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Spatial Context Analysis for Elderly Drivers' Left-Turn Maneuvers

Using Virtual 3D Modeling and Driving Simulation

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***Abstract*— This research objective is to perform left-turn crash risk analysis for elderly drivers, by analyzing geographically referenced spatial data surrounding road users through 3-dimensional (3D) visualization. The visualization model is simulated as driving simulator scenarios to study human factors affecting elderly drivers. The expected benefit will be specific planning and geometric design recommendations, as well as specific guidelines for education, licensing, and training for elderly drivers to improve the safety of the aging population. For this study, a 3D model of a selected intersection is developed for spatial analysis. This model is converted into a drivable simulation tile that is imported into a driving simulator to develop several scenarios to examine the spatial context and geometric properties of the intersection as related to the cognitive abilities of tested drivers. Younger adults were far more risky making left-turns compared to older adults. Older adults waited significantly longer to make the first judgment that it was safe to proceed with a left-turn. Older adults judged far fewer gaps to be safe compared to younger adults. Older adults are found to be at differential risk for left-turn crashes despite being so cautious. Other factors may be at play influencing risk. One possible explanation for increased risk is that, although older adults make conservative decisions, these decisions may be reached and executed too late to allow enough distance between their vehicle and oncoming traffic. This is partially supported by the fact that the median distance between oncoming traffic and the participant's vehicle making a left-turn was smaller for older adults compared to younger adults. Once an appropriate gap has been identified, older adults may wait additional time to verify that their speed and distance estimates of oncoming vehicles are correct.**

***Keywords*— elderly drivers; driving simulation; 3D Modeling; left-turn maneuvers**

I. INTRODUCTION

In 2008, 13% (34 million) of the total U.S. population was aged 65 and older. This age group is projected to grow to exceed 50 million by 2020, accounting for roughly one-fifth of the driving age population in this country. In effect, the "design driver" of the 21st century will be an individual over the age of 65. Elderly drivers can be expected to experience difficulties navigating the roadway as drivers and pedestrians as a consequence of normal age-related changes to their perceptual, cognitive, and psychomotor abilities, presenting many challenges to transportation planners and engineers who must ensure system safety while increasing operational efficiency (FHWA 2001).

The majority of the ageing population is dependent on automobiles for their transportation needs, especially in rural and semi-urban areas that lack adequate public transportation. With the projected increase in ageing drivers' population, and their involvement in higher severity crashes, their transportation safety concerns have become of paramount importance. The desire of the ageing population to remain independent necessitates them to continue to drive for as long as they can, making them more susceptible to severe injuries. Driving cessation is associated with a number of negative outcomes including increased risk of depression, isolation, and a decreased quality of life and health (Edwards et al., 2009). Consequentially, designers must work to improve the driving environment to better match the abilities of the older driver/pedestrian.

One of the areas that designers must analyze to ensure a safer environment for older drivers is intersection design. The Federal Highway Administration (FHWA) has listed several strategies in their Handbook for Designing Roads for the Aging Population's chapter on Intersections with the goal of ensuring that intersections are designed with features aimed at reducing collision severity and quantity. Two of these strategies that will be analyzed in this study are Proven Practices 5 (Offset Left-Turn Lanes) and 8 (Left-Turn Traffic Control for Signalized Intersections). As the literature review shows, left turns at signalized intersections have the potential to produce severe collisions that can cause fatalities, particularly when considering elderly drivers.
For this study, a 3D model of a selected intersection is developed for spatial analysis. This model is converted into a drivable simulation tile that is imported into a driving simulator to develop several scenarios that will examine the spatial context and geometric properties of the intersection as well as the cognitive abilities of

tested older drivers. The main goals of this research are as follows:

1. Demonstrating the potential for using a driving simulator to test both the geometric elements of an intersection and the cognitive abilities and habits of older drivers (this study defines older drivers as those aged 65 and over).
2. Exploring the potential for modeling real-world intersections rather than relying on driving simulator software generic tiles.
3. Gaining a greater insight into elderly driver's behaviors when attempting to perform a left-turn during a permitted turn phase at a signalized intersection.
4. Utilizing a series of tests to understand the reasoning abilities, processing speed, and spatial abilities of older drivers.

