SHIFTING THE DESIGN PARADIGM TO ACCOMMODATE OLDER DRIVERS AT INTERSECTIONS AND WORK ZONES

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ABSTRACT

The Census Bureau estimates that one in four people will have reached the age of 65 or older by 2030. Recent trends indicate that older Americans are more mobile than ever, with noted increases in both the number of licensed drivers aged 70 and older and their average miles driven. Concurrent with this increase in the number of older drivers is the increase in the number of fatalities involving older drivers. From 1991 to 2001, the number of Americans aged 70 and older killed in traffic crashes increased 27 percent, while overall motor vehicle fatalities increased only 2 percent during the same time period (NHTSA, 2001).

Certain driving situations are more challenging and hazardous to older drivers; intersections and work zones are among the most problematic. The design of existing intersections and work zones is based upon current population demographics and 85th percentile performance abilities. With a higher proportion of drivers aged 65 and older in the population, a decline in 85th percentile performance abilities and a concurrent decline in safety will occur.

Based on known effects of aging (i.e., deteriorating vision, cognitive ability, reaction time and muscular dexterity) and the manifestation of these aging effects as drivers negotiate intersections and work zones, transportation engineers currently have the knowledge base to begin addressing this challenge. Designing a safer road system will not only increase the safety and mobility of older drivers, but will also enhance the overall driving environment for the general population.

This paper addresses how the design paradigm at intersections and work zones must shift to accommodate the aging population through a discussion of (1) older driver challenges at intersections and work zones, (2) the aging phenomenon and relative near-term design alternatives for these sites, and (3) recommended directions for future research to further increase aging driver safety and mobility.

GRAYING OF THE BABY BOOMERS

With the graying of the Baby Boom generation, the Census Bureau estimates that one in four people will have reached the age of 65 or older by 2030. Recent trends indicate that older Americans are more mobile than ever; the National Household Travel Survey reported that the average miles driven by people 70 and older had increased by 21 percent from 1995 to 2001. Furthermore, from 1991 to 2001, the number of licensed drivers aged 70 and older increased 32 percent, from 14.5 million to 19.1 million (BTS, 2001). Concurrent with this increase in the number of older drivers is the increase in the number of fatalities involving older drivers. From 1991 to 2001, the number of Americans aged 70 and older killed in traffic crashes increased 27 percent, while overall motor vehicle fatalities increased only 2 percent during the same time period. Figure 1 depicts the fatality crash rates per 100 million vehicle-miles traveled by age (NHTSA, 2001).

