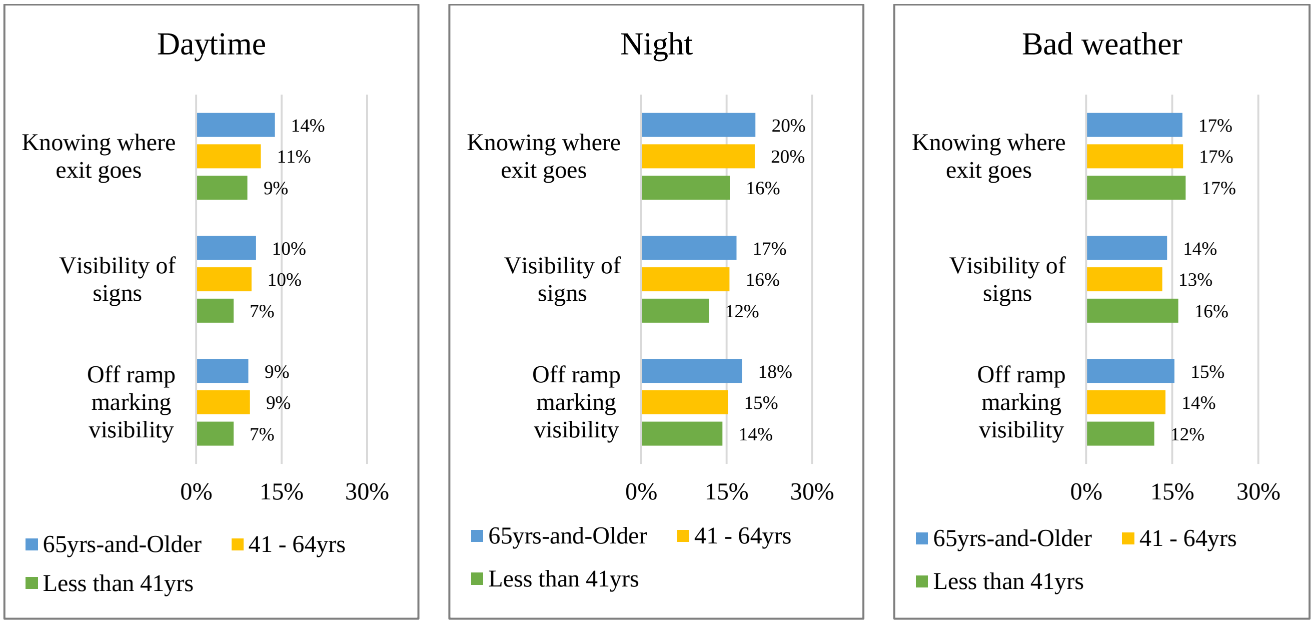
6c. At intersections with a yield/stop sign



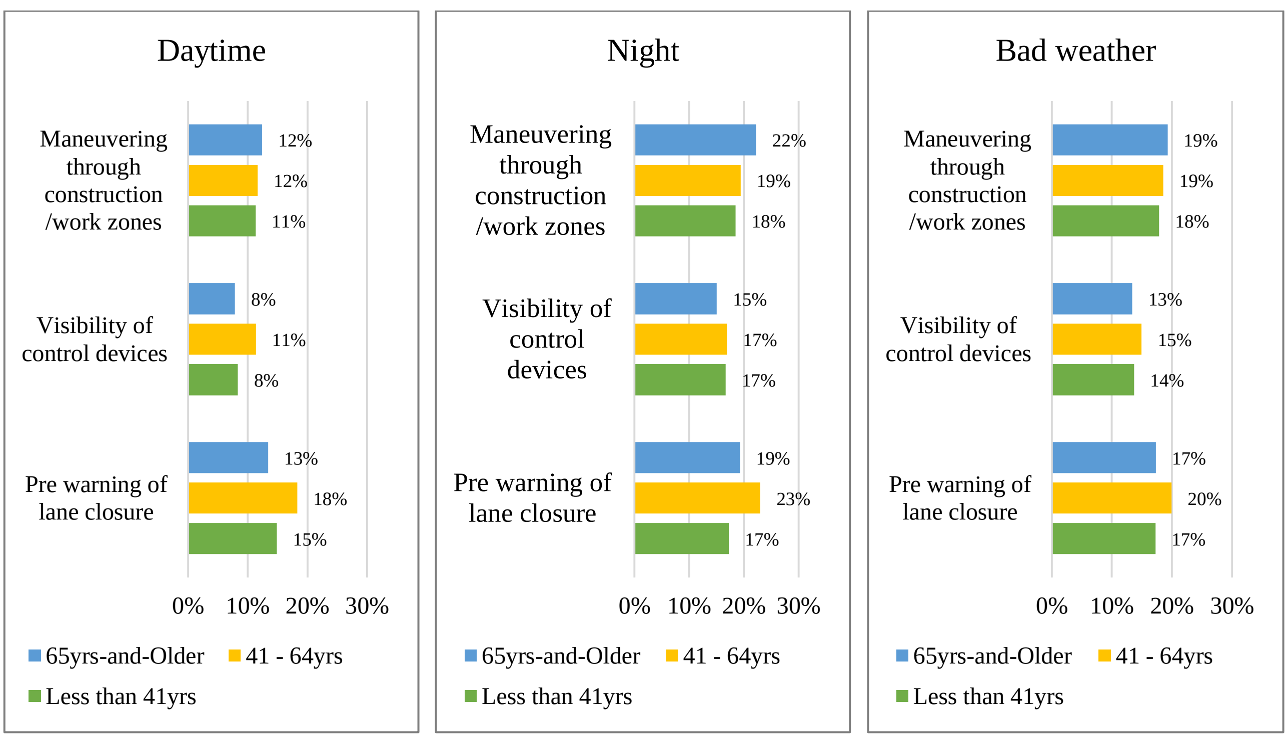
6d. Pavement marking/signs at intersections



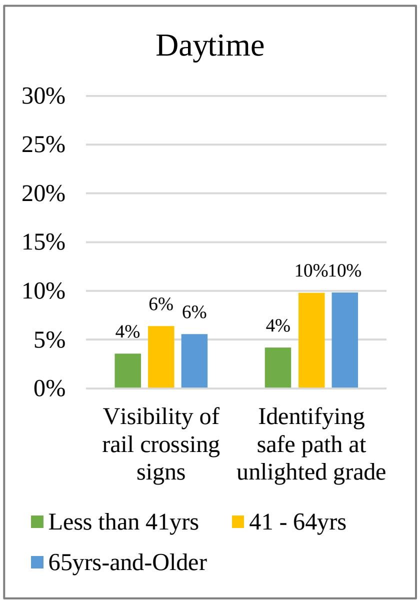
6e. When approaching freeway exit

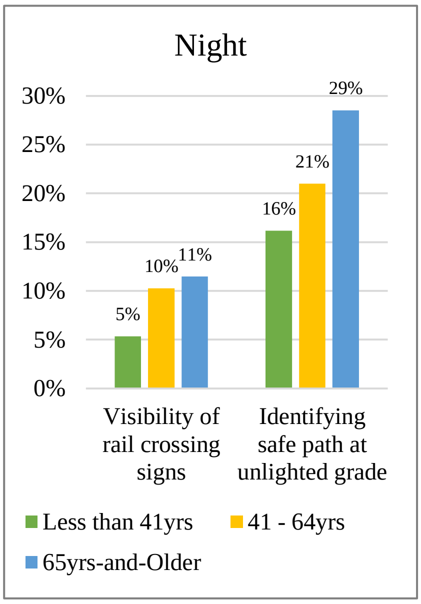


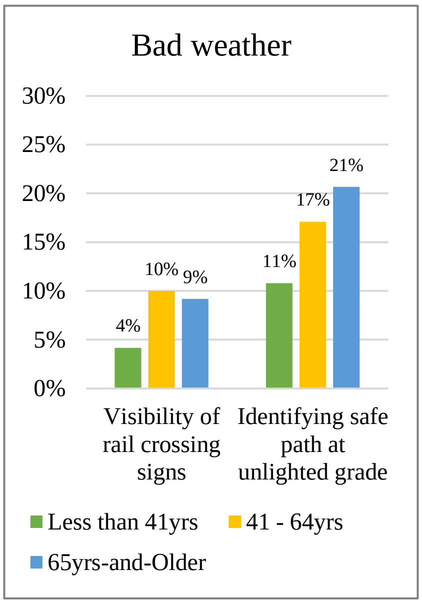
3.6f. When approaching or traversing construction/work zones



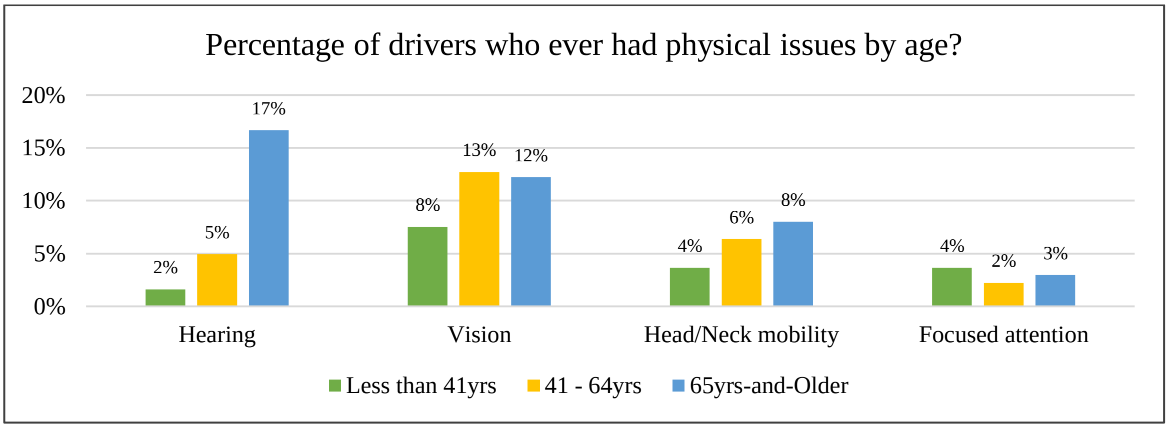
6g. When approaching or traversing highway-rail crossing