II. Background

The Insurance Institute for Highway Safety reports, when controlling for miles driven, older drivers (particularly drivers 75 years of age and older) are at a substantially higher risk compared to all but the most inexperienced drivers (drivers in their teens and 20s) with respect to fatal crash involvement. Much of this increased risk is associated with increased fragility: all else being equal, an older adult is more likely to be seriously injured or killed in a crash compared to a younger driver. In fact, increased fragility has been described by some as the primary reason for older drivers' overrepresentation in fatal crashes [1]. Others, however, have argued that excessive crash involvement (irrespective of fragility) contributes to the risk of older drivers [2].

Regardless of the relative contributions of increased fragility and excessive crash involvement, age related declines in perceptual and cognitive abilities make the driving task more challenging and potentially less safe [3]. Due to the increasing difficulty of the driving task many older adults will modulate their driving behavior (e.g., opting to drive less at night, in inclement weather, during heavy traffic periods, and at reduced speeds). Driving difficulties are related to age-related declines in perceptual and cognitive abilities. Basic perceptual and cognitive operations take approximately two times longer for older adults compared to younger adults [4]. Furthermore, there are clear age-related differences in spatial ability and working memory capacity. Declines in spatial ability and working memory can help explain older adults' differential involvement in crashes involving crossing a stream of moving traffic (typically left-turn crashes in the United States), as these maneuvers involve the accurate estimation and updating of speed and distance information [5].

Intersections in general are a dangerous place for drivers and pedestrians. For example, in Florida, even though intersections make up only a small proportion of the total roadway, 43% of serious injuries and deaths occur at or near intersections. Crashes involving a left-turning drivers being struck by opposing traffic are especially dangerous, and older adults are at greater risk for these crashes [6] and [7]. Furthermore, crash statistics highlight the need to understand the particular mechanisms resulting in increased risk of older drivers at and near intersections [8], [9], and [10].

III. Research Methodology

Data was acquired from the Florida Department of Transportation (FDOT), consisting of crashes occurring in District 3 between 2008 and 2012, in order to determine intersections that have an overrepresentation of older driver collisions. ArcGIS software was selected to be the platform to import, filter, and visualize the data. Using ArcGIS, a case study intersection was selected using the following criteria:

1. To have at least 5 or more collisions involving elderly drivers (+65 years) in which there was no suspicion or drugs or alcohol involved and there was at least the possibility of an injury.

2. To be located where there is knowledge of the topography, the intersection, and its local surroundings.

3. The intersection should be typical or near-typical. The analysis of atypical intersections may produce results that only have a narrow applicability to other intersections.

The Capital Circle NE /Hermitage Boulevard intersection in Tallahassee, Florida shown in Fig. 1, was selected to be modeled due to its high rate of older driver collisions, its location with a mix of residential and commercial buildings, the conversion of the actual intersection from allowing protected and permitted left turns to only allowing protected left turns, and due to the possible sight distance deficiencies that could be created by the hilly topography surrounding the intersection or by the lack of any positive offset in intersection's two opposing left-turn lanes along Capital Circle NE.

Fig. 1. *GIS Photo-map of study intersection*

A. Police Crash Reports

Thirty-nine police reports were obtained from the Leon County Sheriff's Office for the study intersection from 2008 to 2012. The majority of crashes occurred during daylight (30 crashes out of 39), with a smaller number of crashes occurring under low-light conditions (dusk or dark: 5 crashes). Most crashes occurred during clear weather conditions (21 crashes), with only 6 crash reports indicating rain at the time of the crash. Nine crashes involved left-turning vehicles, and the majority of crashes involved one vehicle rear-ending another (24 crashes). Sixty-nine drivers' ages were recorded in the thirty-nine crash reports (average age = 44.9 years). Twelve out of 69 drivers were 65 years of age or older at the time of the crash.

B. Scenario Generation

Left-Turn Traffic Control for Signalized Intersections, which is Design Element 8 of the FHWA Handbook for Designing Roadways for the Aging Population, is an area of focus for this study due to the nature of the severity of left-turn collisions involving elderly drivers. The proposed model considers two different scenarios based on the previous and current traffic light set-up at Hermitage Blvd/NE Capital Circle. The protected left turn-only scenario falls under section A of Design Element 8, which calls for the use of protected-only left turns when the appropriate offsets (from Design Element 5) are not applied to the intersection.

