Center for Accessibility and Safety for an Aging Population

Florida State University

In Partnership with Florida A&M University and University of North Florida

RESEARCH FINAL REPORT

Spatial Context Transportation Safety Analysis for the Aging Population: An Integrated 3-Dimensional Visualization and Human Factors Simulation Approach

Yassir Abdelrazig
Eren Erman Ozguven
Walter Boot
Ren Moses

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PI: Yassir AbdelRazig, Ph.D.
Associate Professor
Department of Civil & Environmental
Florida A & M University

Eren Erman Ozguven, Ph.D.
Assistant Professor
Department of Civil & Environmental
Florida State University

Walter R. Boot, Ph.D.
Associate Professor
Department of Psychology
Florida State University

Ren Moses, Ph.D., P.E
Professor
Department of Civil Engineering
Florida A & M University

Report on Research Sponsored by

Center for Accessibility and Safety for an Aging Population

Florida State University
in Partnership with Florida A&M University and University of North Florida

March 2015

Technical Report Documentation Page

<table>
<tr><td>1. Report No.</td><td>2. Government Accession No.</td><td>3. Recipient's Catalog No.</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle

Spatial Context Transportation Safety Analysis for the Aging Population: An Integrated 3-Dimensional Visualization and Human Factors Simulation Approach</td><td>5. Report Date
March 2015</td></tr>
<tr><td>6. Performing Organization Code</td></tr>
<tr><td colspan="2">7. Author(s)
Yassir AbdelRazig, Walter R. Boot, Eren Erman Ozguven, Ren Moses, Ryan Doczy, Ainsley Mitchum</td><td>8. Performing Organization Report No.</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address
Center for Accessibility and Safety for an Aging Population
2525 Pottsdamer St., Suite A 129,
Tallahassee FL 32310</td><td>10. Work Unit No.</td></tr>
<tr><td>11. Contract or Grant No.
DTRT13-G-UTC42</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
Research and Innovative Technology Administration
1200 New Jersey Ave., SE
Washington, D.C. 20590</td><td>13. Type of Report and Period Covered
Technical Report, 1/14 – 3/15</td></tr>
<tr><td>14. Sponsoring Agency Code</td></tr>
<tr><td colspan="3">15. Supplementary Notes</td></tr>
<tr><td colspan="3">16. Abstract

Older drivers are at differential risk for injury/death as a result of a crash compared to younger drivers, partly due to age-related changes in perceptual and cognitive abilities, but also due to age-related increases in fragility. As the population ages in the United States and around the world, we will have more older drivers on the road than ever before, making understanding older driver crash risk and developing effective countermeasures of critical importance. This will serve the goal of protecting aging road users and helping older adults maintain their mobility and independence. Research reported here developed an approach to understanding older adult crash risk at specific intersections. First, crash records were examined for crashes within the Tallahassee region to identify intersections associated with older adult crashes. Then, using 3D modeling software, this intersection was recreated to help identify potential reasons for this crash risk in terms of the intersection's spatial context. Then, this 3D model was converted to a driving simulator tile to further understand older driver risk in a driving simulator study, which identified potentially risky decisions by older drivers. We propose this process of identifying risky intersections, modeling them, and importing them into the driving simulator as a potentially promising methodology to better understand specific properties of intersections that pose risk to older drivers, the perceptual and cognitive changes related to this differential risk, and countermeasures to reduce older driver risk. The promise and challenges of this approach are discussed.</td></tr>
<tr><td colspan="2">17. Key Words
GIS, 3D Visualization, Crash Analysis, Older Drivers, Left-Turns, Cognition</td><td>18. Distribution Statement</td></tr>
<tr><td>19. Security Classif. (of this report)
Unclassified</td><td>20. Security Classif. (of this page)
Unclassified</td><td>21. No. of Pages | 22. Price</td></tr>
</table>

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List of Abbreviations

Florida Department of Transportation (FDOT)
Florida State University (FSU)
Florida A&M University (FAMU)
University of North Florida (UNF)

Acknowledgments

We would like to thank the Center for Accessibility and Safety for an Aging Population (ASAP) for the support to complete this work, as well as the Florida Department of Transportation for providing matching funds. We are grateful to Jared Dirghalli, Kimberly Barajas, and Craig Carnegie for their crucial efforts testing scenarios, recruiting and testing participants, and organizing and reducing data. We thank the many undergraduate research assistants who assisted with this project. Finally, we would like to thank the younger and older members of the Florida State University and Tallahassee communities who participated in the reported driving simulator study.

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the U.S. Department of Transportation's University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

Abstract

Older drivers are at differential risk for injury/death as a result of a crash compared to younger drivers, partly due to age-related changes in perceptual and cognitive abilities, but also due to age-related increases in fragility. As the population ages in the United States and around the world, we will have more older drivers on the road than ever before, making understanding older driver crash risk and developing effective countermeasures of critical importance. This will serve the goal of protecting aging road users and helping older adults maintain their mobility and independence. Research reported here developed an approach to understanding older adult crash risk at specific intersections. First, crash records were examined for crashes within the Tallahassee region to identify intersections associated with older adult crashes. Then, using 3D modeling software, this intersection was recreated to help identify potential reasons for this crash risk in terms of the intersection's spatial context. Then, this 3D model was converted to a driving simulator tile to further understand older driver risk in a driving simulator study, which identified potentially risky decisions by older drivers. We propose this process of identifying risky intersections, modeling them, and importing them into the driving simulator as a potentially promising methodology to better understand specific properties of intersections that pose risk to older drivers, the perceptual and cognitive changes related to this differential risk, and countermeasures to reduce older driver risk. The promise and challenges of this approach are discussed.

1. Problem Statement and Objectives

The majority of the aging population is dependent upon automobiles for their transportation needs, especially in rural and semi-urban areas that lack adequate public transportation. With the projected increase in the aging driver population, and their involvement in higher severity crashes, their transportation safety concerns have become of paramount importance. The desire of older adults 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 (e.g., Edwards et al., 2009). Since many older adults wish to continue to drive to maintain their independence, and because there are a number of negative outcomes associated with driving cessation, we should work to improve the driving environment to better match the abilities of the older driver. We should also work to better understand the mechanisms through which older adults are at greater crash risk. The presented research focused on developing models and tools to better understand older driver risks, and also aimed to propose a framework for how to develop and test countermeasures to alleviate crash risk, particularly with respect to older drivers. The factors that impact the crash rates and crash severity rates amongst aging drivers include human factors such as declines in perceptual, cognitive, and psychomotor performance, as well as spatial context parameters such as road intersections, interchanges, curvatures, construction zones, railway crossings, signage, speed limits, etc. (FHWA, 2001). The goal of the research described in this report was to analyze these spatial context parameters using 3D visualization complimented with simulated human factors, and provide specific recommendations in order to address this safety issue. This approach will help planners and designers to make policy and design decisions that are tailored to improve the safety of the aging population.

Objectives

Specific objectives of this research were to:

1. Develop a framework to understand older adult crash risk, which involved:
    a. Identifying a specific intersection within the Tallahassee region associated with increased older driver risk.
    b. Modelling this intersection with 3D visualization tools to better understand the specific characteristics that might make intersection navigation particularly challenging for older drivers.
    c. Importing this visualization model into a driving simulator to better understand the behavior of younger and older drivers at this risky intersection, and particular cognitive declines associated with more risky behavior.

2. Background

Due to population aging in the United States and around the world, we have more older drivers on the road today than ever before, and this number will only increase over the next few decades. In 2009, there were 39.6 million adults 65 years of age or older living in the United States. This number is projected to increase to 72.1 million by 2030, and 88.5 million by 2050 (Figure 2.1). To maintain their independence, many of these older adults will choose the automobile as their primary form of transportation. Unfortunately older drivers (and pedestrians) are at greater risk for serious injury and death as a result of a vehicle crash. A major goal of human factors researchers and roadway engineers is to better understand crash risk and develop countermeasures to ensure safety and mobility for this rapidly growing aging population.

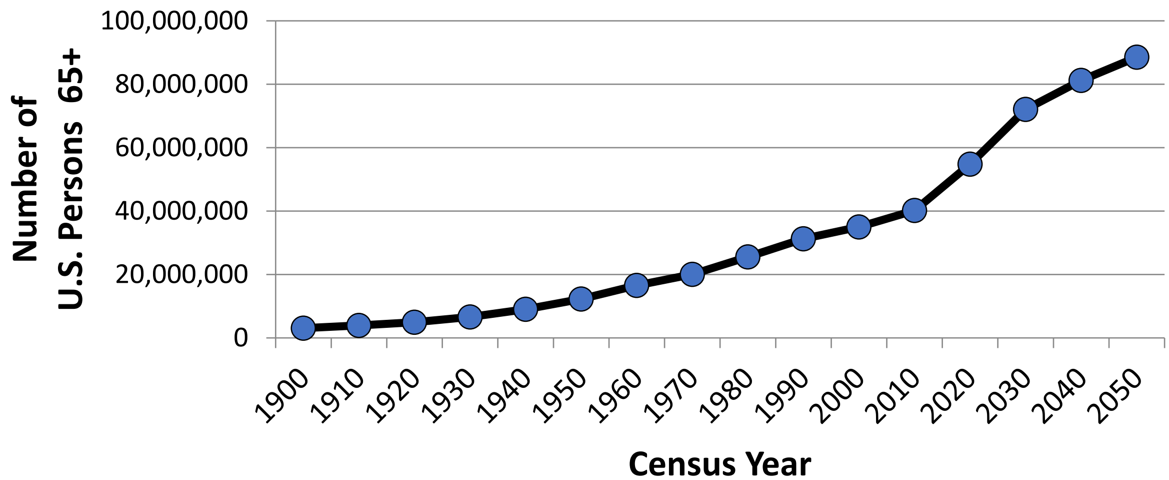


Figure 2.1. The number of persons 65 years of age or older in the United States (2010-2050 are projections). Source: Projections of the Population by Age and Sex for the United States: 2010 to 2050 (NP2008-T12), Population Division, U.S. Census Bureau; Release Date: August 14, 2008.

As can be seen from Figure 2.2, 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 (Li, Braver, & Chen, 2003). Others, however, have argued that excessive crash involvement (irrespective of fragility) contributes to the risk of older drivers (Teft, 2008).