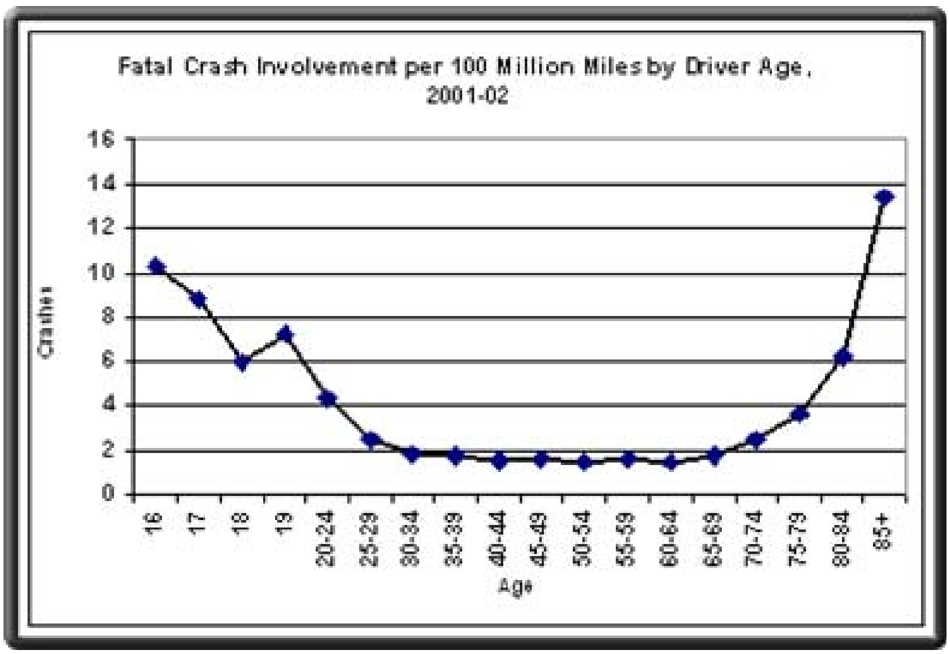

Figure 1. Fatality Crash Rate by Age

Certain driving situations are more challenging and hazardous to older drivers; intersections and work zones are among the most problematic. In these environments, drivers are faced with a high number of stimuli, complex speed-distance judgments and violations of driver expectancy. Older drivers suffer from deteriorating vision, reaction time, cognitive ability and muscular dexterity that heighten the challenges presented in these driving environments.

The design of existing intersections and work zones is based upon current population demographics and 85th percentile performance abilities. With a higher proportion of drivers aged 65 and older in the population, a decline in 85th percentile performance abilities and a concurrent decline in safety will occur. Consequently, the "design driver" of the early 21st century will be an individual over the age of 65 (FHWA, 2001).

This paper addresses how the design paradigm at intersections and work zones must shift to accommodate the aging population through a discussion of (1) older driver challenges at intersections and work zones, (2) the aging phenomenon and relative near-term design alternatives for these sites, and (3) recommended directions for future research to further increase aging driver safety and mobility.

OLDER DRIVER CHALLENGES AT INTERSECTIONS AND WORK ZONES

Intersections

According to the Federal Highway Administration (1997), the most alarming circumstance in accommodating older drivers is the ability of these drivers to safely negotiate intersections. The required complex speed-distance judgments under time constraints, combined with slower reaction times for the motor-cognitive activities involved in intersection tasks provide the underlying basis for concern (Eck, 2002). In 2001, 50 percent of older driver fatalities occurred at intersections, twice as many as with younger drivers. Figure 2 illustrates the percent of intersection-related fatalities by age group.

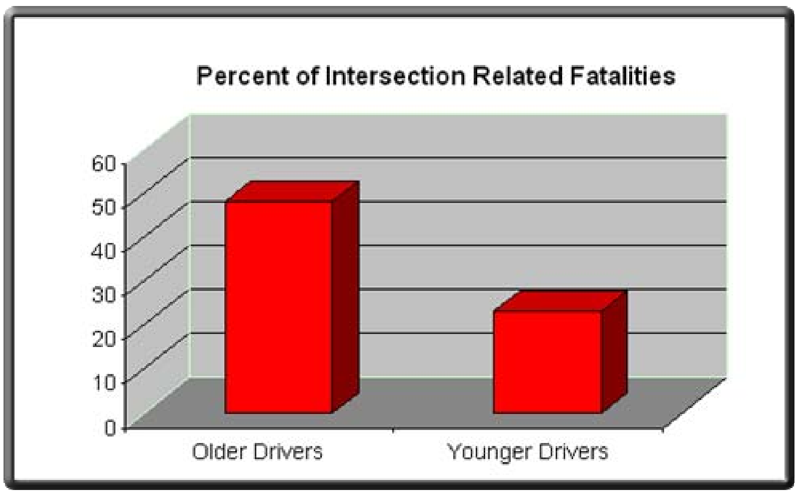

Figure 2. Percent of Fatalities at Intersections

In particular, the most difficult maneuver for older drivers is unprotected left turns due to the need to judge speed, distance, and gap before, when in, and while exiting the intersection. The National Cooperative Highway Research Program (NCHRP) found that older drivers have difficulty in negotiating gaps and estimating speed of oncoming traffic during left turns (FHWA, 2001).

Deteriorating vision impairs the ability of older drivers to see road signs and traffic signals. Signage that is too small or complex can be misunderstood and not recognized as quickly as intended to inform motorists of upcoming traffic situations such as exits, lane changes, obstacles, speed zones, construction zones, etc. (FHWA, 2001). Furthermore, the impaired vision of older drivers may be exacerbated during nighttime conditions.