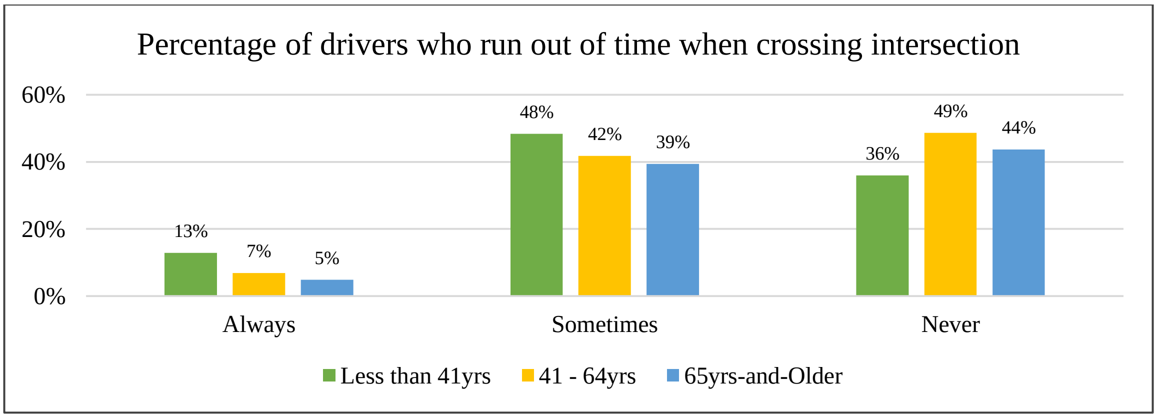




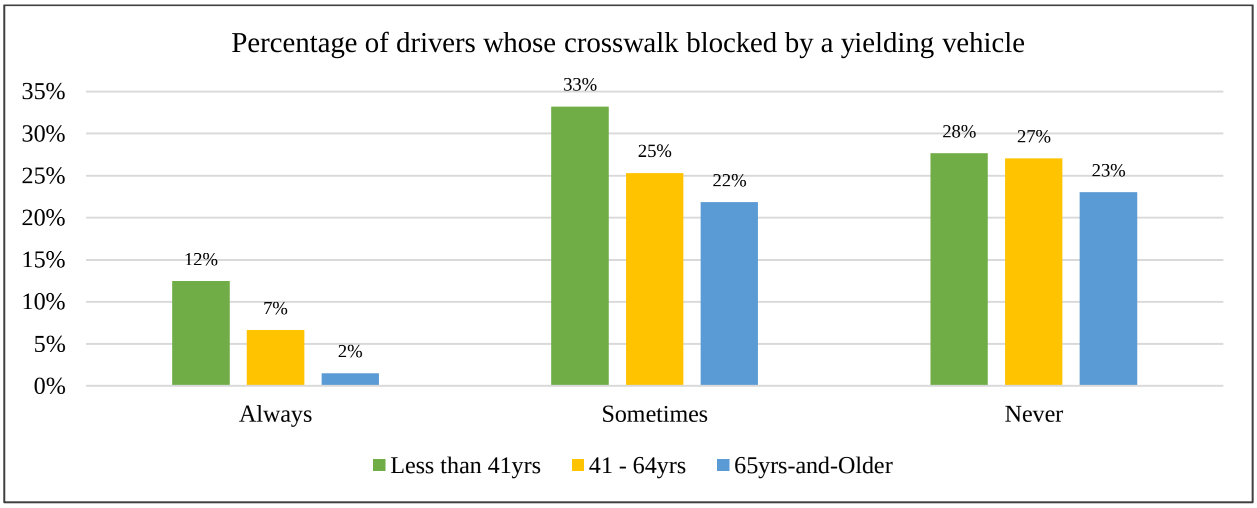
7 Have you ever had any of the following physical issues?



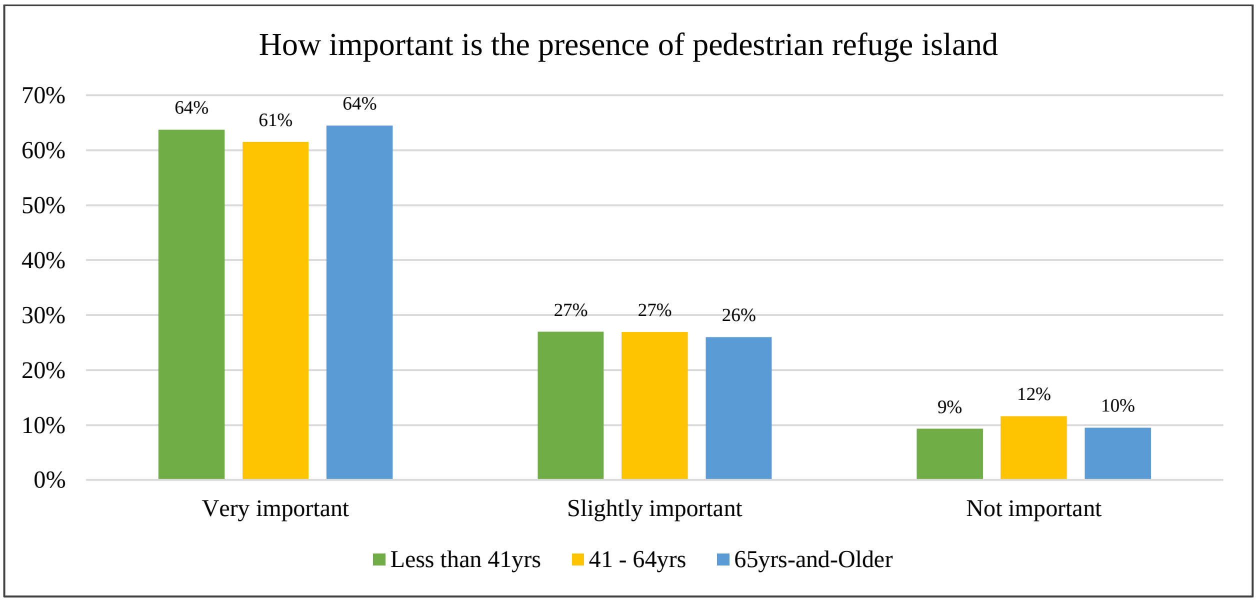
8 How often do you run out of time when crossing an intersection?



9 How often does a yielding vehicle at a roundabout block your crosswalk?



10 How important is the presence of a pedestrian refuge island when crossing wider streets?

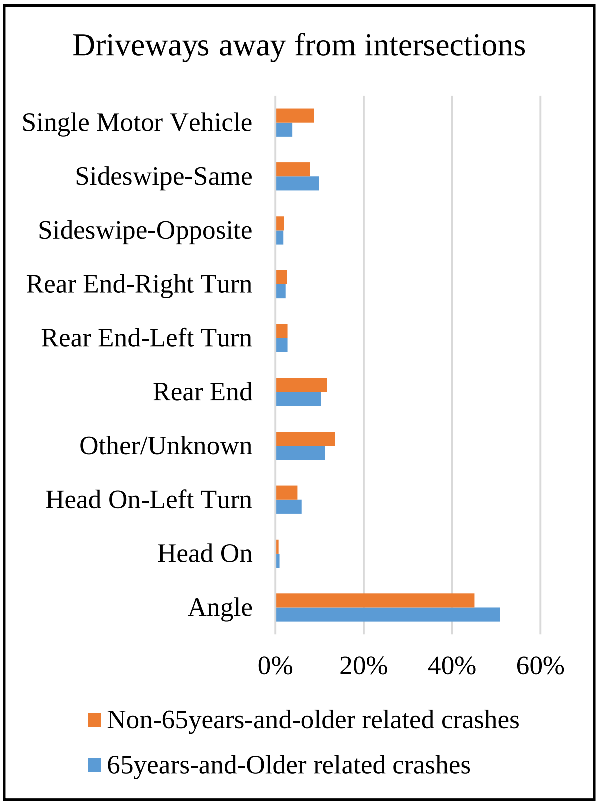


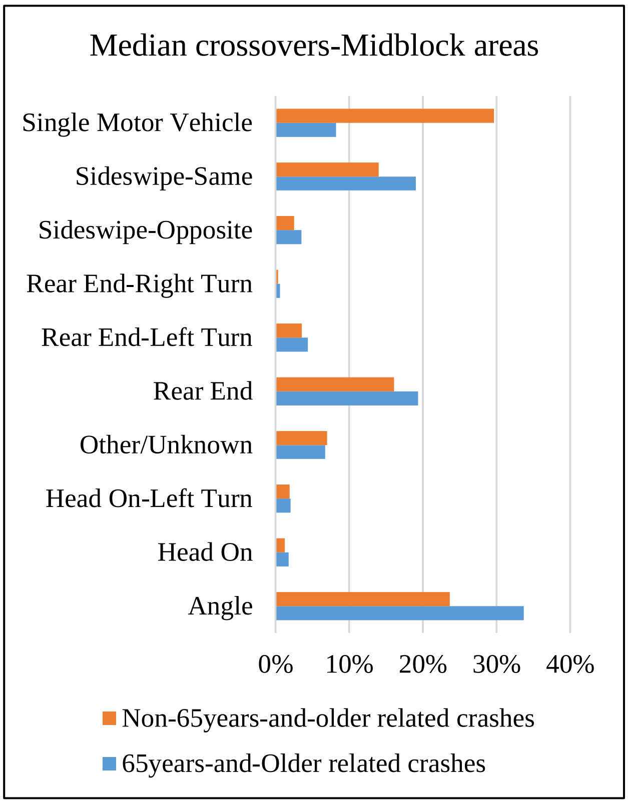
9.2 Appendices for Chapter 4: Analysis of Michigan's Older Adult Crashes

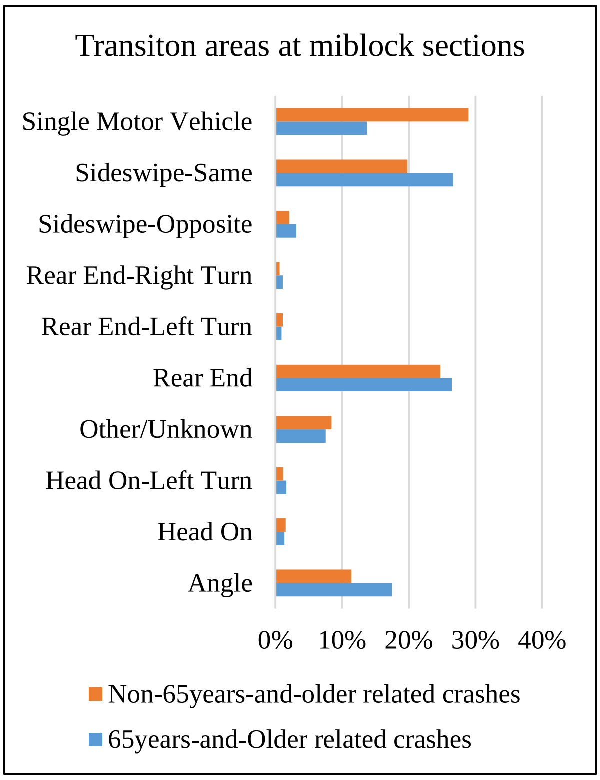
9.2.1 Hazardous actions committed by 65years-and-older drivers by action prior to crash at intersection

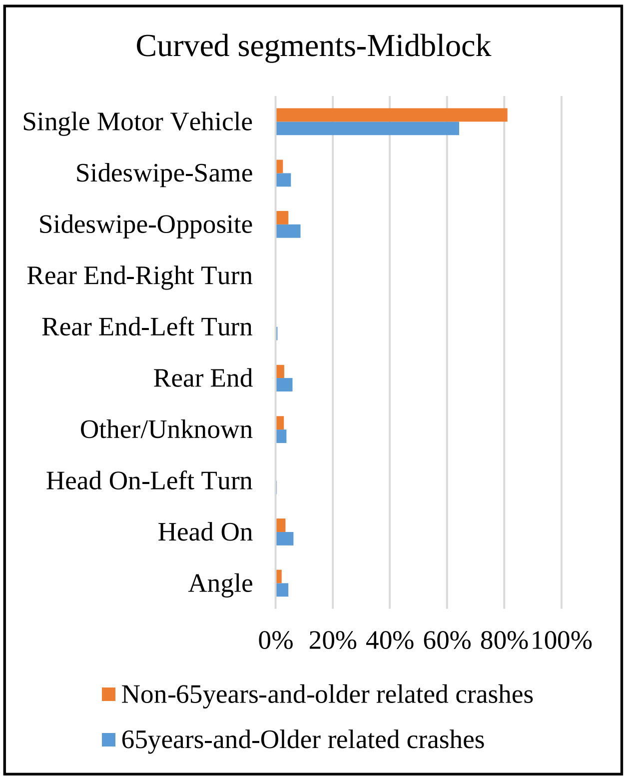
	Signal-controlled intersection			Stop-controlled intersection		
	Going Straight Ahead	Turning Left	Turning Right	Going Straight Ahead	Turning Left	Turning Right
Careless Driving	1%	1%	2%	2%	1%	2%
Disregard Traffic Control	11%	4%	2%	6%	2%	3%
Drove Left of Center	0%	0%	1%	1%	1%	4%
Drove Wrong Way	0%	0%	0%	0%	0%	0%
Failed to Yield	6%	63%	39%	15%	59%	32%
Improper / No Signal	0%	0%	0%	0%	1%	1%
Improper Backing	0%	0%	0%	0%	0%	0%
Improper Lane Use	2%	2%	8%	1%	1%	3%
Improper Passing	0%	0%	0%	0%	0%	0%
Improper Turn	0%	6%	11%	0%	7%	8%
None	53%	19%	23%	57%	22%	26%
Other	3%	2%	5%	3%	2%	5%
Reckless Driving	0%	0%	0%	0%	0%	0%
Speed Too Fast	2%	1%	2%	4%	2%	8%
Speed Too Slow	0%	0%	0%	0%	0%	0%
Unable to Stop	22%	1%	6%	10%	1%	7%