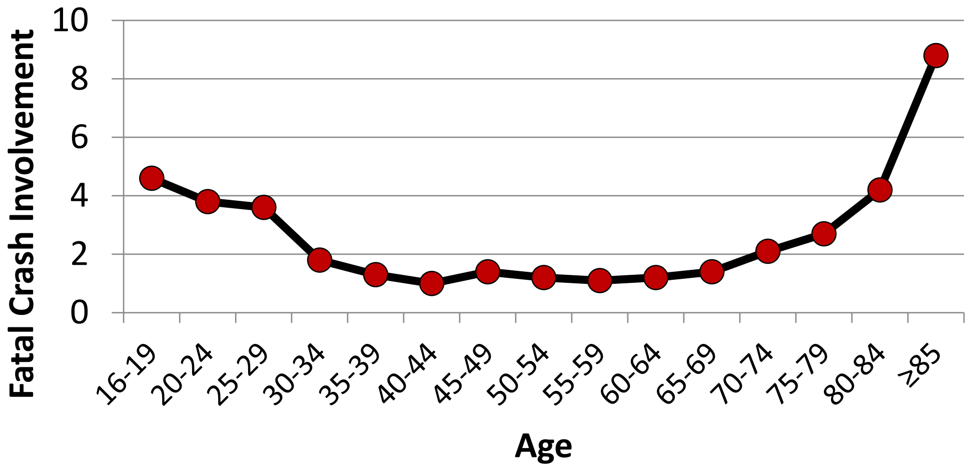


Figure 2.2. Fatal crash involvement per 100 million miles traveled as a function of driver age. After reaching stability at age 30, fatal crash rate begins to increase around the age of 75. Source: Insurance Institute for Highway Safety, http://www.iihs.org/iihs/topics/t/older-drivers/fatalityfacts/older-people

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 (see Boot, Stothart, & Charness, 2013; for review). 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. For example, the ability to rapidly extract information from the visual periphery (Useful Field of View) declines substantially with age, with this decline being a strong predictor of crash rate (Ball & Owsley, 1991; Ball Owsley, Sloane, Roenker, & Bruni, 1993; Owsley et al., 1998). Basic perceptual and cognitive operations take approximately two times longer for older adults compared to younger adults (Jastrzembski & Charness, 2007), with implications for how fast older drivers can react to unexpected road hazards. Furthermore, there are clear age-related differences in spatial ability and working memory capacity (Anderson & Enriquez, 2006; Scialfa et al., 1991). 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), and merging into a moving stream of traffic (Staplin, Lococo, Martell & Stutts, 2012), as these maneuvers involve the accurate estimation and updating of speed and distance information.

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 (FDOT, 2006). Crashes involving a left-turning drivers being struck by opposing traffic are especially dangerous (left-turn crashes), and older adults are at greater risk for these crashes (ADOT, 1996; Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998; Wang & Abdel-Aty, 2008, Brehmer et al., 2003; Knodler et al., 2005). Unfortunately, for drivers 80 years of age and older, intersection crashes are the most common type of crash (Figure 2.3). Interventions at intersections (e.g., increased countermeasures) and training on intersection navigation appear to be promising avenues to explore to minimize crash injuries and deaths, especially with respect to older drivers. (FHWA, 2001; Dobbs et al., 2009). Furthermore, crash statistics highlight the need to understand the particular mechanisms resulting in increased risk of older drivers at and near intersections.

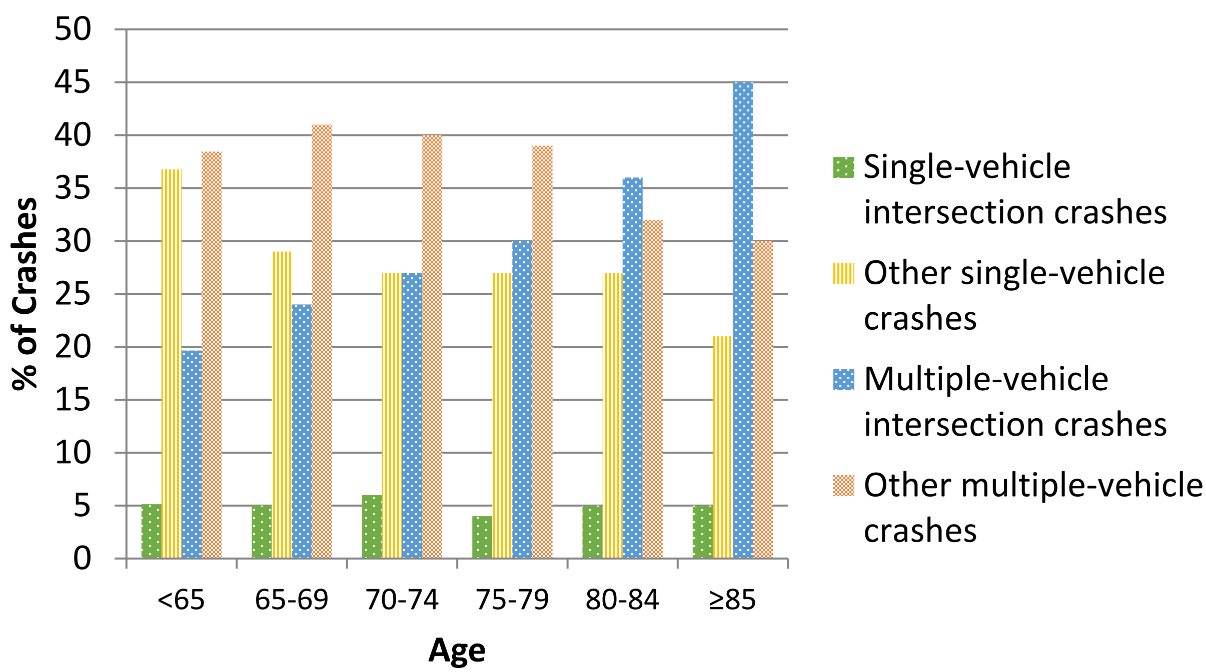


Figure 2.3. Distribution of fatal crash type by driver age for drivers involved in fatal crashes (2013 data from the Insurance Institute for Highway Safety). Note the increase in the percentage of multiple-vehicle intersection fatal crashes as a function of driver age (blue bars). For drivers 85 and older involved in fatal crashes, 45% were involved in multiple-vehicle intersection

crashes (compared to < 20% for drivers under the age of 65). Source: Insurance Institute for Highway Safety, http://www.iihs.org/iihs/topics/t/older-drivers/fatalityfacts/older-people

Even if age-related changes do not result in a crash, they can cause older drivers to limit the amount and type of driving they do, and in the most extreme cases, cause an older driver to cease driving all together. While driving cessation may reduce crash risk, it may also result in increased isolation and decreased mobility and independence. The cessation of driving is associated with poorer health, reduced activity, increased depression, and social isolation (Dobbs, Harper & Wood, 2009; O'Connor et al., 2013; Maratolli et al., 1997). Driving cessation may be particularly challenging for older adults in rural communities lacking convenient public transportation. Thus, the goal should be to support older drivers in their desire continue to drive, and the independence associated with driving, as long as it is safely possible to do so.

The research reported here aimed to use animation and 3D visualization to aid in our understanding of crash risk of older drivers by focusing on the modeling of a specific intersection at which older adults have increased crash risk. Animation and 3D visualization technologies have improved significantly in the last decade and are being used gainfully in many areas of science and engineering such as mapping environmentally sensitive areas, design of buildings, assembling of vehicles, etc. There are moves to incorporate animation and 3D visualization for transportation application such as the use of AutoCAD 3D in visualizing roadway design and the use of Google Earth in roadway visualization (El-Gafy, AbdelRazig, & Abdelhamid, 2011; Utila, Karas, & Rahman, 2013). The analysis of the transportation safety of the aging population needs to migrate from static and two-dimensional analysis to dynamic and three-dimensional analysis taking advantage of advances in technology in 3D visualization of roadway geometry. Important geometric and traffic factors that research findings have consistently shown to affect the safety of older drivers, pedestrians, and other road users include; road intersections, interchanges, curvatures, construction zones, railway crossings, speed limits, stopping sight distance, visibility of traffic signs, blockage of driver's sight by heavy vehicles, and channelization of intersections (FHWA, 2001). Through 3D visualization in a simulated environment, researchers can gain a better understanding and propose engineering solutions and behavioral guidelines to effectively reduce crash involvement and increase the safety and comfort of the aging population as they interact with the surface transportation system.

3. <u>Geographic Information System (GIS) and 3D Visualization Model</u>

<u>Task 1 Data Acquisition and GIS Modelling</u>

To begin to determine intersections that have an overrepresentation of older driver collisions, data was acquired from the Florida Department of Transportation (FDOT) consisting of a GIS file containing all of the recorded collisions from 2008 to (partial) 2012 for the entire state and several pieces of information about the occupants involved in the collision. ArcGIS, a GIS software developed by Esri, was selected to be the platform that would import, filter, and visualize the data. The use of ArcGIS as the GIS program of choice was made partially due to suitability to proposed analysis and compatibility with the FDOT collision data. The further use of ArcGIS for the generation of the 3D model of the intersection was considered during the initial phases of the project. Eventually, the decision was made to utilize Google SketchUp for the generation of a 3D model. This was due in large part to the knowledge that the team tasked with converting the 3D model into a driving simulator tile had gained from previous experience working with Google SketchUp files. Further information about the 3D model and its design will be explained in a later section.

The data that was obtained from the FDOT contained properties that included both crash site and vehicle occupant information. The data include categories for the severity of the injury to the occupant in the collision, the age and gender of the occupant, the position of the occupant in the vehicle, the data and exact location of the collision, if/what drugs and/or alcohol the occupant was under the influence of, etc. The information was useful because of the ability to filter the data (to allow for only the collisions of interest to remain) and to gain an understanding of the nature of the collision. The data allows for one to obtain some information about the collision and its occupants without having to view police reports. While the data isn't a substitute for police reports at the intersection, it does allow us to gain a preliminary understanding of the types of collisions occurring at an intersection and some of the information about the drivers involved in the collisions. Using this information and an examination of the intersections and their surroundings, a shortlist of intersections can be generated for further study.

Upon importing the data to ArcGIS, the data can be filtered in order to allow for the examination of individual intersections in regards to their number of older adult collisions, overrepresentation of elderly collisions, and the severity of the collisions. Specifically, the older adult collisions of interest consisted only of collisions involving a driver 65 years or older in which there was no evidence of the driver being under the influence of drugs and/or alcohol, the site of the collision was located in District 3, and the collision had at least the possibility of an injury (this would allow for focusing on improving the safety of the most dangerous intersections). Using these filters, dangerous intersections (i.e. those with a large number of elderly collisions) in District 3 were investigated for the potential to be modeled in the driving simulator task. A screenshot of intersection data, roadway data, and a satellite image are provided below to show the extents of the study (Figure 3.1).