Benekohal, Resende, Shim, Michaels, and Weeks (1992) conducted a statewide survey of 664 older drivers at intersections and found that as drivers age they become less competent in:

- reading street signs in town (27 percent)
- driving across an intersection (21 percent)
- finding the beginning of a left-turn lane at an intersection (20 percent)
- making a left turn at an intersection (17 percent)
- responding to traffic signals (12 percent)

This study went on to investigate the highway features that become more important as drivers age. These included the following:

- lighting at intersections (62 percent)
- pavement markings at intersections (57 percent)
- number of left-turn lanes at an intersection (55 percent)
- width of travel lanes (51 percent)
- concrete lane guides (raised channelization) for turns at intersections (47 percent)
- size of traffic signals at intersections (42 percent)

Furthermore, older drivers reported that intersections with too many islands are confusing and raised curbs that are unmarked are difficult to detect, but that textured pavements are valuable in warning of upcoming raised medians, approaches to signals, and roadway edge/shoulder boundaries.

In a similar investigation, Staplin (1997) found that the most commonly reported problems for older drivers include the following:

- difficulty turning their heads at skewed angles to view intersecting traffic
- difficulty in smoothly performing turning movements at tight corners
- hitting raised concrete barriers (i.e., channelizing islands) in the rain at night
- difficulty at the end of an auxiliary (right) turn lane in seeing potential conflicts well and rapidly enough to smoothly merge with adjacent-lane traffic
- merging with adjacent-lane traffic at pavement reduction, when the lane drop occurs near an intersection

Work Zones

Highway construction and maintenance work zones pose similar challenges to those of intersections, and are especially difficult for elderly drivers due to their strong potential to violate driver expectancy (Alexander, 1986). Research has shown that driver expectancy is a key factor affecting a driver's ability to safely negotiate work zones, as well as *all* aspects of driving. In a mail survey conducted by the American Association of Retired Persons (AARP), members aged 50 to 97 stated that they have difficulties in accurately judging distances in work zones. Additional problems reported included a lack of adequate warning, narrow lanes, lane closures and lane shifts and difficulty staying in their lane. Studies have consistently shown more crashes on highway segments containing work zones than on the same highway without these zones (Juergens, 1972).

Older drivers are particularly disadvantaged at work zones due to their inability to respond to a stimulus as quickly as their younger counterparts and often respond with attention errors. In a crash analysis study of work zones researchers found that driver attention and failure to yield right-of-way are the greatest contributors (Pigman, 1990). Additional studies indicate that when older drivers approach new traffic patterns they respond in an "automatized" fashion, resulting in more driver errors (Fisk, 1998).

THE AGING PHENOMENON AND RELATIVE NEAR-TERM DESIGN ALTERNATIVES

As stated previously, the design of existing intersections and work zones is based upon current population demographics and 85^{th} percentile performance abilities. With a higher proportion of drivers aged 65 and older in the population, a decline in 85^{th} percentile performance abilities and a concurrent decline in safety will occur unless near-term design alternatives are implemented to improve the safety and mobility of older drivers at intersections and work zones. What follows is an overview of the aging phenomenon and corresponding design improvements, based on sound research, that have been shown effective in increasing safety for the older driver.

As people age the skills needed to drive safely begin to deteriorate. These include: (1) vision (e.g., visual acuity, night vision, visual field) (Morgan and King, 1995), (2) cognitive ability, (3) reaction time, and (4) muscle dexterity (Chapanis, 1996).

Vision

Beginning after age 40, visual acuity and contrast gradually desensitize. By age 75, visual acuity declines to approximately 20/30 Snellen acuity (Pitts, 1982). As a result, older people have difficulty reading under dim lighting conditions, especially when glare is present. Reading signs, detecting pedestrians, driving at night, exiting tunnels, and negotiating worn lane lines are very difficult. For street signage, the current design standard is based on a visual acuity of 20/25 that includes 50 feet of legibility distance for each inch of letter height. This visual acuity standard is not only higher than the standards enforced for licensing in most states (usually 20/40), but exceeds visual capabilities of 40 percent of drivers over age 64 (Alicandri, 1999).