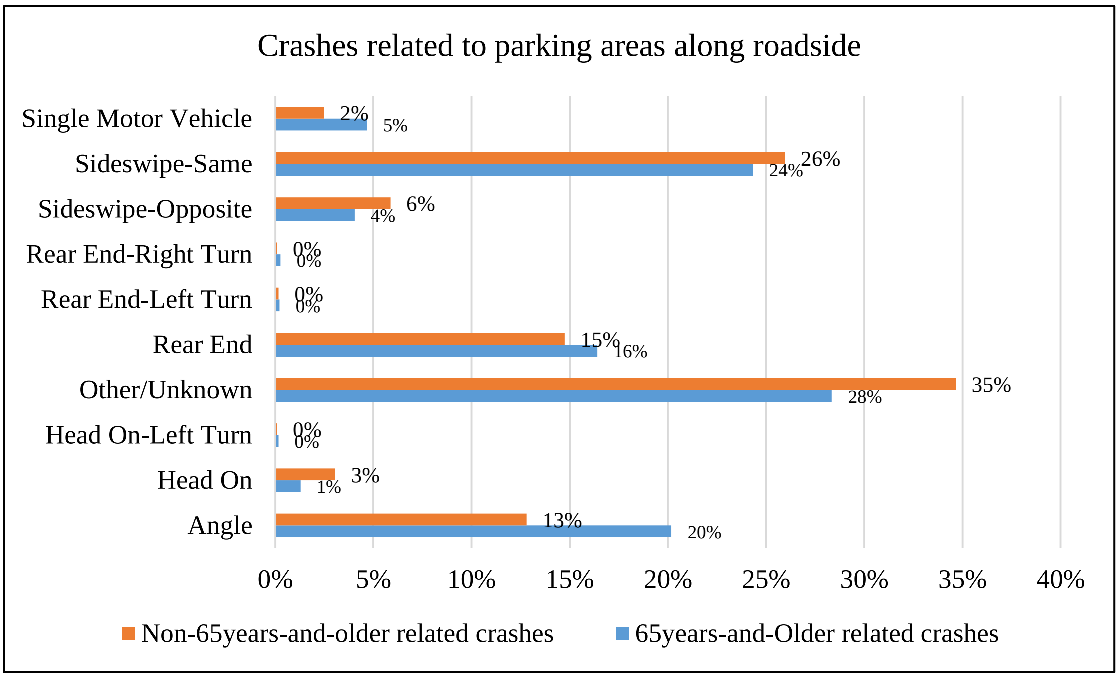
9.2.2 Crash type distribution at various locations in midblock areas



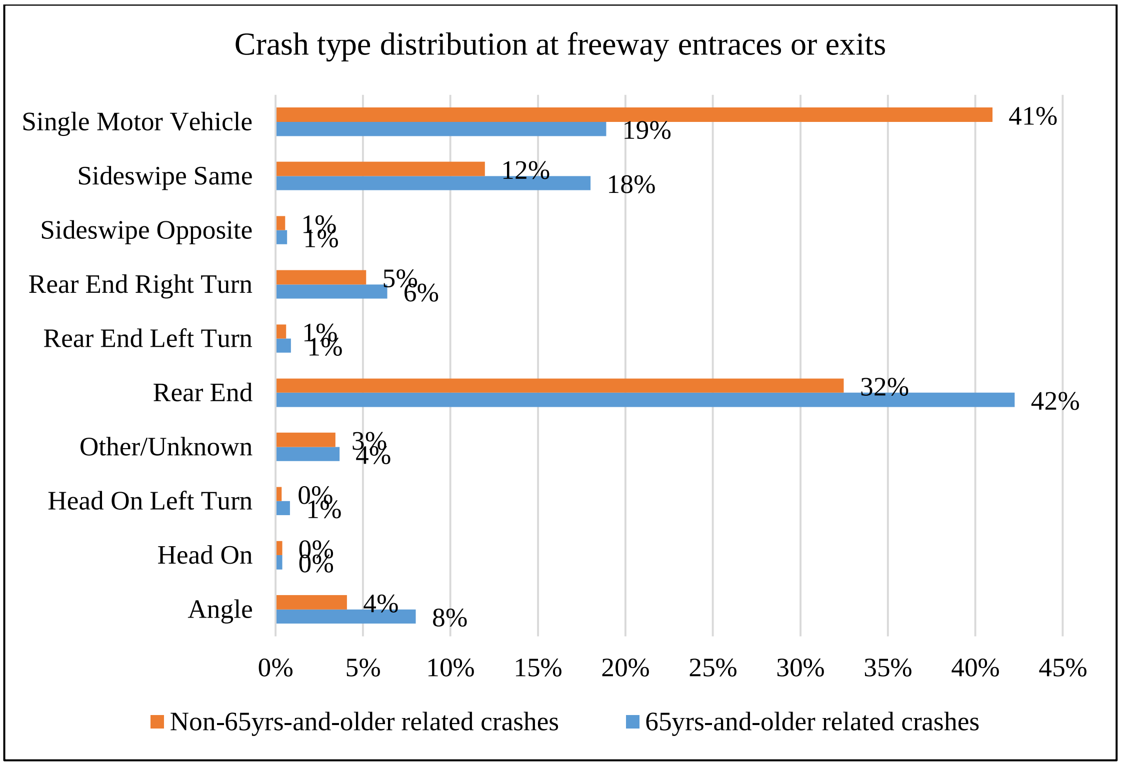








9.2.3 Crash type distribution at freeway entrances or exits



9.2.4 Hazardous actions committed by drivers involved in two-vehicles 65years-older-related crashes at midblock locations

	Median crossover		Non-frwy curved roadway segment		Driveways away from intersection		Parking area along roadside		Transition areas	
Hazardous Action	65+ yrs	<65yrs	65+ yrs	<65yrs	65+ yrs	<65yrs	65+ yrs	<65yrs	65+ yrs	<65yrs
Careless Driving	2%	1%	2%	4%	1%	1%	1%	2%	2%	2%
Disregard Traffic Control	5%	2%	0%	0%	0%	0%	1%	0%	2%	3%
Drove Left of Center	0%	0%	6%	8%	0%	0%	0%	0%	1%	0%
Drove Wrong Way	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Failed to Yield	28%	14%	11%	4%	39%	23%	15%	11%	21%	8%
Improper / No Signal	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Improper Backing	2%	1%	2%	2%	5%	5%	23%	15%	2%	1%
Improper Lane Use	4%	3%	5%	3%	2%	1%	2%	2%	8%	4%
Improper Passing	1%	0%	1%	1%	1%	1%	0%	1%	1%	1%
Improper Turn	2%	1%	1%	1%	2%	1%	1%	1%	3%	1%
None	38%	62%	56%	44%	41%	56%	44%	57%	43%	58%
Other	4%	3%	3%	4%	2%	2%	7%	8%	5%	4%
Reckless Driving	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
Speed Too Fast	1%	0%	7%	21%	0%	1%	0%	1%	2%	3%
Speed Too Slow	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Unable to Stop	13%	12%	6%	8%	5%	8%	5%	2%	10%	15%

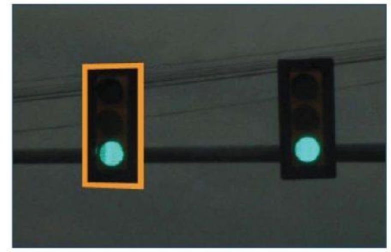
9.2.5 Hazardous actions committed by 65years-and-older drivers in single-vehicle crashes at midblock locations

	Driveway away from intersections	Median crossover	Non-frwy curved roadway segment	Parking area along roadside	Transition areas
Careless Driving	10%	9%	10%	20%	8%
Disregard Traffic Control	1%	2%	0%	0%	0%
Drove Left of Center	0%	0%	1%	0%	0%
Drove Wrong Way	0%	4%	0%	0%	0%
Failed to Yield	11%	0%	0%	5%	1%
Improper / No Signal	0%	0%	0%	0%	0%
Improper Backing	9%	0%	0%	10%	0%
Improper Lane Use	1%	0%	1%	1%	1%
Improper Passing	1%	2%	0%	0%	1%
Improper Turn	4%	7%	0%	1%	1%
None	25%	27%	34%	14%	53%
Other	23%	20%	11%	32%	10%
Reckless Driving	0%	0%	0%	0%	0%
Speed Too Fast	9%	22%	40%	3%	22%
Speed Too Slow	0%	0%	0%	0%	0%
Unable to Stop	6%	7%	2%	14%	3%

9.3 Appendices for Chapter 5: Guidance in Roadway Design for Michigan

9.3.1 MDOT Countermeasures for Older Driver Safety

Description	**Summary**	**Details**
Intersection		
Box signal configuration	For the new construction or design, continue to provide signal heads on the far side of the intersection in the optimal viewing position for drivers. This strategy has been found to reduce the risk of angle crashes at signalized intersections for older drivers.	
Enhanced traffic signal visibility	In order to ensure visibility and conspicuity of traffic signals, it is suggested that MDOT continue to provide 12 inch signal lenses. Larger signal lenses have been found to reduce the risk of angle crashes involving older drivers.	

Description	Summary	Details
Traffic signal backplates	It is suggested that MDOT continue its current efforts to utilize backplates with reflective yellow borders. This countermeasure enhances the target value of signal indications and reduce the potential for sun glare particularly for older drivers.	
Traffic signal head per lane	It is suggested that MDOT continue to provide traffic signals for each lane at intersections with higher speed limits and traffic volumes. This approach helps drivers position themselves in the correct lane and significantly increases visibility of the signal displays particularly for older drivers.	
Pedestrian crossings and signal timing	MDOT should continue to provide countdown pedestrian signals at all signalized intersections where pedestrian signals are warranted using the slower walking speeds now required in the MUTCD.	 (MMUTCD, MDOT)

Description	Summary	Details
High-visibility crosswalks	MDOT should continue to provide high visibility crosswalk markings at high pedestrian areas such as downtowns, schools, community colleges. High visibility crosswalk markings have been found to be visible from a further distance which increases the amount of perception reaction time available.	
Street Name Signs	MDOT should continue to provide advance street name sign or advance intersection warning sign (W2-1) or advance traffic control sign (with accompanying advance street-name plaque). Advanced intersection warning signs to provide additional warning to unfamiliar and older drivers.	 
Roadway segments		

Description	Summary	Details
Rumble strips	It is suggested that MDOT continue to provide edge line and centerline rumble strips on its roadways. Centerline rumble strips encourage drivers to position themselves more centrally in lanes, leading fewer encroachments over centerlines and thus reducing the risk of head-on crashes. Edge line rumble strips warn drivers to position themselves back in the lanes and thus reducing the risk of lane departure and single vehicle crashes.	 