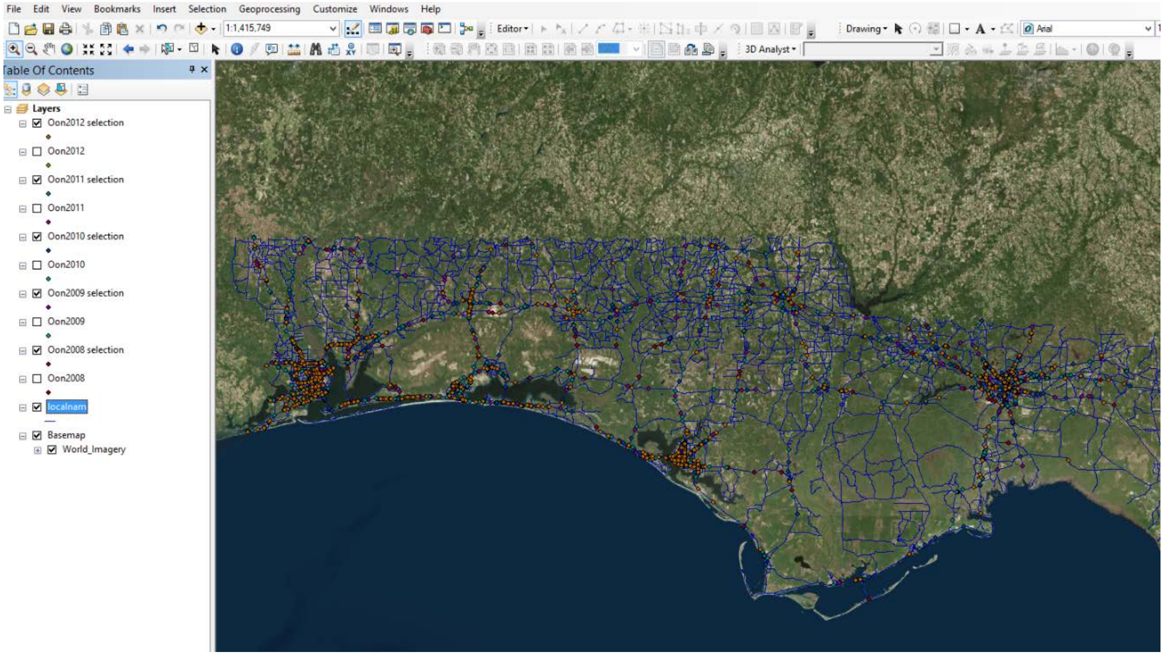
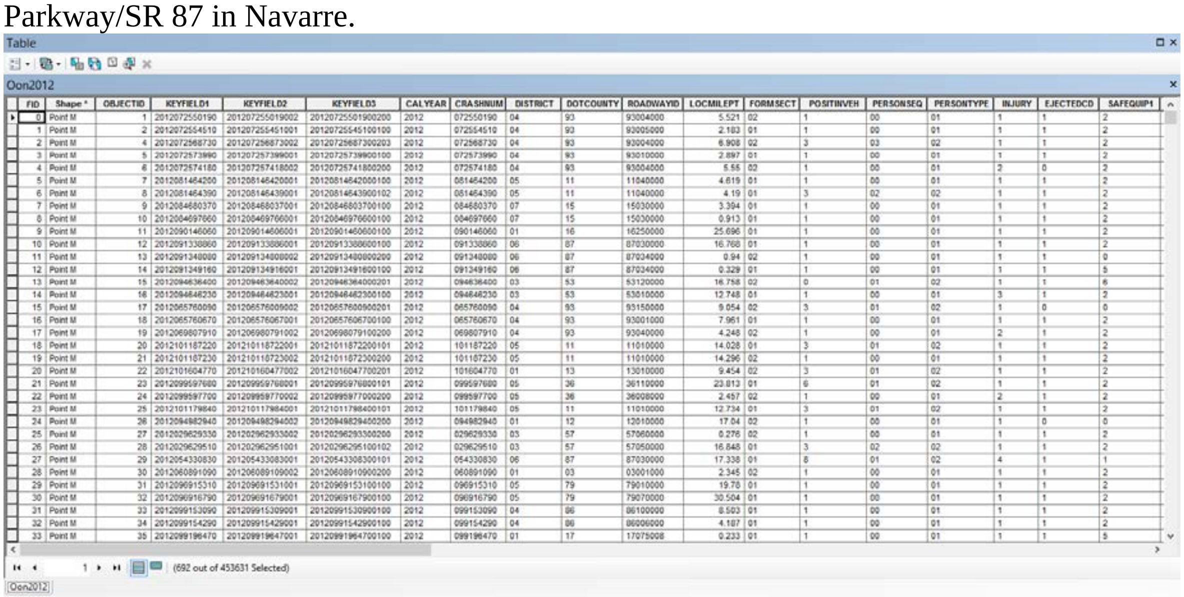


Figure 3.1. Study GIS Map with Roadway and Crash Data Added

Upon the completion of the aforementioned data filtering, various intersections located in District 3 were analyzed utilizing the ArcGIS file shown in Figure 3.2. Upon investigating several different intersections and the numbers of severe older adult collisions at the intersections, a shortlist of intersections to further examine was developed. The shortlist consisted of Apalachee Parkway/Blairstone Road in Tallahassee, North Palafox Street/Beverly Parkway in Pensacola, Hermitage Blvd/NE Capital Circle in Tallahassee and Navarre Parkway/SR 87 in Navarre.



Table

Oon2012

FID	Shape *	OBJECTID	KEYFIELD1	KEYFIELD2	KEYFIELD3	CALYEAR	CRASHNUM	DISTRICT	DOTCOUNTY	ROADWAYID	LOCMILEPT	FORMSECT	POSITINVEH	PERSONSEQ	PERSONTYPE	INJURY	EJECTEDCD	SAFEQUIP1
0	Point M	1	2012072550190	201207255019002	20120725501900200	2012	072550190	04	93	93004000	5.521	02	1	00	01	1	1	2
1	Point M	2	2012072554510	201207255451001	20120725545100100	2012	072554510	04	93	93005000	2.183	01	1	00	01	1	1	2
2	Point M	4	2012072568730	201207256873002	20120725687300203	2012	072568730	04	93	93004000	6.908	02	3	03	02	1	1	2
3	Point M	5	2012072573990	201207257399001	20120725739900100	2012	072573990	04	93	93010000	2.897	01	1	00	01	1	1	2
4	Point M	6	2012072574180	201207257418002	20120725741800200	2012	072574180	04	93	93004000	5.55	02	1	00	01	2	0	2
5	Point M	7	2012081464200	201208146420001	20120814642000100	2012	081464200	05	11	11040000	4.619	01	1	00	01	1	1	2
6	Point M	8	2012081464390	201208146439001	20120814643900102	2012	081464390	05	11	11040000	4.19	01	3	02	02	1	1	2
7	Point M	9	2012084680370	201208468037001	20120846803700100	2012	084680370	07	15	15030000	3.394	01	1	00	01	1	1	2
8	Point M	10	2012084697660	201208469766001	20120846976600100	2012	084697660	07	15	15030000	0.913	01	1	00	01	1	1	2
9	Point M	11	2012090146060	201209014606001	20120901460600100	2012	090146060	01	16	16250000	25.696	01	1	00	01	1	1	2
10	Point M	12	2012091338860	201209133886001	20120913388600100	2012	091338860	06	87	87030000	16.768	01	1	00	01	1	1	2
11	Point M	13	2012091348080	201209134808002	20120913480800200	2012	091348080	06	87	87034000	0.94	02	1	00	01	1	1	0
12	Point M	14	2012091349160	201209134916001	20120913491600100	2012	091349160	06	87	87034000	0.329	01	1	00	01	1	1	5
13	Point M	15	2012094636400	201209463640002	20120946364000201	2012	094636400	03	53	53120000	16.758	02	0	01	02	1	1	6
14	Point M	16	2012094646230	201209464623001	20120946462300100	2012	094646230	03	53	53010000	12.748	01	1	00	01	3	1	2
15	Point M	17	2012065760090	201206576009002	20120657600900201	2012	065760090	04	93	93150000	9.054	02	3	01	02	1	0	0
16	Point M	18	2012065760670	201206576067001	20120657606700100	2012	065760670	04	93	93001000	7.961	01	1	00	01	1	1	2
17	Point M	19	2012069807910	201206980791002	20120698079100200	2012	069807910	04	93	93040000	4.248	02	1	00	01	2	1	2
18	Point M	20	2012101187220	201210118722001	20121011872200101	2012	101187220	05	11	11010000	14.028	01	3	01	02	1	1	2
19	Point M	21	2012101187230	201210118723002	20121011872300200	2012	101187230	05	11	11010000	14.296	02	1	00	01	1	1	2
20	Point M	22	2012101604770	201210160477002	20121016047700201	2012	101604770	01	13	13010000	9.454	02	3	01	02	1	1	2
21	Point M	23	2012099597680	201209959768001	20120995976800101	2012	099597680	05	36	36110000	23.813	01	6	01	02	1	1	2
22	Point M	24	2012099597700	201209959770002	20120995977000200	2012	099597700	05	36	36008000	2.457	02	1	00	01	2	1	2
23	Point M	25	2012101179840	201210117984001	20121011798400101	2012	101179840	05	11	11010000	12.734	01	3	01	02	1	1	2
24	Point M	26	2012094982940	201209498294002	20120949829400200	2012	094982940	01	12	12010000	17.04	02	1	00	01	1	0	0
25	Point M	27	2012029629330	201202962933002	20120296293300200	2012	029629330	03	57	57060000	0.276	02	1	00	01	1	1	2
26	Point M	28	2012029629510	201202962951001	20120296295100102	2012	029629510	03	57	57050000	16.848	01	3	02	02	1	1	2
27	Point M	29	2012054330830	201205433083001	20120543308300101	2012	054330830	06	87	87030000	17.338	01	8	01	02	4	1	1
28	Point M	30	2012060891090	201206089109002	20120608910900200	2012	060891090	01	03	03001000	2.345	02	1	00	01	1	1	2
29	Point M	31	2012096915310	201209691531001	20120969153100100	2012	096915310	05	79	79010000	19.78	01	1	00	01	1	1	2
30	Point M	32	2012096916790	201209691679001	20120969167900100	2012	096916790	05	79	79070000	30.504	01	1	00	01	1	1	2
31	Point M	33	2012099153090	201209915309001	20120991530900100	2012	099153090	04	86	86100000	8.503	01	1	00	01	1	1	2
32	Point M	34	2012099154290	201209915429001	20120991542900100	2012	099154290	04	86	86006000	4.187	01	1	00	01	1	1	2
33	Point M	35	2012099196470	201209919647001	20120991964700100	2012	099196470	01	17	17075008	0.233	01	1	00	01	1	1	5

1 (692 out of 453631 Selected)

Oon2012

Figure 3.2: Properties of FDOT GIS Data

The intersections that were shortlisted needed to fulfill two or more of the following criteria to at least make it on the shortlist:

1. Have at least 5 or more collisions involving older adult 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. 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 intersections mentioned above had high quantities of older adult collisions, when compared with surrounding areas, and many of these collisions tended to have a high severity. When the need for the selection of an intersection arrived, both the Navarre and Okaloosa Island intersections were not chosen due to a lesser understanding of the local conditions of the area (the other two intersections have the convenience of being located in Tallahassee, where the study took place) and due to the atypical nature of the intersections themselves. The Navarre intersection was T-shaped (SR 87 didn't proceed southbound passed the intersection), which might cause some safety suggestions from the study to be bespoke to this particular type of intersection. The Pensacola intersection was not selected due to a lack of information of the local area and due to the nature of some of the collisions. Some of the collisions in the area were located not at the intersection but near the beginning of the left turn lanes northbound on North Palafox Street. This location had a gap in the raised median that allowed for vehicles to turn left on to Carolyn Way south of the North Palafox/Beverly Parkway intersection. This gap has since been closed (as can be seen on Google Earth); therefore eliminating some of hazards leading up to collisions. Additionally, the scope of these collisions didn't fall under the study focus on signalized intersections, which is the type of intersection that the study is interested in. While the remaining collisions occurring in and very near the intersection of North Palafox and Berverly Parkway still made the intersection one that would met the requirement of being a dangerous intersection, the above mentioned reasons caused the intersection to become unfavorable as a location for further study.