To further demonstrate older driver vision challenges, Figure 3 depicts a road sign as seen by a driver with normal contrast sensitivity, while Figure 4 depicts the same road sign seen by a driver with a cataract condition that often occurs as people age.

Figure 3. Normal Vision   Figure 4. Vision with Cataracts
(http://www.tfhrc.gov/pubrds/mayjun99/olddrvrs.htm)

Near-term design alternatives to enhance vision. In designing for the older driver, transportation engineers should consider the following near-term design alternatives at intersections to accommodate compromised vision:

(1) increase font size in signage and symbol size in directional signals

(2) increase the use of delineation markings for edge treatments, curbs, medians, channelization, or obstacles

(3) reduce clutter around intersections

(4) redesign left-turn lane geometry, intersection angles, or receiving lane widths by adding or widening left-turn lanes and/or redesigning curb radii

(5) use higher performing retro-reflective material in signs and pavement markings for nighttime driving (general retro-reflection requirements are provided in FHWA's *Roadway Delineation Practices Handbook* (Migletz, 1994); the retro-reflection requirements of older drivers is detailed in FHWA's *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians)*.

Many of the same recommendations apply at work zones. Markings, signage, and channelization should be conspicuous and unambiguous and there must be delineation of crossovers.

Cognitive Ability

The cognitive abilities related to attention and reaction time vary dramatically with age. During the aging process, working memory, selective attention, and processing speed are usually the most affected. As a result of deteriorating working memory and processing speed, densely placed roadside signage or phased variable message signs can be difficult to comprehend. Selective attention problems challenge the older drivers' ability to locate critical information that is needed when they are confronted with an extensive array of signs. During alternative maneuvers (i.e., braking or steering), the ability to quickly process the decision affects perception-reaction time (Alicandri, 1999).

Near-term design alternatives to enhance cognitive ability. To combat the decline of cognitive abilities at intersections, the following are practical means in improving safety for older drivers:

(1) provide less complex and confusing signage (e.g., when different street names are used for different directions of travel on a crossroad, the names should be separated and accompanied by directional arrows on both midblock and intersection street-name signs (see Figure 5) (FHWA, 2001).

Figure 5. Examples of Adequate Signage for Older Drivers

(2) provide overhead street-signs and indicators for turning lanes and traffic control for left-turn and right-turn/right-turn-on-red movements

(3) conduct elderly training programs via simulation or on-road training (Simulation products such as the DriveSafety 500c shown in Figure 6 has been used as a safe, cost-effective and valid technique in measuring driver responses to weather, road condition, distractions, new technologies, and others. A recent study completed by the *Driving Assessment and Consultancy Center* of Perth, Australia found that driving simulation is a safer and more economical method than on-road testing to assess the driving performance of older adult drivers (Lee, 2003)).

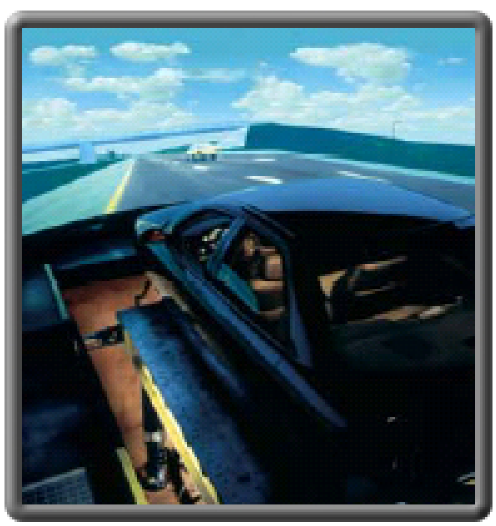

Figure 6. DriveSafety™ Driving Simulator (*http://www.drivesafety.com/src-docs/Sim500c.pdf*)

At work zones, it's important to provide adequate notice to older drivers of the condition ahead, the location, and the required driver responses. Information about the work-zone must be communicated in a dramatic manner, even more so than at intersection locations. When portable variable messaging systems are used to warn drivers in two phases, the problem and location statements should be displayed during Phase One and the effect or action statement during Phase Two (see Figure 7) (FHWA, 2001).