Description	Summary	Details
Horizontal Curve Delineation	It is suggested that MDOT continue to be proactive in systemically implementing chevrons and curve delineation. These devices indicate to drivers a change in the alignment of the roadway and reduces the risk of lane departure and single vehicle crashes. Retroreflective pavement markings should be used especially for horizontal curves to increase nighttime wet pavement visibility	 Chevron and curve delineation
Road Diets	MDOT was one of the early adopters of road diets. A traditional road diets involves converting an undivided four-lane roadway section into three lanes made up of two through lanes and a center two-way left turn lane; however, there are many other configurations that have been implemented. It is suggested that MDOT continue to proactively consider roadway segments for conversions to road diets.	

Description	Summary	Details
Fluorescent Yellow Sheeting	The replacement of standard yellow sheeting with retro-reflective yellow sheeting increases conspicuity of drivers. Studies have shown a difference between retro-reflective and non-retro-reflective yellow signs. Particularly, older drivers have been observed to benefit the most since they detect the fluorescent yellow signs from a far distance ahead compared to the non-fluorescent signs. It is recommended that MDOT continue installation of fluorescent yellow sheeting.	
Arrow-Per-Lane Signs	The use arrow-per-lane on freeway signing was originally recommended in the *FHWA Highway Design Handbook for Older Drivers and Pedestrian*. Studies have indicated that this design to be clearer to older drivers by indicating which lane they needed to be in when approaching a freeway interchange with optional exit lanes. It is recommended that MDOT continue implementing arrow-per-lane signs at freeway interchanges with optional exit lanes.	

9.3.2 Comparison of MDOT Guidelines for Countermeasures to FHWA Guidebook

The rating followed this scale:

1-No Guidance from MDOT

2-Ambiguous Guidance from MDOT

3-Clear Guidance from MDOT not consistent with Handbook

4-Optional or Similar Guidance from MDOT consistent with Handbook

5-MDOT consistent with Handbook

Grouping	**Chapter**	**Section**	**Topic**	**MDOT Guidance**	**Rating:**
Intersections	2	1	Intersecting Angle (Skew)	A. Unrestricted Right-of-Way - MDOT not in agreement. *Road Design Manual 3.07.04* - "The angle of intersection between the approach road and the trunkline should not be less than 60 or more than 120 degrees, with desirable values between 75 and 120" B. Restricted Right-of-Way - Loose agreement per MDOT desirable values as indicated above. C. Skewed Signalized Intersections - *MMUTCD Section 2B.54* in loose agreement with federal handbook, by stating a RTOR should be considered for skewed intersections in general.	A. 3 B. 4 C. 4

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
	2	2	Receiving Lane (Throat) Width	No receiving lane specifics are given verbatim, however, the minimum lane widths are presented as follows: -**3R Projects (Rehab)** - MDOT not consistent; they req 10' or 11' lanes with a min. 2' shoulder (varies w/ ADT) - See *MDOT Road Design Manual 3.09.02* -**4R (New Construction)** - MDOT is consistent; A lane width of 12ft desirable (shoulder width varies from 4' to 8') - See *Road Design Manual Appendix 3A-2*	3
	2	3	Channelization	A. Left- and Right-Turn Lanes - MDOT is not consistent with the handbook. While MDOT acknowledges channelization as an effective strategy to enhance safety in *Section 2.0* of their *Michigan Intersection Guide*. This strategy is not explicitly covered in the right turn sub section. B. Retroreflective Markings - MDOT does provide guidance in Section 3B.10 of the MMUTCD for pavement markings, raised pavement markers, etc. relating to an obstruction (including channelization islands). This is somewhat consistent with the handbook, due to the lack of explicit direction relating to the treatment.	A. 1 B. 2 C. 1 D. 2 E. 2 F. 5

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
				C. Acceleration Lane - MDOT is not consistent. There is no specific guidance on acceleration lanes relating to channelization in the *MDOT Road Design Manual*. D. Sloping vs. Vertical Curbs - MDOT does not provide explicit guidance the use of curb relating to channelization. However, they do provide details for mountable curb for speeds of 45mph or less. See *Section 6.06.06C of the MDOT Road Design*. E. Pedestrian Refuge Island - MDOT references the ADAAG guidelines for pedestrian islands. However, they do not provide guidance for right turn channelization of pedestrian islands. See *Section 3I.06 of the MMUTCD*. F. Median Channelization - MDOT supports delineation of the turning path as evidenced by *2.1.e of the Michigan Intersection Guide*. Also the Geo 670 series from the MDOT Geometric Design Guide provides details on median left turns and crossovers.	
	2	4	Intersection Sight Distance	MDOT is not consistent; they recommend 7.5 sec with 0.5 sec for each additional lane, while the handbook recommends 8.0 sec. See *Road Design Manual 3.03.01*	3

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
	2	5	Offset Left-Turn Lanes	A-C. MDOT mentions that providing a positive offset for Left-turn lanes is beneficial for safety of older drivers, however does not mention specific guidance for minimum values. See *Michigan Intersection Guide 2.1.d* *http://mdotcf.state.mi.us/public/tands/Details_Web/mdot_michigan_intersection_guide.pdf* D. Signs and Markings: D-1 / D-2 - MDOT doesn't have any specific guidance for using the largest practical sized signs under this scenario. D-3 - MDOT provides this as shown in *Figure 2B-17 of the MMUTCD.* D-4 - This is covered by MDOT in *Section 3B.10 of the MMUTCD*. D-5 - Wrong-way arrows are referenced in *Section 3B.20 of the MMUTCD* and are optional for this situation. However, there is not specific guidance from MDOT in this particular scenario. D-6 - MDOT provides guidance for the use of retroreflective markings for raised medians and curbs as suggested by the handbook. See *Section 3B.23 in the*	A-C. 3 D-1/D-2. 1 D-3. 5 D-4. 5 D-5. 4 D-6. 5 E-1/E-2. 3

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
				MMUTCD. E. Pedestrian Accomodations: E-1 / E-2 - MDOT does not provide specific guidance relating to slower walking pedestrians. However, they have guidance for pedestrian refuge islands and references federal guidelines as shown in *Section 3I.06 of the MMUTCD.*	
	2	6	Delineation of Edge Lines and Curbs	A. No specific luminence contrast levels are stated by MDOT. See *MMUTCD Section 3B.06* B. The signs explained by the handbook are consistent: W12-1 is in agreement *MMUTCD Section 2C.25*; R4-7 is in agreement MMUTCD Section 2B.32; The OM1-1 is mention in *Section 2C.64 of the MMUTCD*, where MDOT states, "Obstructions within the roadway shall be marked with a Type 1 or Type 3 object marker. Delineation of curbs and raised medians is also covered in *MMUTCD Sections 3B.23*, however, the MDOT recommendation is not consistent with the handbook.	A. 1 B. 4
	2	7	Curb Radius	A-B. MDOT specifies a minimum raidus of 30' or as required for design vehicle for a standard right angle	A-B. 3

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
				intersection, which is in loose agreement with the handbook (25 to 30; compound curve as needed for heavy vehicles). See *MDOT Geometric Design Guide GEO-650 Series* as referenced in the *Road Design Manual 12.02.01*.	
	2	8	Left-Turn Traffic Control for Signalized Intersections	A. MDOT doesn't indicate a strong preference for protected only phasing over the other options, however, they have an option stating that, "In areas having a high percentage of older drivers, special consideration may be given to the use of protected only mode left-turn phasing, when appropriate." See *MMUTCD Section 4D.17*. B. MDOT is not consistent, "A supplementary sign shall not be required." However, the sign they recommend to be used (if used) is consistent. See *MMUTCD Section 4D.20* C. MDOT is in loose agreement with the handbook, "If needed for additional emphasis, an additional [RB10-12] with an [RB10-31P] may be installed advance of the intersection." See *MMUTCD Section 2B.53*. D. MDOT is not consistent and allows for leading or lagging left turn phasing if advantageous for corridor progression and consistent with driver expectations. See	A. 3 B. 3 C. 4 D. 2

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
				MDOT Electronic Traffic Control Device Guidelines Section 2.1 http://mdotcf.state.mi.us/public/tands/Details_Web/electronic_traffic_control_device_guidelines.pdf	
	2	9	Right-Turn Traffic Control for Signalized Intersections	A-C. MDOT is consistent. See *MMUTCD Section 2B.54*	A-C. 5
	2	10	Street Name Signs	A. MDOT is not consistent; They're in agreement for post-mounted Street Name signs, however, their guidance for upper-case 8" and lower-case 6" lettering is for 40 mph or higher as opposed to the handbook's 25 mph or higher. MDOT is consistent with the use of overhead signs for major intersections via the use of an option, however it's not a specific guidance. See *MMUTCD Section 2D.43*. B-D. MDOT is consistent. *MMUTCD See Section 2D.44*. *E*. MDOT is not consistent and doesn't provide any additional guidance on retroreflectivity in the areas described in the handbook.	A. 3 B-D. 5 E. 1

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
	2	11	Stop and Yield Signs	A. MDOT is consistent with R1-1 (Stop), however, they provide a smaller typical size for the R1-2 (Yield) when compared to the handbook. See *MMUTCD Table 5A-1.* B. MDOT is not consistent with Red retroreflectivity, as they provide a lower minimum value of 7 cd/lx/m^2. See *MMUTCD Table 2A-3.* C. MDOT is not consistent with the size of W4-4P being smaller than handbook recommendations. Also, MDOT does not mention sight distance for the sign option, rather, they use broader language. See MMUTCD Table 2C-2 and *Section 2C.59* D. MDOT is not consistent, because they don't state specific SSD and preview distance values. Again, broad language is used to indicate the use of this sign. See *MMUTCD Section 5C.04.* E. MDOT does not reference the use of pavement markings in the MMUTCD, rather, they specify the use of a supplementary warning beacon (See *MMUTCD Section 2C.36).* They do indicate the benefits of using Pavement	A. 3 B. 3 C. 2 D. 2 E. 3

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
				Markings with Supplementary Messages in the *Michigan Intersection Guide Section 5.6*.	
	2	12	Lane Assignment on Intersection Approach	A. MDOT is consistent with the handbook and provides specific instructions for the consistent placement of overhead signs. See *MMUTCD Section 2B.19*. B. MDOT is inconsistent with the handbook by stating that, "Movement Prohibition signs may be omitted at a ramp entrance to an expressway or a channelized intersection where the design is such as to indicate clearly the one-way traffic movement on the ramp or turning lane. Also, they don't state specific guidelines for sight distance requirements and placement for the sign, rather, they use broader language such as, "...should be placed where they will be most easily seen by road users who might be intending to make the movement." See *MMUTCD Section 2B.18-27.*	A. 5 B. 4

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
	2	13	Traffic Signals	A. MDOT references Vehicle Traffic Control Signal Heads and Traffic Signal Lamps for luminence requirements (**No access to these at the moment - further review needed**). B. MDOT is not consistent with the handbook. The MMUTCD references the ITE "*Traffic Control Devices Handbook*" (Section 4D.26). MDOT's *Electronic Traffic Control Device Guidelines Section 4.1* states a specific formula that is not consistent with the handbook. C. MDOT has consistent rules with the handbook, with the exception of the specified speed limit cut off designations (MDOT - < or > 45 mph; Handbook - < or > 40 mph). See *MMUTCD Section 4D.12*	A. ?? B. 3 C. 4
	2	14	Intersection Lighting	A. MDOT has guidance on intersection lighting relating to nightime crash experience and pedestrians, and also references the "Older Drivers Guide". See *MDOT Michigan Intersection Guide Sections 3.0, 7.1 and 7.4.* B. No guidance or recommendations from MDOT regarding the maintenance of lighting.	A. 5 B. 1