The Apalachee Parkway/Blairstone Road intersection was not chosen for modeling despite having reports of severe elderly crashes and local knowledge. One of the main reasons for opting out of the modeling this intersection is based on the fact that the intersection has a skew angle of around 15 degrees. Being that most intersections have a 0 degree skew (meet at 90 degree angles), the intersection deviated from a typical intersection in this regard. Additionally, westbound Apalachee Parkway, prior to the intersection, doesn't have a bike lane or paved shoulder, which means that the asphalt roadway is directly adjacent to the grass.

The NE Capital Circle/Hermitage Boulevard in Tallahassee (Figure 3.3), Florida was selected as the intersection to be modeled due to its high rate of older adult collisions, its location in a region with a mix of residential and commercial dwellings (thus giving two roadways with differing ADDTs and functions), 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 of the intersection (Note: the intersection is called the Hermitage Blvd/NE Capital Circle intersection even though the portion of Hermitage Blvd east of the intersection is called Eastgate Way. This is done to avoid have the confusion that can be caused by talking as though three separate roadways for one intersection. As such, this portion of roadway east of the intersection will be referred to as Hermitage Blvd instead of Eastgate Way).

1.

Figure 3.3. GIS Map of Hermitage Blvd/NE Capital Circle Intersection with Crash Data

In addition to the ability to obtain FDOT GIS data for the intersection, the site was convenient (as were other intersections being analyzed in Tallahassee) due to the ability to obtain police collision reports for the intersection. By obtaining these reports, the individual crashes could be better investigated to generate hypotheses on why the collisions are occurring; and therefore, determine ways to take preventative actions that would reduce the number and severity of these crashes. The police reports were obtained from the Leon County Sheriff's Office for the NE Capital Circle/Hermitage Boulevard intersection from 2008 to 2012. In total, 39 police reports were obtained for the intersection, of which 12 involved elderly drivers (30.8% of total collisions), thus showing the large ratio of elderly collisions to non-elderly collisions.

<u>Task 2 Aging Safety Criteria Analysis</u>

The major transportation safety criteria considered by the project consisted of the following proven practices from the FHWA's Aging Driver Handbook; intersection sight distance, left-turn traffic control for signalized intersections, right-turn traffic control for signalized intersections, and offset left-turn lanes. By investigating these design elements, the project hoped to be able to make safety suggestions to the FDOT in order to reduce the quantity and severity of collisions, specifically those that proportionally affect the elderly.

Intersection sight distance, Design Element 4, was examined for the intersection. Due to Hermitage Boulevard's varying elevation and its approach to the intersection not running perpendicular to NE Capital Circle until around 100-150 feet from the intersection, the intersection sight distance was investigated for possible safety improvements. While the intersection may have an adequate sight distance according to Design Element 4 part A, the driver's vision may be obstructed by vehicles in other lanes (this was obvious in our 3D modeling attempts in Google SketchUp and within the driving simulator model). This will reduce the ability of the driver turning right to have a clear understanding if traffic will be going through the intersection and preventing them from making a safe turn. Additionally, there may be the possibility that older drivers may utilize the distance leading up to the intersection to determine if there is any traffic heading towards the intersection that would prevent them from turning right. By examining the opposing traffic prior to arriving at the light, the elderly driver wouldn't be as hampered by restricted head and neck movement.

Left-Turn Traffic Control for Signalized Intersections, which is Design Element 8 of the FHWA Handbook for Designing Roadways for the Aging Population, is a particular area of focus for this study due to the nature of the severity of left-turn collisions involving elderly drivers. As will be explained later, the SketchUp model will consider two different scenarios based on the previous and current traffic lighting 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. For the permitted and protected left turn scenario, section B of Design Element 8 is to be implemented in the model (as it was in the actual intersection's previous traffic lighting configuration). The model of this scenario has MUTCD's R10-12 sign on both traffic light sets along NE Capital Circle, as per the FHWA's requirements. Section C of Design Element 8 is not utilized in the permitted and protected left turn scenario due to the fact that there is no knowledge of the actual intersection having any advanced notice R10-12 and R10-31P signs when it allowed for protected and permitted left turns. Figure 3.4 shows an example of the MUTCD R10-12 and R10-31P signs that can be placed prior to the intersection to allow drivers to conduct permitted left hand turns. The study of leading and lagging permitted left turn phases (section D of Design Element 8) has the potential to be conducted to investigate the possibility of differences in driver behavior when faced with the decision to make a left turn prior to the signal turning red.

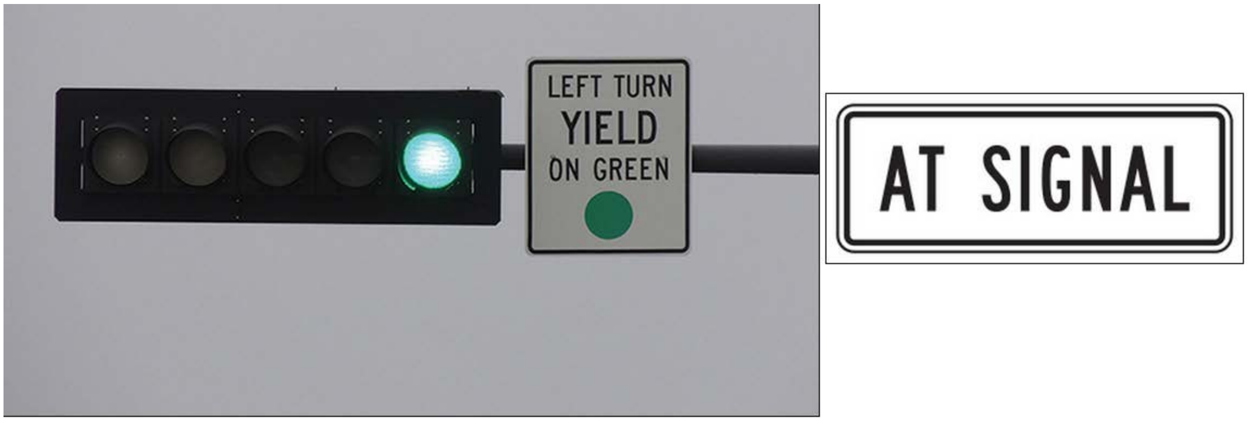


Figure 3.4 MUTCD R10-12 (left) and R10-31P (right) signs [source: FHWA Elderly Driver Handbook]

Right-turn traffic control for the intersection has the potential to be investigated due to the high number of right-hand turn collisions that occur going from Hermitage Boulevard (west-bound) on to NE Capital Circle (south-bound). These collisions generally are not nearly as dangerous as the left-turn collisions due to most of these collisions being the result of a slow speed rear-ending. The manner that older drivers approach right-hand turns in the simulator has the potential to be investigated to see how they perform during permitted right-turn phases and what might be a main cause of these crashes. As mentioned earlier, one of the reasons for the collisions could be due to visual obstructions that reduce the ability of the driver to utilize the designed intersection sight distance. While the actual intersection and its models don't utilize the signage shown in Design Element 9 (MUTCD's R10-11 or R10-15), it does have an R10-6 sign installed to notify drivers attempting to turn right from eastbound Hermitage Blvd to southbound NE Capital Circle to come to a complete stop when arriving at the intersection that isn't allowing for protected right-hand turns. Figure 3.5 shows the MUTCD's R10-6 sign installed at the intersection.

Figure 3.5 MUTCD R10-6 sign [source: FHWA Elderly Driver Handbook]

As mentioned previously, once developed fully, the simulator tile has the potential to have participants drive through two different lighting scenarios in order to allow for data to be obtained on the drivers and to determine if safety recommendations can be made. Simulator studies can have drivers maneuver through a scenario where the intersection has permitted and protected left and right turn phases and a scenario where there is no left-turn permitted phase.

By examining how the elderly drivers handle both types of intersections, it can allow us to better understand the safety advantages of only providing protected-only left turns. To accommodate the testing of these two scenarios, the number of lights along NE Capital Circle would need to change from four (protected-only left turn phase) to two (protected and permitted left turn phases).

In addition to the previously mentioned Design Elements, the models were created to meet many of the appropriate specification listed in the FHWA Aging Driver Handbook. Both in the real intersection and in the models, Design Element 2 is accounted for in the form of 12 foot lanes and 4 foot shoulders. Design Element 10 (Street Name Signs) Section A was followed as best as possible; however, the street signs had their texture generated from an image file, which made controlling the sizing of the lettering difficult. Design Element 12 (Lane Assignment on Intersection Approach) was used in the generation of advanced markings leading up to the intersection (section B). In regards to Design Element 13 (Traffic Signals), the traffic lights were designed with 12 inch signals according to Section 4D.07 of the MUTCD. Additionally, the traffic lights were modeled to ensure that the top of the signal housing didn't exceed 25.6 feet above the pavement or that the bottom of the signal housing was less than 15 feet above the pavement. The model was designed with fixed lighting as per Design Element 14 and the actual lighting scenario of the intersection.

Task 3 3D SketchUp Model

The generation of the 3D model of the intersection was accomplished using the Google SketchUp 3D modeling software. The software was chosen for its ability to generate a 3D topographic surface of the intersection and the area spanning 400 feet from the intersection, develop an aesthetically pleasing model, allow for the importation of objects from an online warehouse, assist in the creation and photo-texturing of buildings and other objects, and due to the fact that the team tasked with converting the 3D model into a driving simulator were capable of doing so with a Google SketchUp file. It was determined from past experiences working with generating intersection models and converting them into driving simulators, that modeling all area within 400 feet of the intersection would be adequate for the project's purposes. Any areas beyond the 400 feet to be modeled would be filled in with a generic tile.

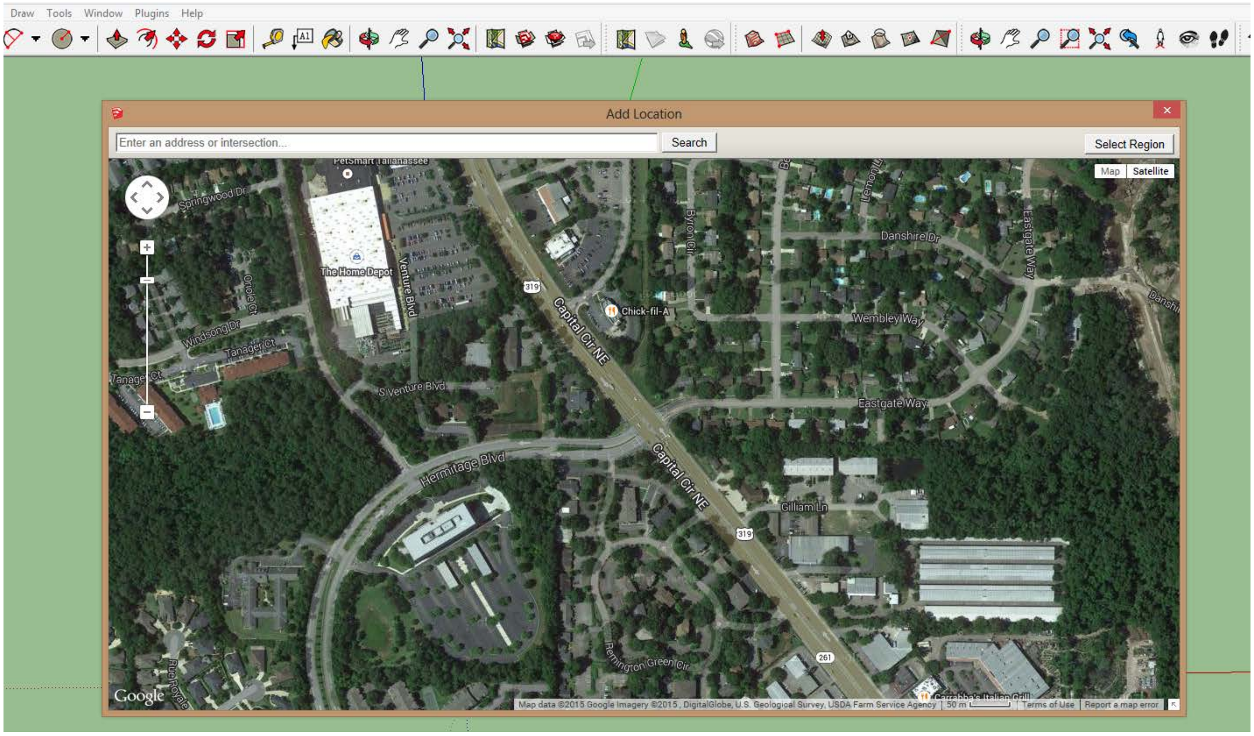


Figure 3.5. The Satellite Image of the Hermitage Blvd/NE Capital Circle Intersection