For the case study intersection, the minimum required offsets are not provided for; therefore, the intersection proves to be a good candidate for the protected-only left turn set up. The scenario allowing both permitted and protected left turn phases was the actual intersection's previous traffic lighting configuration (prior to changing to the protected only left turn phase).

C. Spatial Model

The 3D model of the intersection was created using Google SketchUp 3D modeling software. The software was chosen for its ability to; generate a 3D topographic surface of the intersection and surrounding area, develop realistic visualization model, allow importing objects from an online warehouse, assist in the creation and photo-texturing of buildings and other objects, and integrate with the driving simulator software. Figure 2 illustrates an overview of the intersection and all of the elements within a 400 feet distance from the intersection.

Fig. 2. *3D Virtual model study intersection*

Figures 3 and 4 show a comparison between the actual intersection image and the 3D virtual model.

Fig. 3. *Street view – northbound NE Capital Circle*

Fig. 4. *Driver's view – left-turn judgment task*

D. Human Factors Simulation

PARTICIPANTS: A total of 64 participants, including 31 younger drivers and 33 older drivers, were recruited from the Tallahassee, FL region. Most participants completed the study in a single 1.5 to 2 hour session. Data from two participants were excluded from analyses, one due to simulator sickness, and the other due to experimenter error.

PROCEDURE: Participants completed a variety of cognitive tasks tapping spatial ability, processing speed, and reasoning ability, as well as a left-turn judgment task. A NADS MiniSim high-fidelity driving simulator was used to present the left-turn task. The NADS MiniSim incorporates a dashboard with a virtual instrument cluster and steering wheel; accelerator and brake pedals; and three 42" plasma displays that gives the driver a 180° horizontal and 50° vertical field of view of the simulated environment. Each display had a resolution of 1360 x 768 pixels and a refresh rate of 60 Hz. The simulator is integrated with an eye-tracker to monitor eye and head movements.

The simulator experiment consisted of two practice scenarios to acclimate participants to the driving simulator, followed by the main task in which participants were placed in a left-turn lane and were asked to make judgments regarding whether or not it was safe to turn. This left-turn judgment task took place at a simulated version of the Hermitage Way and Capital Circle intersection. The two practice scenarios took a combined total of approximately 15 minutes to complete, and the main task took an additional 5 minutes. The purpose of the two practice scenarios was to acclimate participants to the driving simulator to encourage better judgments.

Practice scenarios: The first practice scenario involved a long stretch of interstate highway with two gradual curves. Participants were instructed to keep a constant speed of 55 miles-per-hour and to switch lanes multiple times in order to experience the dynamics of the simulator. The second practice scenario began with the participant placed in the left-turn lane of a generic intersection, and participants were instructed to make a left turn.

Left-Turn Judgment Task: After completing the practice scenarios, a SensoMotoric Instruments (SMI) iViewX™ HED mobile eye-tracker was set up to record participants' eye movements. Participants began in the left-turn lane Northbound on Capital Circle North-East and were instructed to indicate when a gap in traffic was large enough for them to safely make a left turn. In order to make the task more challenging and realistic, vehicles were placed in the left-turn lane opposite of the participant. This meant that older adults had to partly rely on spatial working memory to anticipate the position of occluded vehicles approaching the intersection to aid in gap size judgments. Gap judgments were especially challenging due to the curvature of the road near the intersection, which further limited the visibility of opposing traffic when the opposing left-turn lane was occupied as shown in Fig. 4.

Participants were asked to push a button on the steering wheel whenever they felt that the gap in traffic was large enough to allow a safe left turn. Participants were instructed to respond only one time per oncoming vehicle. The simulator logged each button press, allowing the distance between the participant's static vehicle and the next closest vehicle in the stream of oncoming traffic to be calculated. There were a total of 60 pre-determined gaps falling into three pre-defined categories:

Risky Gaps: Gaps between 100 and 275 feet

Safe Gaps: Gaps between 296 and 337 feet

Cautious Gaps: Gaps between 410 and 690 feet

Oncoming traffic was programmed to spawn at specific times to control for gap-size between each vehicle, and was also programmed to come across all three 'through' lanes at a constant speed of 50 MPH (though the speed limit in this area is 45 MPH, 50 MPH is a more realistic speed). Vehicles were spawned at exactly the same time and location for each participant and were equally distributed across all three lanes.