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
	2	15	Pedestrian Crossings	A. Walking Speed - MDOT uses a higher walking speed (3.5 sec vs 3.0 sec) when compared to the handbook. Both agree on how to perform distance measurement. See *MMUTCD Section 4E.06*. B. Channelized Right-Turn lane: B-1 / B-2 - MDOT doesn't provide specific guidance regarding pedestrian islands relating to channelized right-turn lanes. Rather, they provide a reference to Federal ADAAG guidelines. See *Section 3I.06 of the MMUTCD*. C. Educational Signs - MDOT provides standards and options for signs consistent with the handbook. See *Section 2B.52 in the MMUTCD*. D. Turning Vehicles Yield to Pedestrians Sign - MDOT provides guidance to use this sign as an option supplementing traffic signal control. See *Section 2B.53 in the MMUTCD*. E. Leading Pedestrian Interval - MDOT is consistent with the manual by providing an option for a leading pedestrian interval. However, the formula provided in the handbook for LPI is not referenced, rather MDOT indicates a minimum of at least 3 seconds be used. See *Section 4E.06 of the*	A. 3 B-1/B-2. 3 C. 5 D. 4 E. 3 F. 5

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
				MMUTCD. F. Countdown Signal - MDOT is consistent with the handbook. See *Section 4E.07 of the MMUTCD*.	
	2	16	Roundabouts	A. Number of Lanes - MDOT agrees with the single lane mandate from the handbook, but states the guidance from a safety perspective, "Designers should also keep in mind that single-lane roundabouts typically provide a greater crash reduction than multilane roundabouts." See *Section 3.1 of the MDOT Roundabout Guidance Document.* B. Pedestrian Crossings - MDOT specifies one car length before the yield line. The specific measurement for a car length is not provided elsewhere in the guide, but remains comparable to the 25' specified in the handbook. Both MDOT and the handbook are consistent with the inclusion of a pedestrian refuge island. See *Section 4.9 of the MDOT Roundabout Guidance Document.* C. Splitter Islands - MDOT is consistent with the handbook, and advocates the use of splitter islands in accordance with *Section 6.3.8 of the FHWA Roundabouts: An Informational Guide*	A. 4 B. 4 C. 5 D. 3 E. 5 F-G. 5

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
				D. Conspicuity - MDOT's guidance suggest painting curb faces with reflective paint as an optional treatment, but doesn't specify minimum luminance contrast levels like the handbook. See *Section 5.2 of the MDOT Roundabout Guidance Document.* E. Advance Warning Sign - MDOT is consistent with the handbook recommending the use of an advanced roundabout warning sign. See Figure 10 in *Section 5.3 of the MDOT Roundabout Guidance document* and Section 7.1 of the FHWA Guide. F-G. Directional Signs/Roundabout Circulation Plaque - MDOT is consistent with the handbook. See *Section 2B.45 of the MMUTCD.*	
	2	17	Right-Turn Channelization Design	MDOT does not have reference to channelized right-turns in the Michigan Intersection Guide, Geometric Design Guide, or Road Design Manual.	1
	2	18	Combination Lane-Use/Destination Overhead Guide Signs	MDOT provides an option (Not a standard) that is consistent with the handbook. See *MMUTCD Section 2D.33.*	5

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
	2	19	Signal Head Visibility	MDOT is consistent with the handbook. See *MMUTCD Section 4D.11*.	5
	2	20	High-Visibility Crosswalks	MDOT is consistent with the handbook by providing an option (not a standard) in *Section 3B-18 of the MMUTCD.*	4
	2	21	Supplemental Pavement Marking for Stop and Yield Signs	MDOT is consistent with the handbook by providing an option (not a standard) for including STOP AHEAD and YIELD AHEAD pavement markings in *Section 3B-20 of the MMUTCD.*	4
	2	22	Reduced Left-Turn-Conflict Intersections	MDOT is consistent with the handbook and utilizes median u-turn intersections. See the *GEO-670 series* in the *Geometric Design Guide* for more details.	5
	2	23	Accessible Pedestrian Signal (APS) Treatments	A. Pushbutton-Activated Extended Pedstrian Crossing Phase - MDOT is consistent with the handbook by providing an option (not a standard) in *Section 4E.06 of the MMUTCD*. B. Passive Pedestrian Detection - Also covered in Section 4E.06, passive detection is suggested as an option.	A. 4 B. 4
	2	24	Flashing Yellow Arrow	MDOT is not consistent with the handbook because they allow a circular green signal indication or a flashing left-turn yellow arrow. See *Section 4D.17 of the MMUTCD.*	3

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
	3	25	Exit Signs and Markings	A-B. Letter Size / Mixed-Case Lettering - MDOT is consistent with the handbook. See *Section 2A.13 of the MMUTCD* C. Overhead Arrow-per-Lane Sign - MDOT is consistent with the handbook. See *Section 2E.20-21 of the MMUTCD* D. Retroreflective Sheeting - MDOT provides guidance for Enhanced Conspicuity for Standard Signs in Section 2A.15 of the MMUTCD. While this could be applied to Exit Signs, the direction is not explicitly there. Therefore, MDOT is not consistent with the handbook in this case.	A-B. 5 C. 5 D. 3
Interchanges	3	26	Freeway Entrance Traffic Control Devices	A. Guide Sign - MDOT is consistent with the handbook. See *Section 2D.46 of the MMUTCD*. B. Adjacent Entrance/Exit Ramps - No specific guidance from MDOT on this scenario, however, this a median seperator is depicted in *Detail 5 of GEO-370-E in the MDOT Geometric Guide*. C. Diagrammatic Entrance Signs - MDOT is in agreement that signage should be placed on conventional roads to indicate which direction to turn and/or which specific lane to use for ramp access to each direction of the freeway or	A. 5 B. 2 C. 3

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
				expressway. However, they do not explicitly say a diagrammatic sign should be used as stated in the handbook. See *Section 2D.45 of the MMUTCD.*	
	3	27	Delineation	A. Delineators/Raised Pavement Markers - MDOT advocates for the use of delineators and raised pavement markers for curves, however they don't have a typical or guidance for the layout provided in the handbook for exit gores as an example. Also, the spacing in the handbook is 10-20 ft where MDOT specifies 100 ft spacing on curve sections. See *Sections 3F.03-04 in the MMUTCD.* B. Object Marker - MDOT is consistent with the handbook. See *Section 2C.65 in the MMUTCD.* C. Chevrons/Post-Mounted Delineators - MDOT is consistent with the handbook. See *Figure 2C-3 in the MMUTCD.*	A. 3 B. 5 C. 5
	3	28	Acceleration/Deceleration Lane Design	A. Entrance Ramp Geometry - MDOT is not consistent with the handbook, as they allow both parallel or tapered ramps. See the *Geo 100 Series in MDOT Geometric Design Guide*. B. Location of Exit Ramps - MDOT is in agreement with	A. 3 B. 5

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
				the handbook, as they recommend following the AASHTO guidelines when determining sight distances. See *Section 3.03.01 in the Michigan Road Design Manual.*	
	3	29	Interchange Lighting	A. Complete versus Partial Lighting - MDOT is currently working on a P3 project for lighting in the Metro region (http://www.michigan.gov/mdot/0,4616,7-151-9625_21539_53226-322919--,00.html), which is indicative of MDOT's attitude towards the importance of lighting in general. The handbook appears to reference a general practice towards freeway lighting which should be a directive from MDOT with future projects like the P3 previously mentioned.	A. 1
	3	30	Restricted or Prohibited Movements	A. Signing Practices: A-1 - MDOT is not consistent with the handbook, as they specify the same size signs as the federal MUTCD. See *Table 2B-1 in the MMUTCD.* A-2 - The handbook makes a rather ambiguous statement in this case. MDOT provides a chart of sheeting type in *Table 2A-3 of the MMUTCD*. A-3/A-4 - MDOT is consistent with the handbook, as	A-1. 3 A-2. 3 A-3/A-4. 5 B-1/B-2. 5

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
				they allow the placement of a second DO NOT ENTER sign where traffic approaches from an intersecting roadway and the lowering of sign height. See *Section 2B.37 in the MMUTCD.* B. Pavement Markings: B-1/B-2 - MDOT is consistent and provides an option (not standard) for the use of wrong-way arrows. See *Section 2B-41 of the MMUTCD.*	
	3	31	Advance Pavement (Route Shield) Markings at Major Freeway Junctions	MDOT is consistent with the handbook by allowing an option for route shield markings. See *Section 3B.20 of the MMUTCD.*	5
	3	32	Wrong-Way Driving Countermeasures	MDOT is aware of the problem with Wrong-Way crashes and seeking to implement potential countermeasures. See this presentation for details: http://sdite.org/presentations2012/1A-LEIX--Wrong_Way_Freeway_Crashes_in_Michigan.pdf	4

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
Roadway Segments	4	33	Horizontal Curves	A. Edge Lines: A-1 / A-2 - MDOT does not provide specific guidance on luminance contrast levels. B. Retroreflective Pavement Markers: B-1 / B-2 - MDOT provides an option in Section 3B.12 of the MMUTCD that is consistent with the handbook. C. Post-Mounted Delineators -MDOT provides an option for delineators to be used in conjunction with Chevron Alignment signs. See *Section 2C.09 of the MMUTCD*. D. Pavement Width - MDOT provides guidance for variable shoulder and lane widths as presented in the *MDOT Road Design Manual*. As such, they are not consistent with the handbook's rule. See *Section 3.09.02 and Appendix 3A in the MDOT Road Design Manual*.	A-1/A-2. 1 B-1/B-2. 4 C . 4 D. 3
	4	34	Vertical Curves	A. Perception-Reaction Time - MDOT is consistent with the handbook by assuming a 2.5 sec brake reaction time. See the *Stopping Sight Distance* section of the *MDOT Sight Distance Guidelines*. B. Passive Warning Sign - MDOT is consistent with the handbook. See *Section 2C.18 of the MMUTCD.*	A. 5 B. 5 C. 4

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
				C. Active Warning Sign - MDOT advocates for the use of this sign per engineering judgment and not with specific guidelines such as those stated in the handbook. See *Section 2C.36 of the MMUTCD*.	
	4	35	Passing Zones	A. Passing Sight Distance - MDOT is consistent with the handbook's provided table. See 'Passing Sight Distance - Pavement Markings' in the *MDOT Sight Distance Guidelines*. B. Pennant - MDOT is not consistent with the handbook. MDOT's recommended typical sign size (40x40x30) is the minimum size recommended by the federal MUTCD. Also, MDOT does have recommendations for retroreflectivity, but due to the ambiguous language in the handbook no direct conclusions can be made. See *Tables 2A-3 and 5A-1 in the MMUTCD.* C. Passing Lanes - MDOT does not have any specific language in agreement with the handbook. *Section 3.09.05 of the MDOT Road Design Manual* has guidelines for passing relief lanes, however, they provide broad language and no specifics.	A. 5 B. 3 C. 2

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
	4	36	Lane Control Devices	A. Pixel Specifications - MDOT does not provide specific pixel specifications as outlined in the handbook, however they have a statement, "The color of lane-use control signal indications shall be clearly visible for 2,300 feet at all times under normal atmospheric conditions, unless otherwise physically obstructed." See *Section 4M.03 in the MMUTCD*	A. 3
	4	37	Lane Drop Markings	MDOT provides a standard consistent with the handbook. See *Section 3B.04 of the MMUTCD.*	5
	4	38	Contrast Markings on Concrete Pavement	MDOT provides an option (not a standard) that is consistent with the handbook. See *Section 3A.05 of the MMUTCD.*	4
	4	39	Utilize Highly Retroreflective Marking Material	MDOT provides a standard that is consistent with the handbook. See Section 3A.02 of the MMUTCD.	5
	4	40	Curve Warning Markings	MDOT does not provide guidance for curve warning markings and does not explicitly allow for their use. See *Section 3B.20 in the MMUTCD* for more information.	1
	4	41	Road Diets	MDOT is consistent with the handbook. They have completed research on road diets and have published a	4