Phase 1 Phase 2

Figure 7. Work Zone Phase Accommodations

Reaction Time

Reaction times are highly variable across the population but generally speaking, drivers between 15 and 60 years of age have the lowest (best) reaction times with a noted increase in reaction times required for those aged 60 and older (Chapanis, 1996). Reaction times recommended for design by the American Association of State Highway and Transportation Officials (AASHTO) are assumed to be 2.5 seconds (Oglesby, 1975). To accommodate the current 85th percentile performance abilities, Hooper and McGee (1983) suggest increasing the required design reaction time to 3.2 seconds. As the population demographic evolves to include a greater proportion of older drivers, this assumed required reaction time and subsequent distance traveled for design should continue to increase.

Near-term design alternatives to enhance reaction time. Designing for a longer reaction time at intersections and work zones includes signage and geometry that provides greater allowances for stopping sight distances and advance warning at greater distances than for that of the younger population.

Muscular Dexterity

With age comes physical change that includes reduced muscle mass and decreased efficiency of the circulatory, cardiac, and respiratory systems. Reductions in strength, flexibility, and range of motion make turning the head, merging into traffic and dealing with skewed intersections problematic for older drivers (Chapanis, 1996). Additionally, loss of muscular dexterity increases fragility over time making older drivers more susceptible to injury and death in an accident (Li, 2002).

Near-term design alternatives to enhance muscular dexterity. Accommodating the older drivers' decrease in muscular dexterity can be primarily accomplished through better vehicle designs that limit the range of motion required to perform maneuvers safely at intersections and work zones. Intersection and work zone designs can also accommodate compromised muscular dexterity by reducing the number of required maneuvers and any line-of-sight obstacles that require a turn of the head when merging into traffic or negotiating skewed intersections.

These recommended design alternatives to enhance vision, cognitive ability, reaction time and muscular dexterity are supported in FHWA's *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians* (2001). This Guide also provides comparative benefit/cost ratios for each of the design alternatives discussed here. For example, improved pavement markings offer a benefit/cost ratio of $60:1 (Miller, 1993), lighting offers a benefit/cost ratio of $26.8:1 and traffic signs offer a benefit/cost ratio of $22.4:1 (as determined in FHWA's *1996 Annual Report on Highway Safety Improvement Programs*).

FUTURE RESEARCH

Building upon the state of the practice related to recommended vision, cognitive ability, reaction time and muscular dexterity enhancements for older drivers at intersections and work zones, potential focus areas for future research include the following:

- driver-based night vision goggles or vehicle-based windshields digitally optimized for luminance changes to enhance older driver visibility
- active (light-emitting diode, LED) delineation systems to enhance visibility and cognitive ability by illuminating lane edges and clarifying directional travel and lane tracking
- advanced warning systems, such as upstream flashing beacons for changes in signal indications, to enhance cognitive ability and reaction time
- red-light running sensors, that detect a vehicle's erroneous presence in the intersection and dynamically extend the all-red indication to prevent conflicting vehicle movement, to accommodate older drivers' compromised cognitive ability and reaction time
- vehicle-based crash avoidance systems that assume vehicle control (i.e., braking, turning) from the driver in hazardous situations to accommodate older drivers' compromised muscular dexterity

With each of these emerging technologies, research supporting their use and effectiveness should be conducted and ultimately result in design standards for each application.

THE FINAL SHIFT

Under the current paradigm, intersections and work zones are designed to accommodate the normal population as historically observed. With the aging of the Baby Boom generation, this design paradigm must shift to accommodate the evolving demographic which includes a significant proportion of older drivers. Based on known effects of aging (i.e., deteriorating vision, cognitive ability, reaction time and muscular dexterity) and the manifestation of these aging effects as drivers negotiate intersections and work zones, transportation engineers have the knowledge base to begin addressing this challenge. Designing a safer road system will not only increase the safety and mobility of older drivers, but will also enhance the overall driving environment for the general population.

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