The development of the model started with importing both a 2D and a 3D satellite image from Google Maps via the Add More Imagery tool. Once this tool is selected, a satellite GPS image of will show up of a default location. One can then type in the appropriate address or location (Hermitage Boulevard Tallahassee, FL for this project) and the GPS image of that location will show up, as shown in Figure 3.5.

The next step is the selection of the intersection and surrounding region to be imported into the SketchUp model. With the aid of the scale provided by the Google Maps GPS map, a rectangular portion extending around 400 feet from the intersection was chosen to be imported into the model, as seen in Figure 3.6.

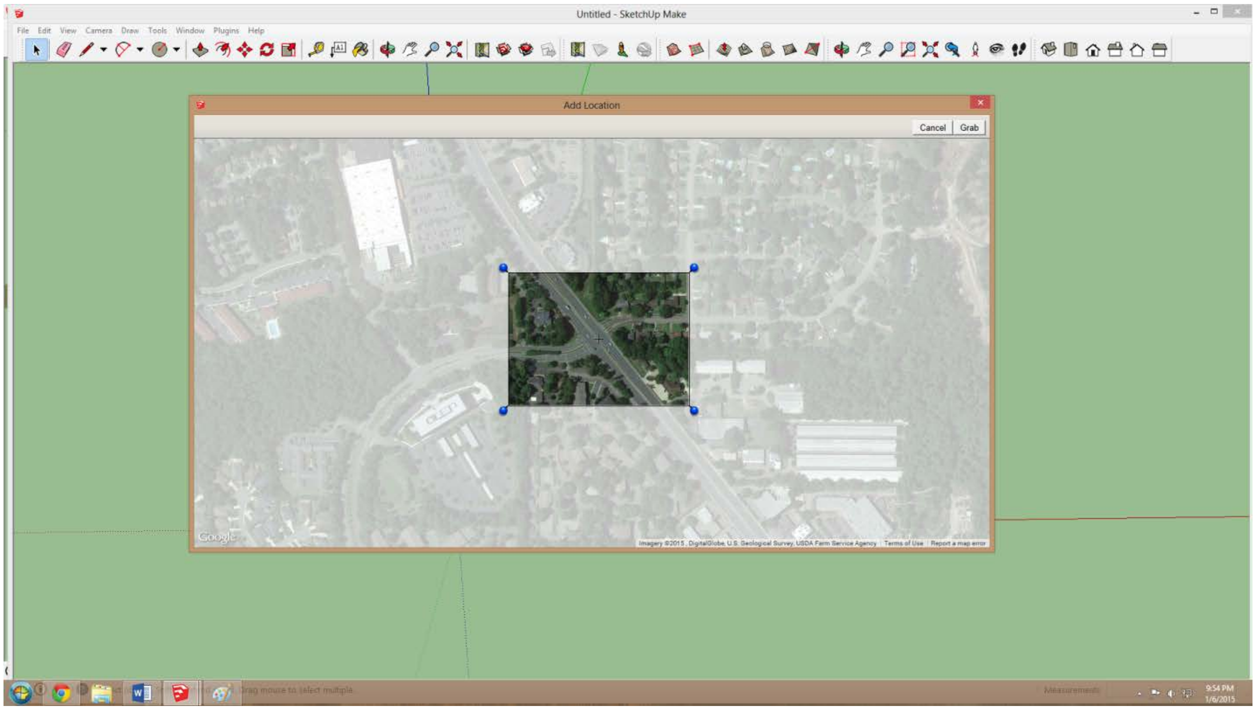


Figure 3.6. Selection of a Region of the Satellite Image to by Imported into SketchUp

Once imported (Figure 3.7), the SketchUp file adds a flat terrain to the model of the selected location. Depending on the zoom of the satellite image at the time and the size of the region selected, the image may show up as quite blurry. The lack of detail will obfuscate the features of the terrain, thus requiring the temporary importation of smaller, more zoomed in portions of the terrain model. With the addition of zoomed in portions of the GSP image, one is left with pieces of terrain with a higher resolution than the original terrain model. Figure 3.8 shows that by temporarily importing a zoomed in section of the terrain model one can see the image with a far better clarity (in this case one can better see the middle of the intersection). The use of these temporary imports is to aid in modeling the intersection to mirror the actual intersection as much as possible. Since the model is imported to its actual scale, the intersection model can be developed using the satellite images as guidelines. Thus the use of the temporary terrain imports with their high level of clarity will allow for more accurate modeling, specifically when trying to overlay a textured terrain on the imported terrain model.

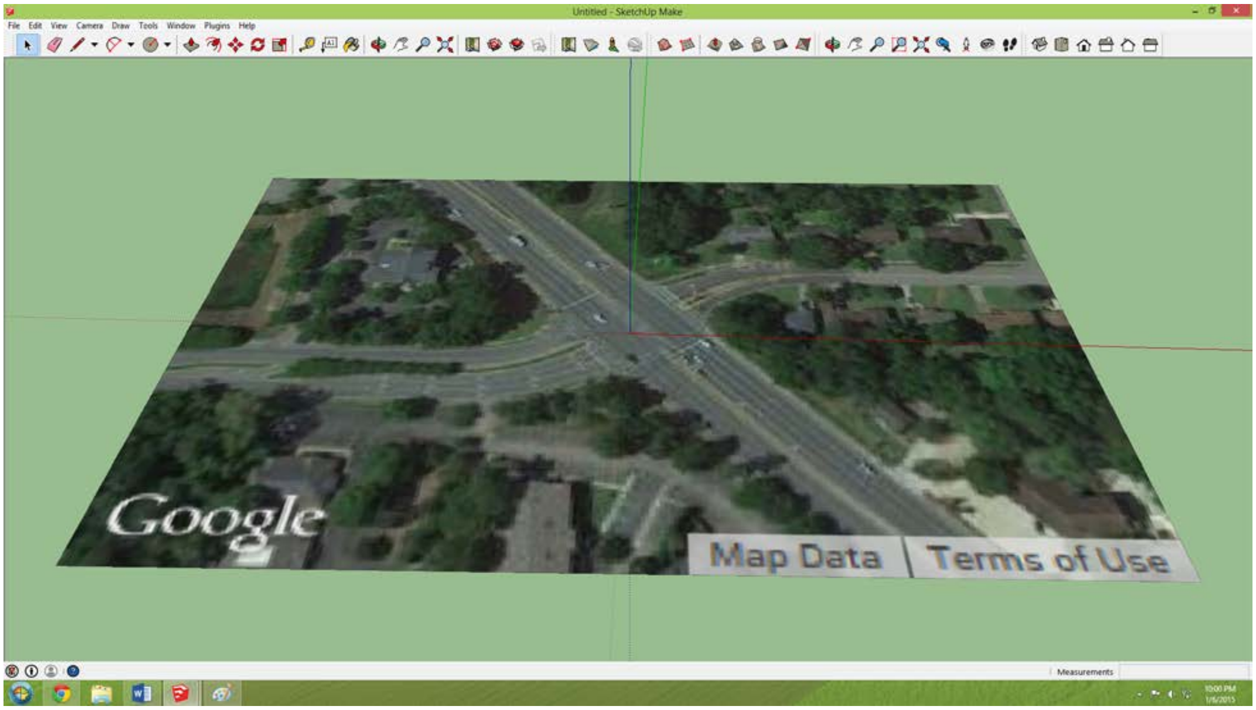


Figure 3.7. Flat Terrain Model of Imported Region

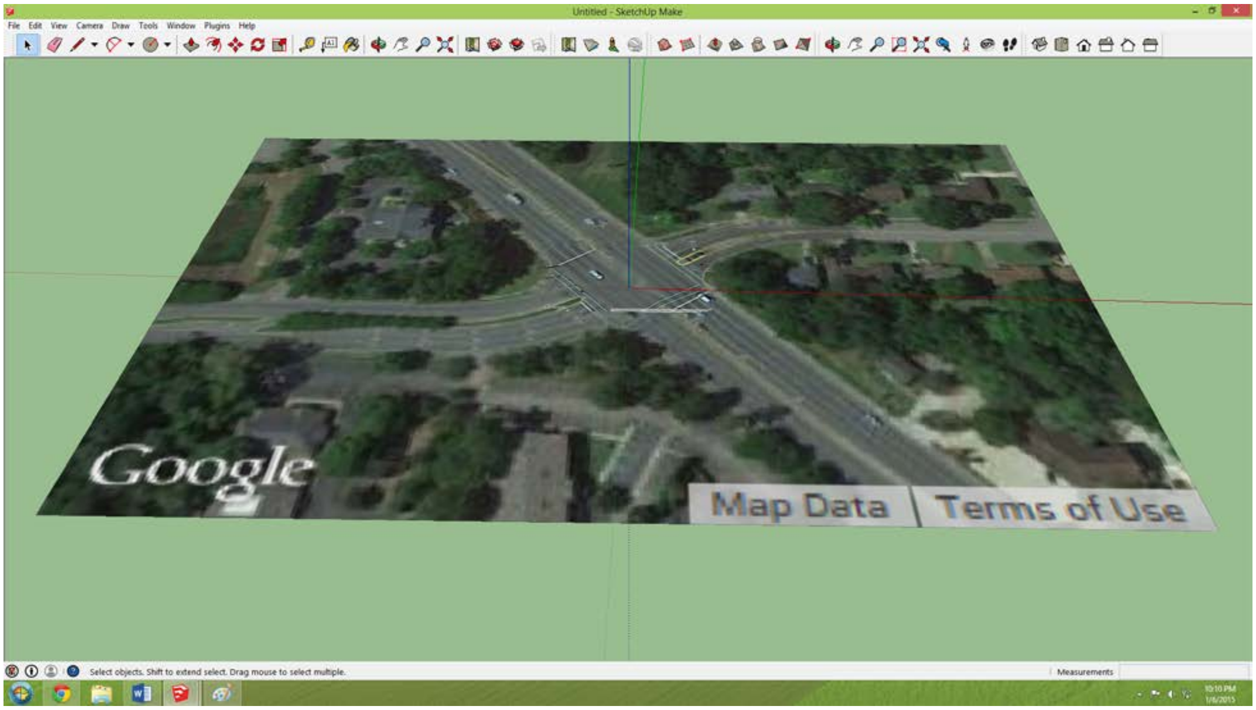


Figure 3.8. Flat Terrain Model with Additional Imported Piece of Terrain (Middle of Intersection)

With the addition of the satellite images, one can begin to develop the terrain that will drape over the 3D terrain model. The intention is to create a 2D terrain model based on the imported satellite image that can then use the sandbox tool, called Drape, and carve the 2D terrain model's shapes into the 3D surface. This will allow for the transition from a 2D terrain model into a 3D terrain model. Once this has occurred, the various lines that were draped on to the 3D terrain model can be welded together to form a shape, which will be capable of being filled with a texture. The terrain model will be based on the satellite image, have the 3D contours based on the imported satellite image, and will have textures that better allow for a better and more aesthetically pleasing model.