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
				research spotlight as shown here: http://www.michigan.gov/mdot/0,4616,7-151-9622_11045_24249-270908--,00.html. Also of note: their Road Safety Audit program uses the Road Safety Audit Toolkit for Federal Land Management Agencies and Tribal Governments (http://safety.fhwa.dot.gov/rsa/resources/toolkitflh/toolkitflh.pdf), where the road diet is currently not mentioned. Finally, MDOT considers road diets based on crash history, turning volumes, presence of transit, travel time/LOS, and accessibility according to the FHWA's Road Diet Informational Guide (http://safety.fhwa.dot.gov/road_diets/info_guide/ch3.cfm).	
	4	42	High Friction Surface Treatments	MDOT is consistent with the handbook and provides methodology for testing and enhancing pavement friction when necessary. See S*ection 6.10.01 of the MDOT Road Design Manual*.	5
Construction / Work Zones	5	43	Signing and Advance Warning	A. Flashing Yellow Arrow Panel - MDOT is consistent with the handbook for recommending use of arrow boards. See *Chapter 6H of the MMUTCD.*	A. 5 B. 4

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
				B. Lane Closure Advance Signing - MDOT recommends the use of advanced signing as shown in their Maintaining Traffic Typicals, however, they do not reference a supplemental portable changeable message sign or mention the use of flashing warning lights as described in the handbook. C. Sign Sheeting - MDOT recommends the use of fluorescent orange as an option (not a standard) to enhance retroreflectivity of signs. Also, they offer beaded or prismatic sheeting along with specifications of each. See *Table 2A-3 and Section 6F.02 of the MMUTCD.* D. Legibility Distance - MDOT is consistent with the handbook. See *Section 2A.13 of the MMUTCD.*	C. 4 D. 5
	5	44	Portable Changeable (Variable) Message Signs	A. Number of Phase - MDOT is consistent with the handbook. See *Section 2L.05 of the MMUTCD.* B. Display Time - MDOT is not consistent with the handbook, as they recommend a minimum of 2 seconds per phase as opposed to 3 seconds. See *Section 2L.05 of the MMUTCD.* C. Units of Information - MDOT is consistent with the	A. 5 B. 3 C. 5 D. 4 E. 3 F. 3

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
				handbook. See *Section 2L.05 of the MMUTCD.* D. Sign Content - MDOT provides content rules that are similar to the handbook, although not exactly the same wording is used. See *Section 2L.05 of the MMUTCD.* E. Legibility - MDOT provides different legibility standards than those described in the handbook, particularly in regard to the maximum stroke width-to-height ratio. Please note, the same pixel matrix is utilized for both MDOT and the handbook. See *Section 2L.04 in the MMUTCD.* F. Sign Height - MDOT does not state the same rule as the handbook, however, they say for example, "...roadways with speed limits of 55 mph or higher should be visible from 1/2 mile under both day and night conditions..." Based on this requirement, the sign would be visible across multiple lanes of traffic. See *Section 2L.03 in the MMUTCD.*	

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
	5	45	Channelization (Path Guidance)	A. Device Dimensions (See *Figure 6F-7 of the MMUTCD*): A-1 - MDOT provides a range in traffic cone height between 24" and 36". The handbook states 36" should be the standard. A-2 - MDOT states the minimum is 28" while the handbook recommends 42". Also, no width dimension is specified by MDOT. A-3 - MDOT provides a range from 8" to 12" wide, while the handbook recommends 12" wide verbatim. A-4 - Again, MDOT provides a range in barricade panel height from 8" to 12" while the handbook recommends 12" minimum. Also, MDOT requires a minimum of 24" while the handbook states 36" for the panel width. A-5 - MDOT is consistent with the handbook in regards to drum requirements. B. Device Spacing - MDOT is not consistent with the handbook. They have a range in spacing requirements depending on speed limit, where the handbook states a definite rule regardless of speed. See *Section 6F.63 of the MMUTCD.*	A-1. 3 A-2. 3 A-3. 3 A-4. 3 A-5. 5 B. 3 C. 3

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
				C. Reflectors - MDOT doesn't say to use reflectors mounted on temporary barrier, rather, they provide the option for warning lights or steady-burn lamps. See *Section 6F.85 of the MMUTCD*.	
	5	46	Delineation of Crossovers/Alternate Travel Paths	A. Positive Barriers - MDOT provides an option for the use of temporary traffic barriers to separate two-way vehicular traffic. See *Section 6F.85 of the MMUTCD.* B. Device Spacing - MDOT provides equations for calculating L as a function of speed which is halfed for taper calculations. The handbook's recommendation of 1/2 the speed limit (mph) is more conservative. See *Section 6C.07 in the MMUTCD.* C. Reflectors - MDOT provides an option for warning lights or steady-burn lamps to be mounted on temporary	A. 5 B. 3 C. 4 D. 3

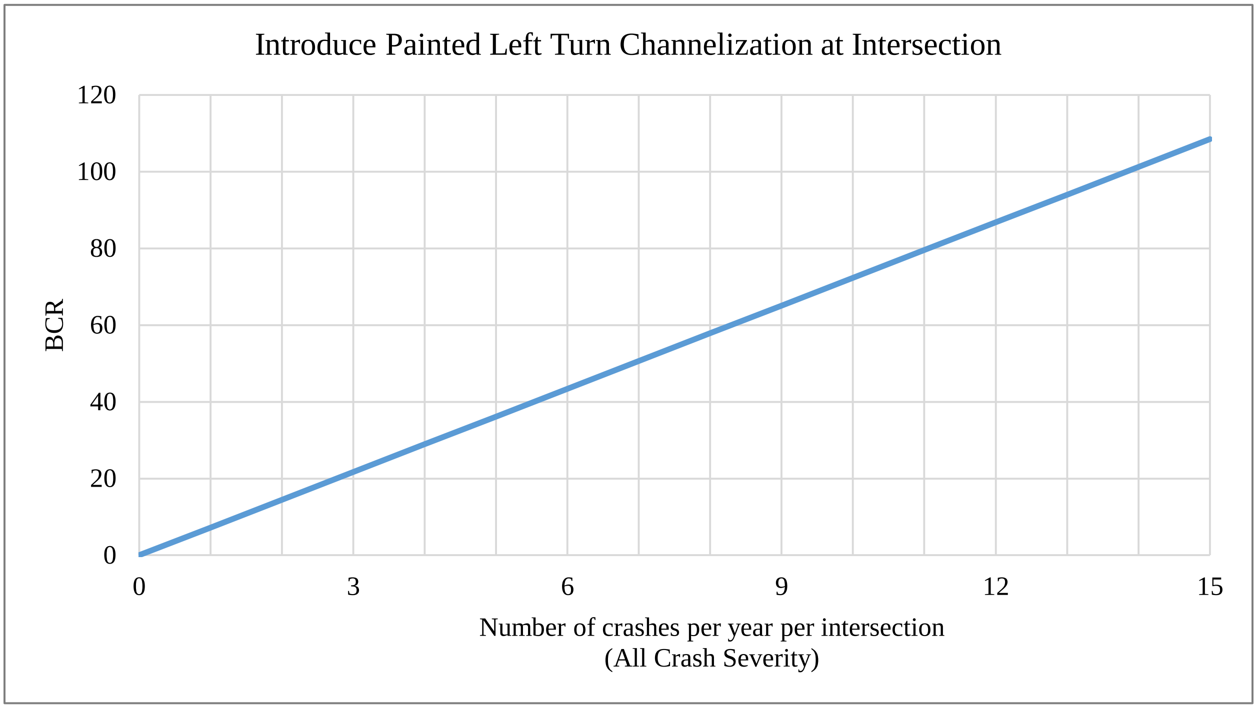
Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
				barriers. These are comparable to the reflectors specified in the manual. Further, MDOT says, "Temporary traffic barriers shall be supplemented with standard delineation, pavement markings, or channelizing devices for improved daytime and nighttime visibility." See *Section 6F.85 of the MMUTCD.* D. Screens - MDOT provides the option for the use of screens in *Section 6F.88 of the MMUTCD*, however they don't specify spacing requirements and therefore are not consistent with the handbook.	
	5	47	Temporary Pavement Markings	A. Raised Pavement Markers - MDOT does not have guidance for using raised pavement markers to supplement temporary markings of less than 10ft. Rather, they allow for the substitution of raised pavement markers in certain circumstances. See *Sections 6F.78-79 of the MMUTCD.*	3
	5	48	Increased Letter Height for Temporary Work Zone Signs	MDOT does not provide guidance for increased letter height regarding temporary work zone signs.	

Grouping	Chapter	Section	Topic	MDOT Guidance	Rating:
	5	49	Work Zone Road Safety Audit (WZRSA)	MDOT provides a Work Zone Audit Report (http://mdotcf.state.mi.us/public/webforms/public/0397.pdf) along with a Work Zone Safety and Mobility Manual (https://www.michigan.gov/documents/mdot/MDOT_WorkZoneSafetyAndMobilityManual_233891_7.pdf) which provide guidance relating to the processes outlined in the handbook.	4
Highway-Rail Grade Crossing	6	50	Passive Traffic Control Devices	A. Post-Mounted Delineators - MDOT is not consistent with the handbook, and does not recommend the use of post mounted delineators in Chapter 5F of the MUTCD.	3
	6	51	Lighting	A. Luminaire Type/Alignment - MDOT doesn't state any specific scenarios or options relating to lighting in the Traffic Control For Highway-Rail Grade Crossings chapter of the MMUTCD, however, they state that other traffic control devices including illumination, "...shall comply with the provisions in Part 8 and other applicable Parts of this Manual." See *Section 5F.06 of the MMUTCD.*	2