IV. Results

Because participants were allowed to respond as many or as few times as they wished, the total number of button responses a given participant made can be considered an indicator of response conservatism. We expect more careful participants to respond less frequently because they would be waiting for only the larger gaps in traffic, whereas less careful participants would make more responses because, in addition to responding to larger gaps in traffic, these participants would also respond on some smaller gap trials.

The median number of responses made during the scenario was compared between older and younger adult groups using a Mann-Whitney U test. Younger adults made significantly more responses overall (Median = 18, range = 6 – 57) than did older adults (Median = 10, Range = 1 to 39), U = 771, Z = 4.11, p = .00004, r = .52. Older adults were far more conservative when judging when it was safe to go compared to younger adults.

To examine potential intersection wait times at an intersection like the one modeled in the current study, we looked at differences in the total amount of time before a participant made their first response. We expect older participants to take longer than younger participants to make their first response. Indeed, the median time until the first button response was significantly longer for older than for younger adults: The median time until the first button response was 21.21 seconds (Range = 12.98 to 54.52) for younger participants but 53.04 seconds (Range = 14.03 to 302.18) for older participants, U = 149, Z = -4.43, p = .000003, r = .57 (Fig. 5).

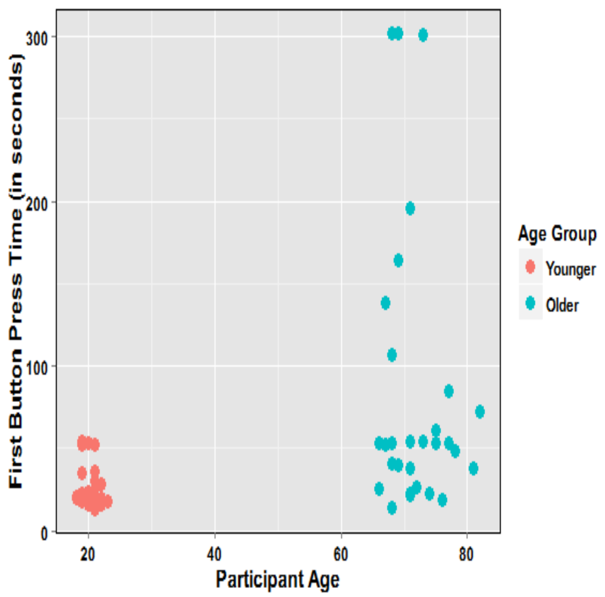

Fig. 5. *Time to first button pressed by participants' age*

A one-way ANOVA was conducted comparing the median oncoming vehicle distance across all button responses as a function of participant age group and gender. Three participants with extreme outlier values for oncoming vehicle distance were excluded from this analysis. Although older adults made fewer responses overall, indicating that they less often judged it to be safe to make an unprotected left turn, the oncoming vehicle tended to be closer when older adults indicated it was safe to turn than was the case for younger adult participants. For the older adult group, the oncoming vehicle distance across all button responses was significantly closer (M = 440.43 ft., SD = 168.44) than was the case for the younger adult group (M = 546.6 ft., SD = 82.67), F (1,55) = 11.11, p = .002, d =. 80 (Fig. 6).