Using a mixture of the satellite imagery, information on the intersection, and of knowledge of general roadway design, the 2D terrain map was developed. Using the satellite image, the roadway was first developed with the line tool. The edges of the roadway were created through tracing the satellite image and inspecting the model to ensure that the boundaries of the two roadways matched. Once the edges of the roadway had been developed, the lanes and their markings could be developed using a mixture of the satellite image and roadway design knowledge. The satellite image proved useful as a way for beginning to develop a roadway segment and for reference, while the knowledge that the roadway had 12 foot lanes, 2.5 foot bike lanes, etc., was used for developing their appropriate sections of the roadway. The satellite image also was needed to develop terrain features that were not roadway related (e.g. parking lot dimensions) or required information that the model designer didn't have access to (e.g. the varying widths of the roadway in the residential portion of Hermitage Boulevard). The final product of this step is shown in Figure 3.9.

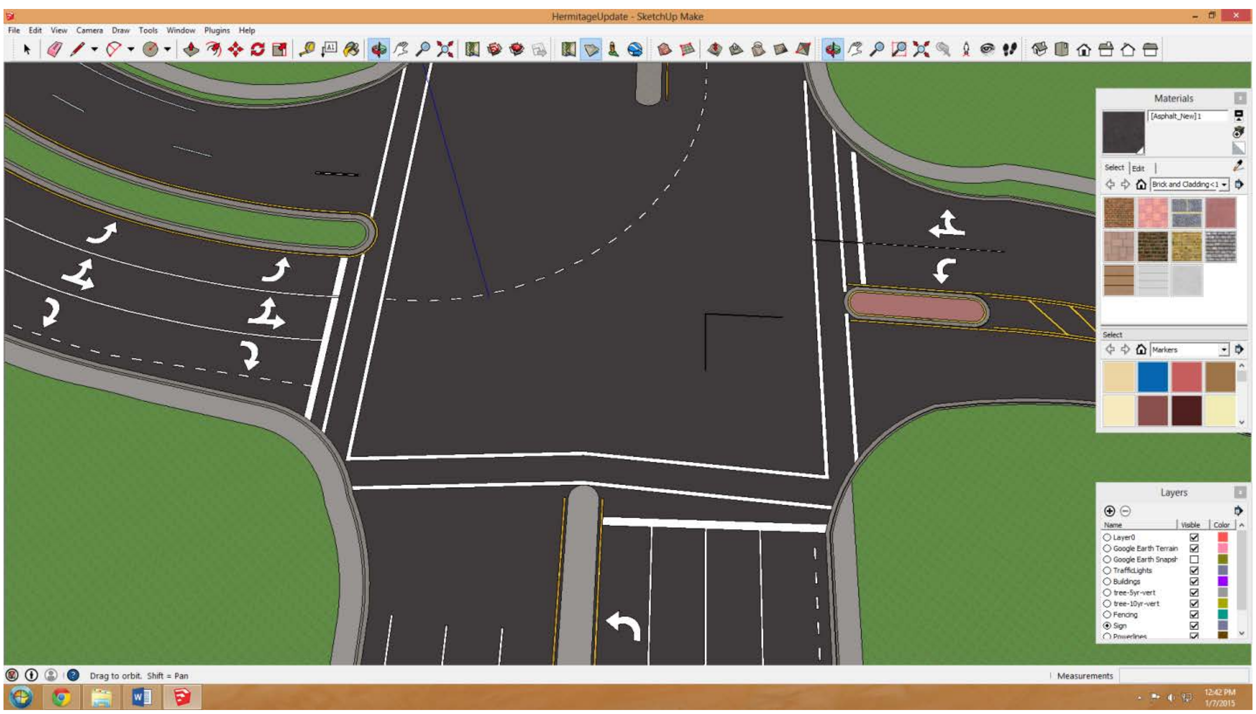


Figure 3.9. 2D Terrain Model of the Intersection

Using the terrain model shown in Figure 3.9, a 3D terrain model that has the same textures as the the 2D terrain model can be generated. However, prior to developing this 3D model, the focus of the model switched to the addition of the non-terrain elements. For this phase, the traffic lights, utility poles, signs, buildings, trees, etc., had to be imported or modeled into the SketchUp model in order to produce a 3D model that comes as close as possible to depicting the actual intersection. In order to place the objects as close as possible to their actual locations, the 2D satellite image was utilized. When creating the 2D terrain model shown in Figure E, the modeler used line and other shape commands to develop the terrain. This terrain shown in Figure 3.9 was modeled on top of and in a different layer than the satellite image it was based on (Figure 3.7). As a result of the original image being intact, in the same location as Figure E, and being in a different layer, the layer containing all of the linework and textures in Figure E was shut off leaving only the image in Figure 3.7. By doing this, one can place the buildings, street lights, signs, etc., in locations as close to their actual counterparts as possible. Thus the layer containing Figure 3.9 was shut off and the modeling of the individual, non-terrain components began.

In order to generate the traffic signals, a combination of methods were used to develop the objects. The traffic lights themselves were imported from the Google SketchUp database and altered to ensure they came close to matching the aethetics of the actual traffic lights. However, the manner in which the traffic lights at the Hermitage Blvd./NE Capital Circle intersection are set up doesn’t match any in the Google SketchUp database. Due to this fact, the wires holding the traffic lights, the metalallic piece allowing the traffic light to hang on the wire, the concrete poles holding up the traffic signals, street signs, and lane assignment signs were created from scratch using simple shape generation and texture tools. The only object in the traffic signal set-up that is imported from the SketchUp database are the pedestrian traffic crosswalk indicators. Figure 3.10 depicts the finished product of the process described in this paragraph.

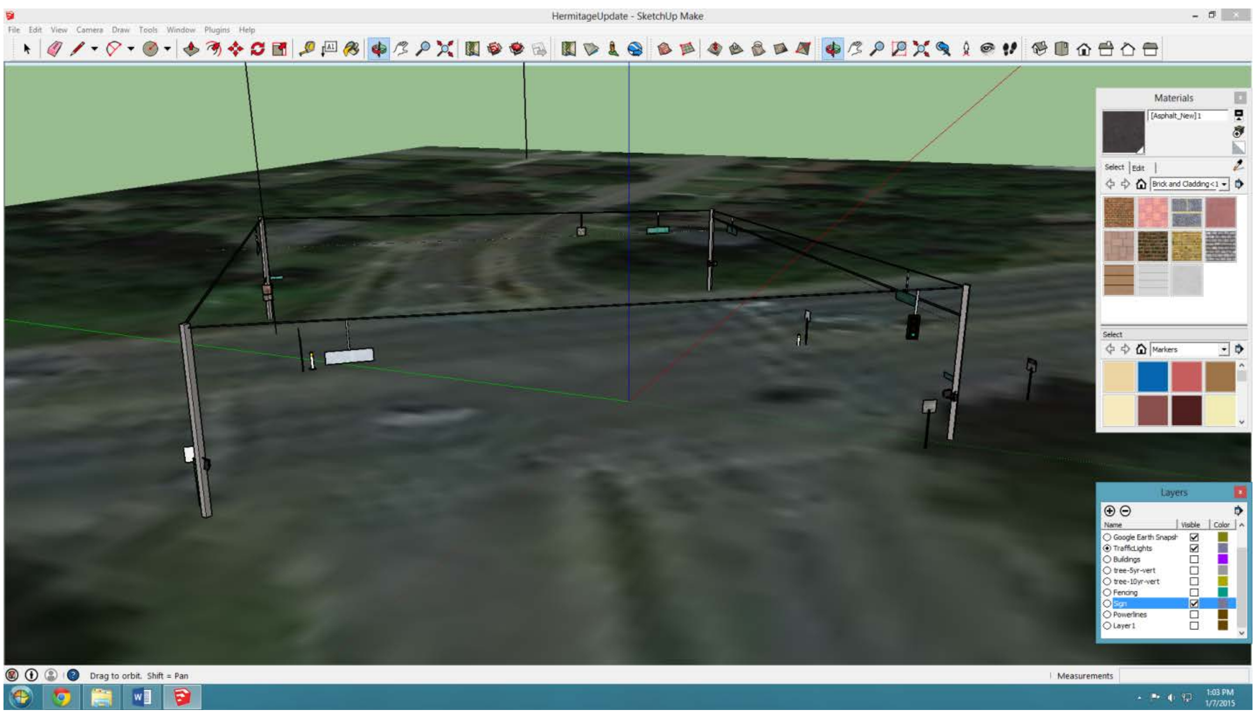


Figure 3.10. Traffic Lights and Signs on the Satellite Image

On top of the textures applied to some of the intersection’s objects (e.g. the SketchUp concrete texture used on the concrete columns holding the traffic lights up), photo textures were added in order to bring the model closer to replicating the real world intersection. The use of these photo textures allows for the generation of street signs with textures that match the actual intersection's street sign textures. In addition to the street signs, the lane assignment signs and the speed limit signs (shown in Figure 3.10) utilized the photo textures that matched their real world equivalents. The process of applying photo textures is similar to the process for adding a terrain to a model. One will select a portion or face of an object they wish to apply the texture to and right-click to open a dropdown menu where one will select the "Add Photo Texture" option (Figure 3.11).