9.4 Appendices for Chapter 6: Benefit-Cost Analysis of Potential Countermeasures

9.4.1 Painted Left Turn Channelization

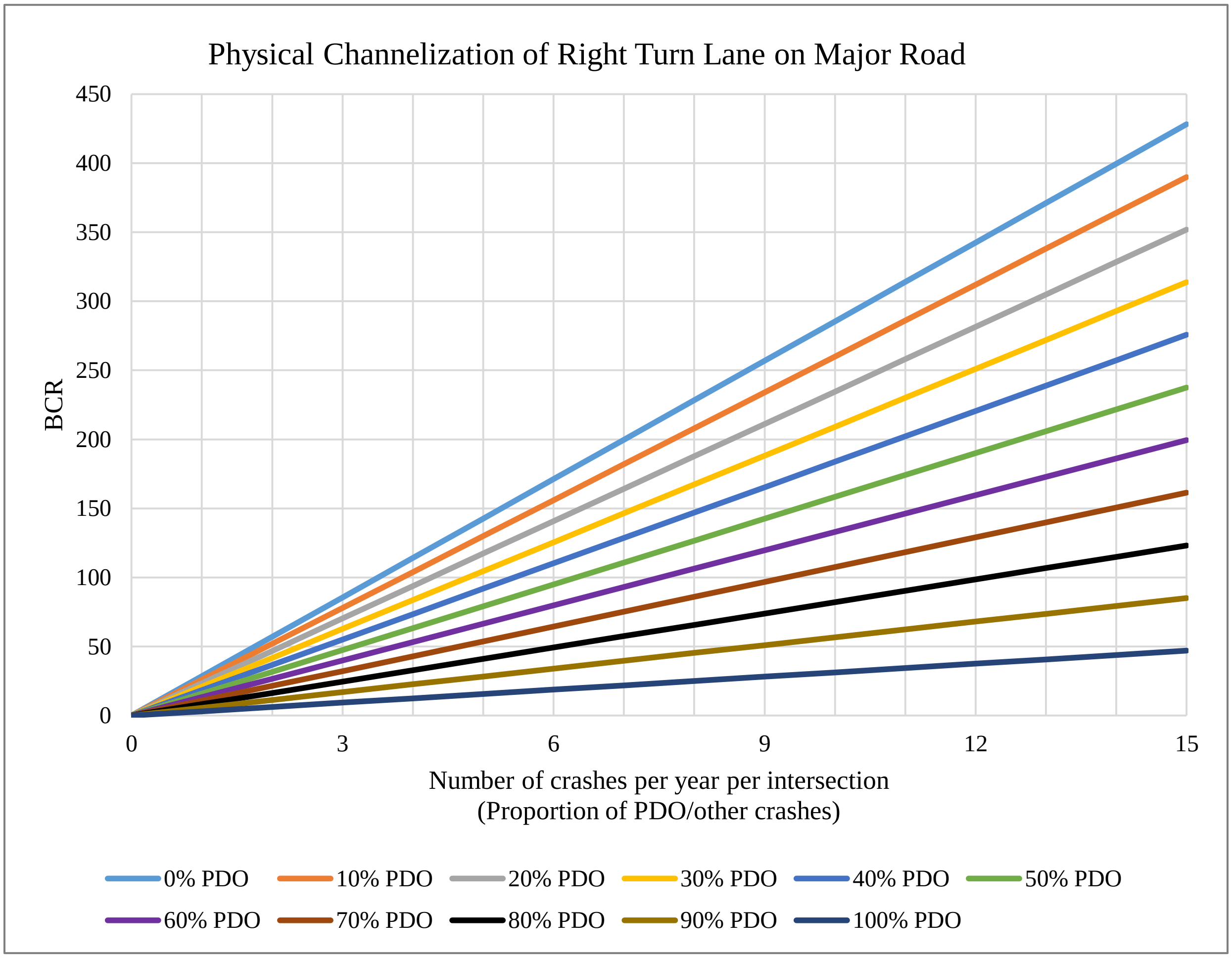
CMF applicability			
Item	Description	Item	Description
CMF Value	FI/PDO = 0.67	Area type	Rural
CRF Value	FI/PDO = 0.33	Intersection geometry	4-leg
Crash type	All	Traffic control	Stop control
Roadway types	Not specified	Methodology used	Regression cross-section



BCR for introduction of painted left turn channelization at stop controlled 4-leg rural intersection

9.4.2 Physical channelization on both roads (left or right turn lanes (250ft-12ft lanes)

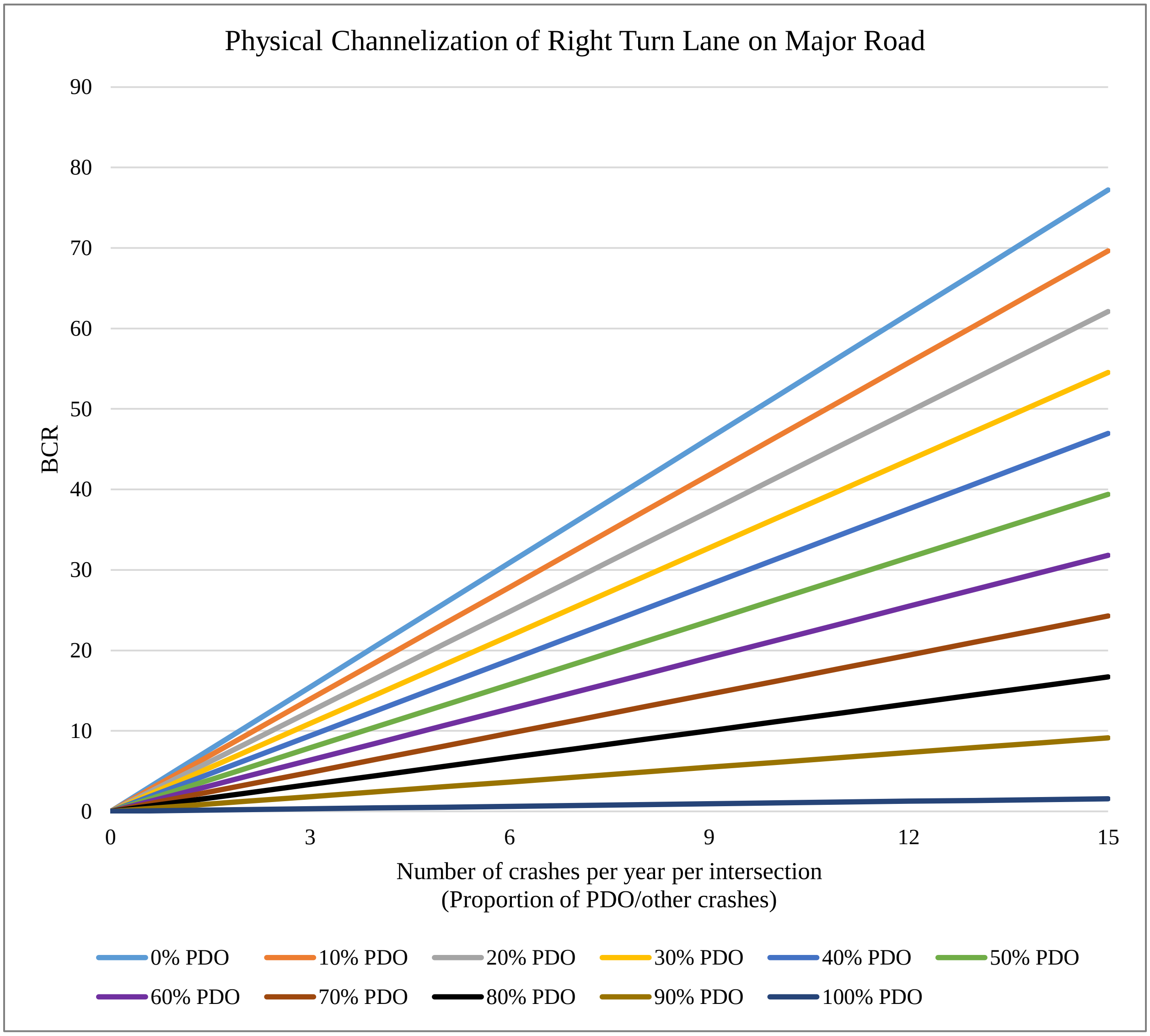
CMF applicability			
Item	Description	Item	Description
CMF Value	FI = 0.73 & PDO = 0.87	Area type	Rural
CRF Value	FI = 0.27 & PDO = 0.13	Intersection geometry	4-leg
Crash type	All	Traffic control	Not specified
Roadway types	Not specified	Methodology used	Meta-analysis



BCR for construction of physical channelization of both roads at 4-leg rural intersection

9.4.3 Physical channelization on Right Turn Lane on Major Roads

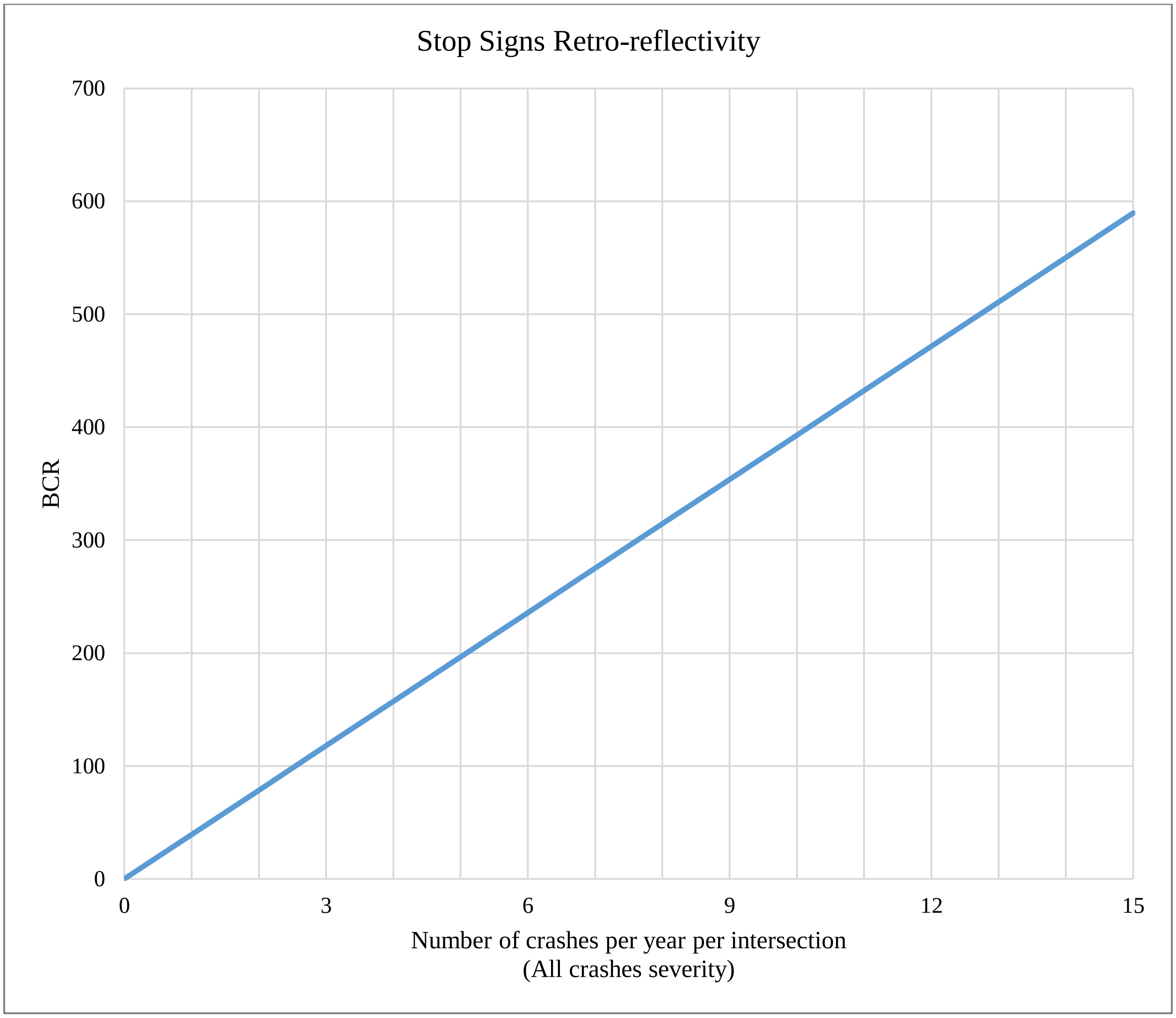
CMF applicability			
CMF Value	ABC = 0.87 & PDO = 0.81	Area type	Rural
CRF Value	ABC = 0.13 & PDO = 0.19	Intersection geometry	4-leg
Crash type	All	Traffic control	Not specified
Roadway types	Not specified	Methodology used	Meta-analysis



BCR for construction of physical channelization of right turn lane on major roads at 4-leg rural intersection