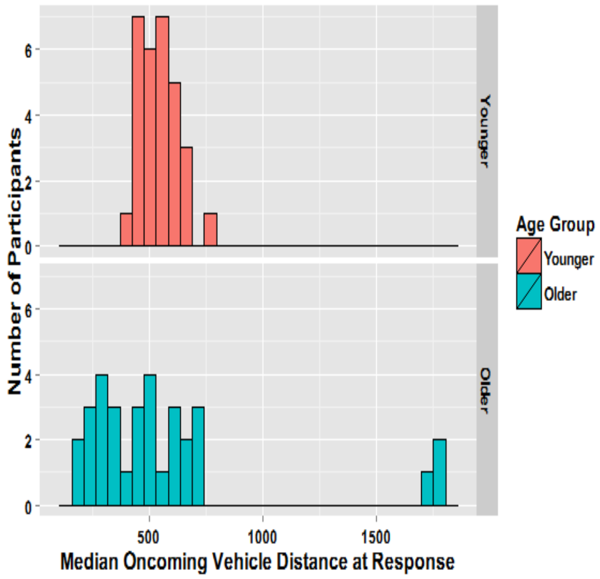

Fig. 6. *Median oncoming vehicle distance at button press*

There was no evidence that male and female participants differed overall, $F < 1$, but there was an age group by gender interaction, $F(1,55) = 4.32$, $p = .04$ such that the distance of oncoming vehicles from the participant at response was nearly identical for younger males and females. For older participants, the distance of the oncoming vehicle from the participant at response was slightly smaller for women than men, $F(1,27) = 2.84$, $p = .10$ ($M = 387.63$ vs. $M = 489.72$).

V. Conclusions

Younger adults were far more risky compared to older adults. Older adults waited significantly longer to make the first judgment that it was safe to proceed with a left-turn, and older adults judged far fewer gaps to be safe compared to younger adults. It is interesting that older adults are found to be at differential risk for left-turn crashes despite being so cautious. Other factors may be at play influencing risk. One possible explanation for increased risk is that, although older adults make conservative decisions, decisions may be reached and executed too late to allow enough distance between their vehicle and oncoming traffic. This is partially supported by the fact that the median distance between oncoming traffic and the participant's vehicle was smaller for older adults compared to younger adults. Once an appropriate gap has been identified, older adults may wait additional time to verify that their speed and distance estimates of oncoming vehicles are correct.

Many of the older adults in our study explicitly complained about the difficulty seeing oncoming traffic with the opposing left-turn lane occupied, and desired to wait to turn until this vehicle turned and their view was unobstructed. This was consistent with insights gained from the 3D model, and also being able to explore this model in the simulator. This difficulty, combined with the number of older adult crashes at this particular intersection, suggest that a switch from allowing protected and permitted left turns to only allowing protected left turns was a wise choice.

This paper illustrates a method that might be replicated to better understand older adult crash risk and to understand the potential impact of countermeasures to reduce this risk. First, we examined crash reports to identify intersections that appeared to be problematic with respect to older driver crashes. Next, we modeled this intersection in 3D to: 1) gain insights into the geometry of the intersection, and 2) to serve as a basis for a driving simulator tile and scenario so the investigators could further explore the geometry from a first-person perspective, and so that the behaviors of younger and older drivers could be examined at this high-risk intersection.

Also, environmental conditions might be incorporated to observe their effect. If crashes differentially occurred at night, or under bad-weather conditions, these could be replicated in the simulator and countermeasures could be explored under the exact conditions linked to crash risk at a particular intersection. Countermeasures could also be tested to ensure that they are effective with a variety of different types of vehicles (e.g., compact cars vs. trucks/SUVs that have different views of the road due to driver height).

From an engineering perspective, this approach has the potential to better match countermeasures with specific problematic intersections, and to increase our understanding of crash risk, and the differential crash risk of older drivers. For human factors researchers conducting simulator work, much might be gained from understanding driver behavior at specific, real-world intersections, rather than driving simulator scenarios that depict generically risky situations. The presented work here indicates the initial promise of this approach and lays out a framework for future investigations of high-risk intersections for older adults.

Due to the difficulties that many of the drivers were having in regards to being able to see oncoming traffic when trying to perform a left-hand turn while a car occupies the opposing lane, one can verify the importance of designing roadways in accordance to the FHWA Older Driver's Handbook Chapter 2 Proven Practice 5 Offset Left-Turn Lanes. By applying these principles to left turn situations (particularly at intersections), drivers (especially those aged 65 and over) can better gauge gap distances and oncoming vehicles speeds and locations due to better visibility. Additionally, as mentioned in the FHWA Older Driver's Handbook, the positive offsets reduce the need for those trying to perform this left turn maneuver to have to be at the far left end of their lane when trying to determine if they could safely perform the turn.

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