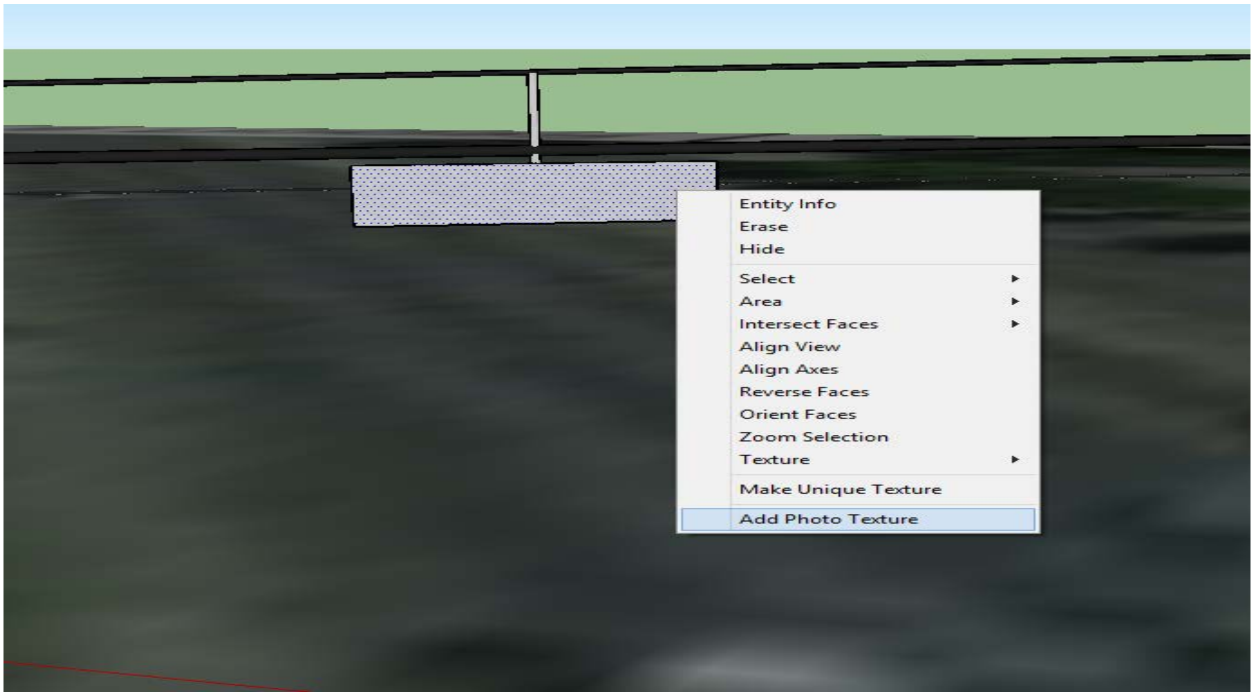


Figure 3.11. Adding Photo Texture to Street Sign

Once the process in the previous paragraph is finished, one will encounter a Google Maps map and street view box. In order to add the photo texture to the object, the modeler will move to a location where the texture of interest (in this case the street sign) can be selected and imported into the model (Figure 3.12). Reiterating a note made previously, the portion of roadway called Eastgate Way is the same as Hermitage Blvd (it is the portion of Hermitage Blvd that lies east of the intersection).

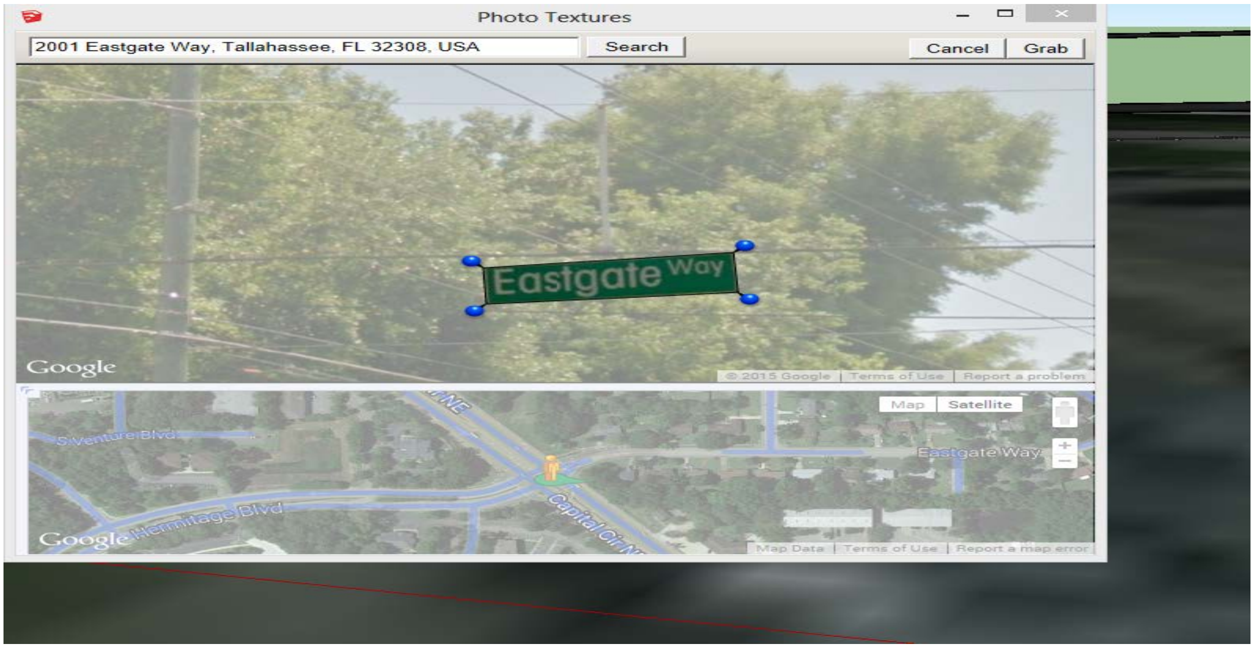


Figure 3.12. Selection of Texture that will be Imported on to an Object

Upon selecting the texture to be imported, the object in the SketchUp model will now have a texture that is the same as the one shown above. SketchUp may have to shrink or expand the size of the texture to ensure that it fits the surface of the object it is being placed on. Figure 3.13 shows the street sign with the texture added on to the appropriate face of the sign.

Figure 3.13. Street Sign with Photo Texture Added to Object Face

The generation of buildings is done in a similar fashion to the intersection's traffic lights, in that the buildings are initially modeled and placed on the 2D surface. The buildings are created utilizing floorplans that are available from the Leon County GIS website. Utilizing the site's interactive map of Leon County, the modeler could find the buildings near the intersection and bring up their footprints. Using these footprints, the base of the building could be generated. In order to make the buildings match the height of their real life counterparts, building height information was obtained from Leon County GIS. The information was extracted from an ArcGIS file and used when determining the appropriate height to model the buildings. Due to the nature of the data, the average height of the individual building was known; however, the heights at various points of the buildings were not. As such, buildings heights were modeled with assumptions about the gradient of the roofs' faces and the determination of where along the roof the roof's height is equivalent to the building's average height. Once building is designed from the floorplan and height information, the building will be placed in the model utilizing the satellite image of the site. The building will be placed as close as possible to the building's actual position in order to avoid having the building impede the driver's sight line more than would be encountered at the actual intersection. Additionally, the opposite is true for the building's positioning. The model doesn't wish to reduce the visual impacts created by the modeled building when compared to the actual building. Figure 3.14 gives an example of an untextured building being placed on the satellite map.

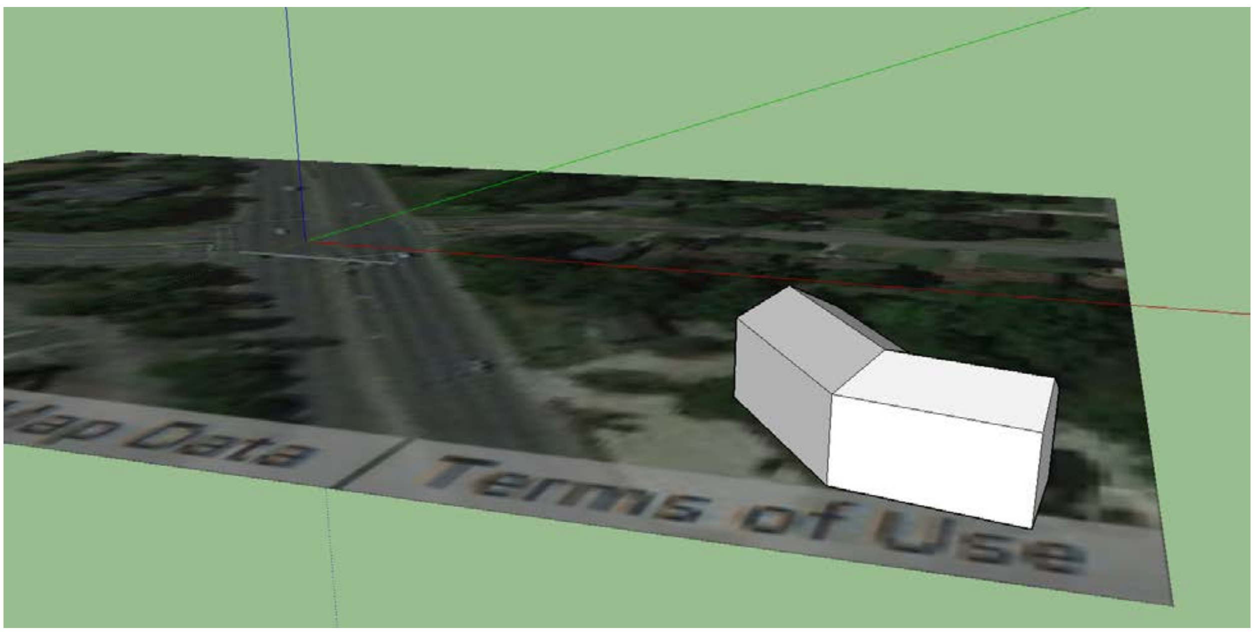


Figure 3.14. Building Placed in SketchUp File on 2D Terrain


Figure 3.15. Building with Photo Texture and Generic Texture Faces

The buildings were given a combination of photo textures and SketchUp textures to ensure that the buildings appear to be aesthetically pleasing and as lifelike as possible. The procedure for adding photo textures to the buildings will be the same as the method described previously for adding phototextures to street signs. One of the differences for this particular method is that several faces of the building will have to undergo the process of adding a photo texture (as opposed to the one face that had to undergo the process with the street sign). In certain areas where adding the photo texture wasn't easily obtainable or when adding the texture wouldn't make a large impact in the visual appearance of the building, an appropriate stock texture was chosen from the SketchUp texture library. This particular method was utilized for faces of buildings not facing traffic and the roofs of buildings. Figure 3.15 shows an example of the building in Figure 3.14 with photo textures and generic, SketchUp textures added to the building faces. The building in the figure has the photo textures taken from the actual building on the sides facing the streets. The roof, sides of the building, and back of the building (not visible to drivers at any angle in the model) are given generic textures in order to reduce the time required to generate the building and to reduce the size and complexity of the model.

The 2D intersection model is finished with the creation of the various other elements that can be seen at or near the intersection, including light poles, trees, fencing, signage, and various miscellaneous elements. These objects were modeled and textured in a similar manner as described above or imported from a SketchUp model database. Once the individual features of the intersection model have been generated and textured, the model must be converted from one on a 2D terrain model to one that lies on a 3D terrain model. By completing this phase, the model will be set up to mirror the intersection's local terrain as best as possible so that the driver will maneuver through the intersection and all areas leading up to and away from it in the same fashion that they would if they drove through the actual intersection. Due to the relatively large magnitudes of the roadway slopes and the visual obstructions leading to and located at the intersection, the accurate modeling of the topography and the addition of the intersection sight distance obstructing objects is crucial to the effectiveness of the model. As such, the conversion of the model to include the 3D terrain of the site is vital to reducing modeling errors and obtaining accurate information.