9.4.4 Increase retro-reflectivity of stop signs

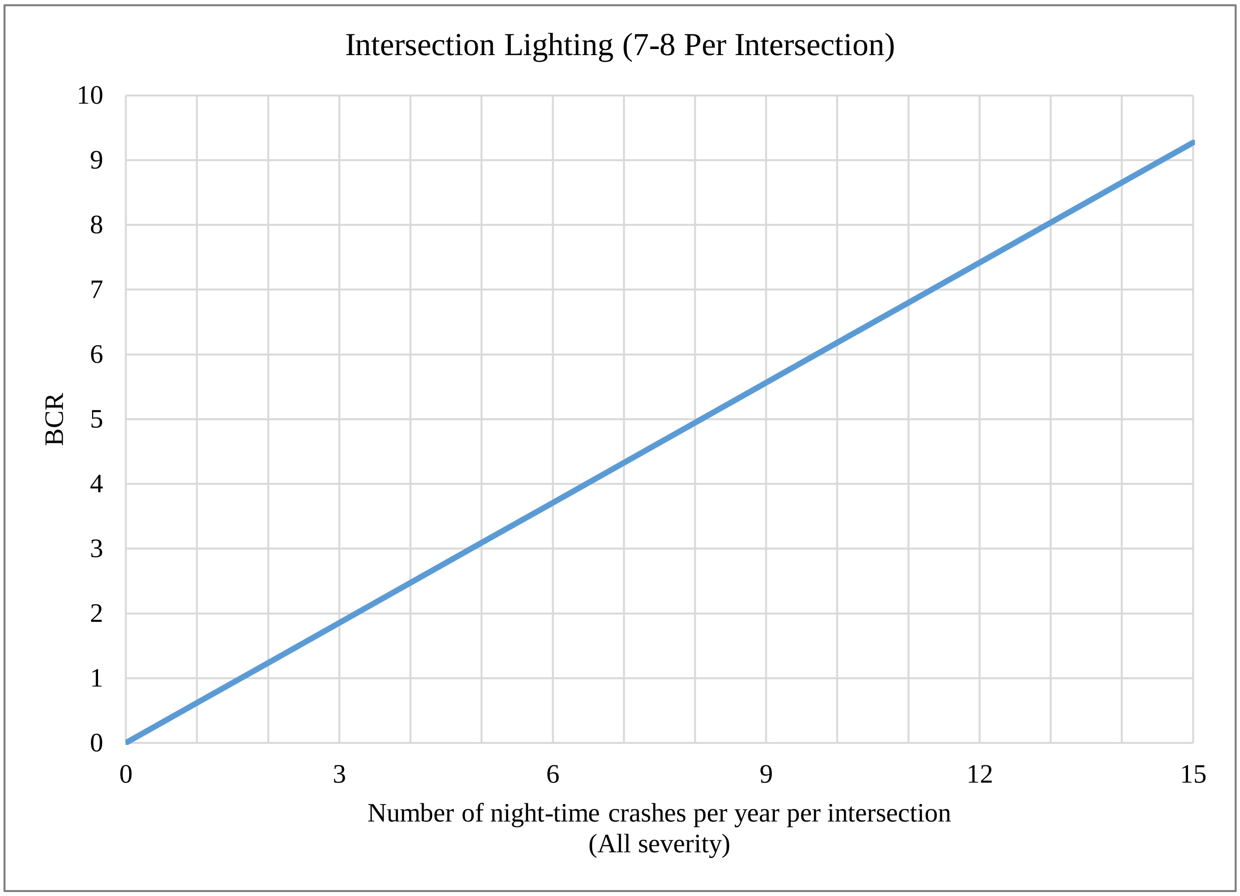
CMF applicability			
Item	Description	Item	Description
CMF Value	FI / PDO = 0.909	Area type	Rural
CRF Value	FI / PDO = 0.091	Intersection geometry	3-leg, 4-leg
Crash type	All	Traffic control	Stop control
Roadway types	Not specified	Methodology used	Before/after using empirical Bayes or full Bayes



BCR for increasing retro-reflectivity of stop signs at rural intersection

9.4.5 Install Intersection Lights

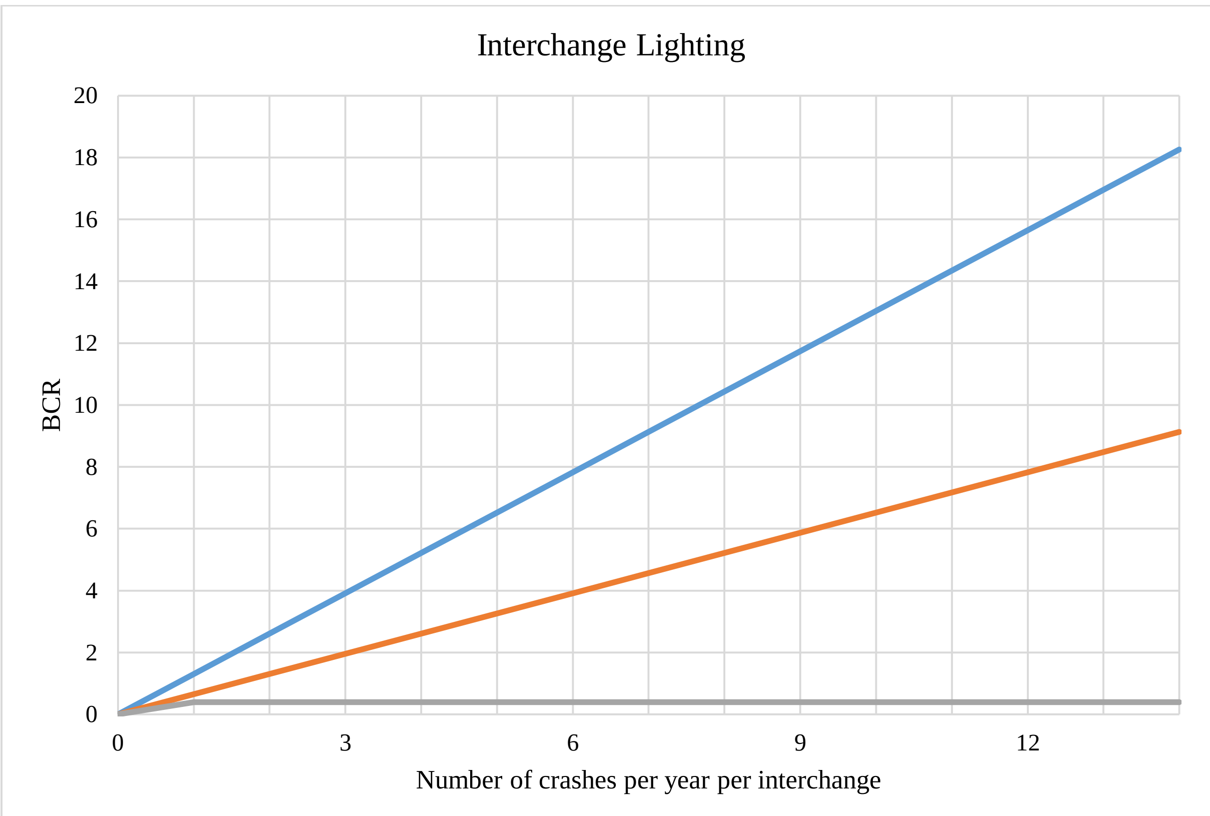
CMF applicability			
Item	**Description**	**Item**	**Description**
CMF value	FI / PDO = 0.881	Area type	Rural
CRF value	FI / PDO = 0.119	Intersection geometry	3-leg, 4-leg
Crash type	Night-time	Traffic control	Stop control
Roadway types	Not specified	Methodology used	Before/after using empirical Bayes or full Bayes



BCR for installation of lights at Stop-controlled rural intersection

9.4.6 Install interchange lights

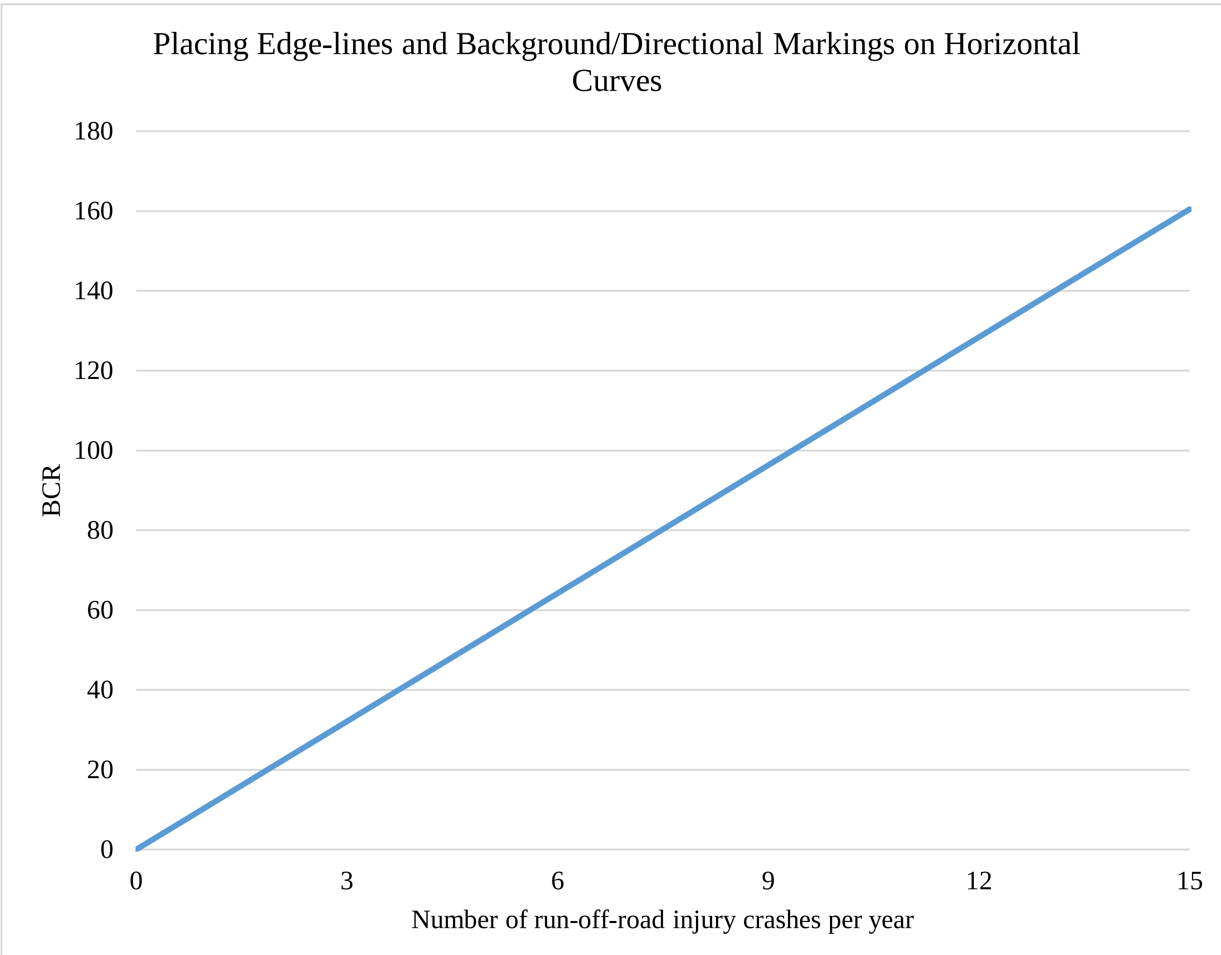
CMF applicability			
Item	**Description**	**Item**	**Description**
CMF Value	FI / PDO = 0.5	Area type	All
CRF Value	FI / PDO = 0.5	Roadway types	All
Crash type	All	Methodology used	Before/after using empirical Bayes or full Bayes



BCR for installation of lights at interchanges

9.4.7 Placing Edge-lines and Background/Directional Markings on Horizontal Curves

CMF applicability			
Item	**Description**	**Item**	**Description**
CMF Value	Injury (ABC) = 0.81	Area type	Rural
CRF Value	Injury (ABC) = 0.19	Roadway types	Not specified
Crash type	Run off road	Methodology used	Meta-analysis



BCR for pavement marking of rural horizontal curves