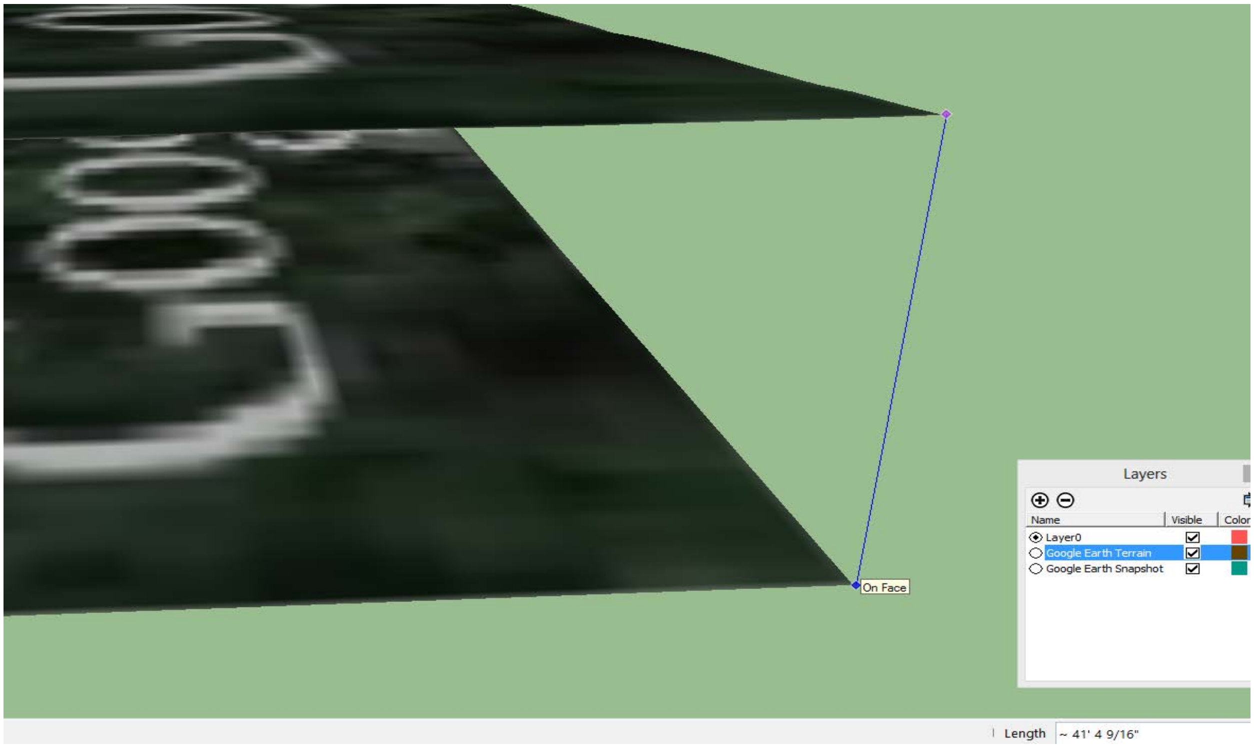


Figure 3.16. Difference in Elevation between 2D and 3D Terrain Models

The process of converting the 2D terrain model into a 3D terrain model in Google SketchUp consists of toggling on the Google Earth terrain layer (this layer is added when the initial site location was imported from the Google Maps image). This layer is very similar to the initial, 2D layer; however, it also contains elevation information for the imported region. For the Hermitage Blvd/NE Capital Circle intersection and its surrounding area, the toggling on of the 3D terrain map will have a drastic impact on the model. Due to the sizable change in elevation encountered along Hermitage Blvd, the buildings and other objects in the model will need to be moved to their appropriate elevations to ensure that the buildings mirror the actual buildings at the site. Before moving the objects, the 2D terrain will need to be converted to a 3D terrain. Once the model has a fully-functioning 3D terrain, the buildings, traffic signals, etc., may be moved to their respective locations. The effects of turning on the 3D terrain in regards to the differences in elevation between the 2D and 3D terrain at a location near the intersection can be seen in Figure 3.16.

As mentioned earlier, the 3D terrain model will be altered in a way that its texture will mirror the 2D terrain model's texture. In order to go about making this alteration, the 2D model will be draped onto the 3D model using the 'Drape' tool. The act of draping the textured, 2D terrain model on to the 3D satellite image model is that the various line work that went into generating the 2D model will be overlaid on to the 3D terrain model. This will copy the line work onto the 3D model, but it will recreate the lines in a way that will cause it to follow the elevation contours of the 3D terrain model. By accomplishing this, the 3D terrain model will be carved into sections that will allow (after some line work errors are fixed) for the appropriate texture to be applied to a region. The application of the textures will finalize all changes that need to occur for the 2D terrain model to be fully converted into a 3D model. After this phase, the various elements of the intersection will need to be moved to their appropriate locations in order to complete the model. Figure 3.17 shows the initial conversion process of going from a 2D to a 3D terrain model, while Figure 3.18 details Hermitage Blvd's westbound approach to the intersection and gives a closer look at how the draped lines sit on the 3D surface.

Figure 3.17. Draping of the Line Work from 2D Terrain Model on to 3D Terrain Model

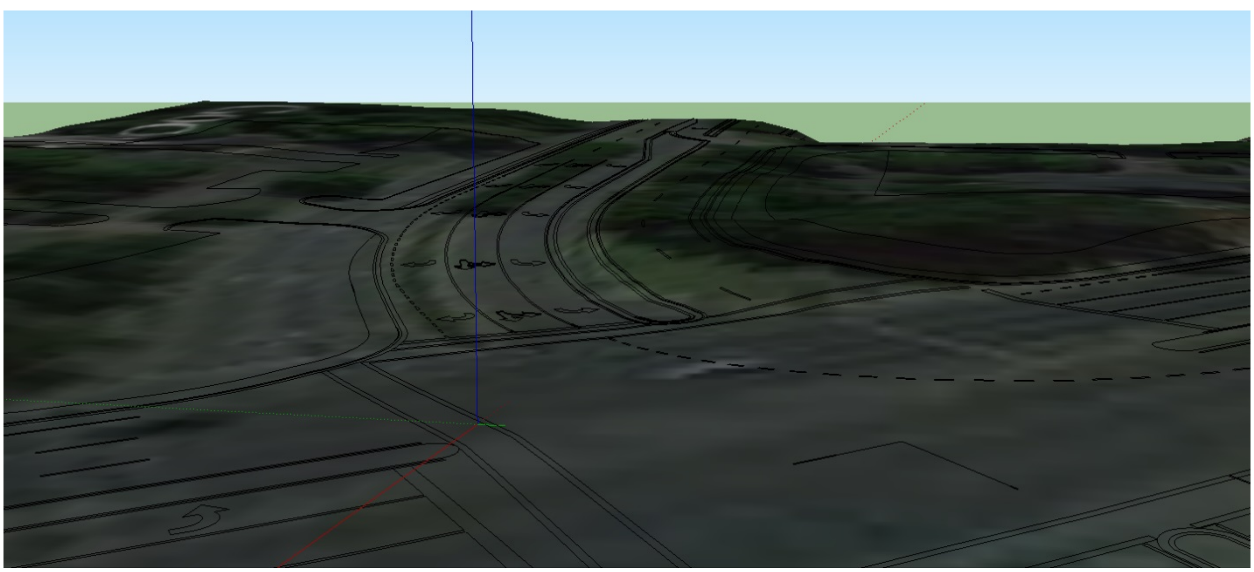


Figure 3.18. Draped Lines Seen on Hermitage Blvd's Westbound Approach to the Intersection

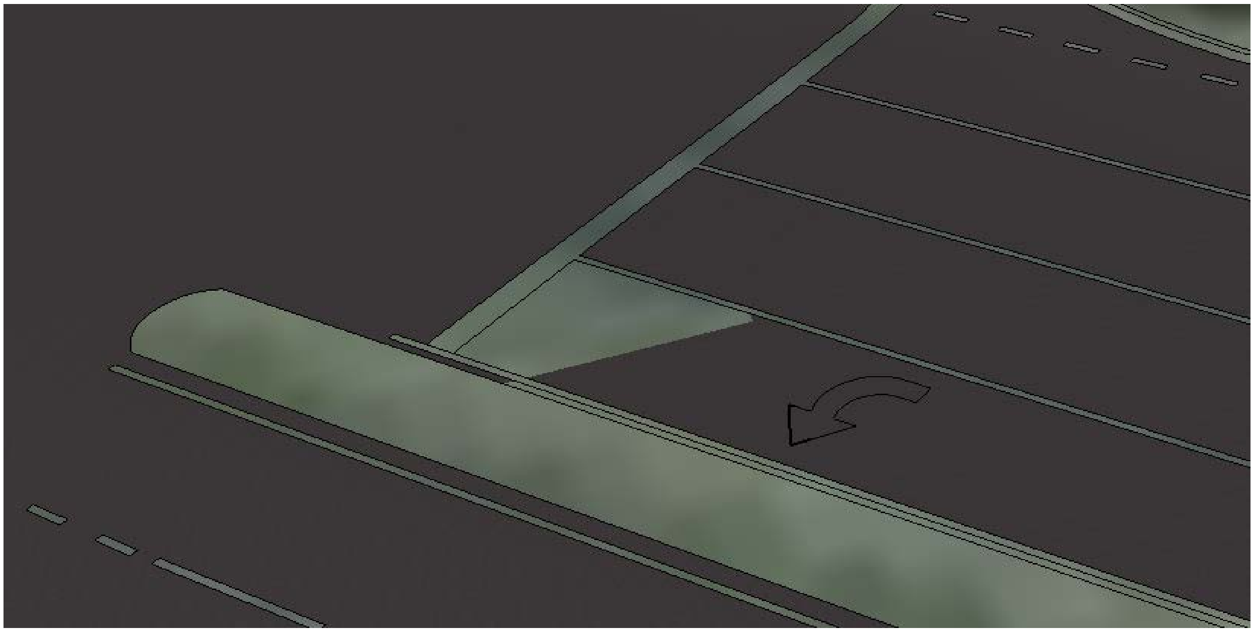


Figure 3.19.Texturing of Both Roadway and Roadway Markings

The addition of texture to the 3D surface allows one to better understand how the completed driving simulator will look. By adding in the various textures, the model not only looks cleaner (as opposed to keeping the satellite image texture) but also eliminates the unwanted elements of the satellite image that are captured (e.g. the images of vehicles on the roadway texture, images of trees on the roadway texture, images of the tops of trees on the ground's texture). The texture will be added to the line work shown in Figures 3.17 and 3.18 by closing off pockets of terrain and filling them in with texture. Initially this can't be done due to the fact that the 3D surface and the line work draped on it consist of one selectable object. The object will need to be exploded to allow for the texturing of any one element of the terrain. Once the terrain has been exploded, the terrain can begin to have textures applied to it; however, certain elements of the model will need to have their line work redone in order to ensure proper texturing. The examination of Figure 3.19 will allow one to see the line work errors can cause regions to not be considered closed off from the surrounding area, thus causing them to get filled in with the surrounding area's texture. Figure 3.19 depicts left-turn markings leading up to the intersection filled in with the asphalt texture despite the fact that the markings should be closed off from the surrounding area (and the markings were not purposely assigned the asphalt texture).

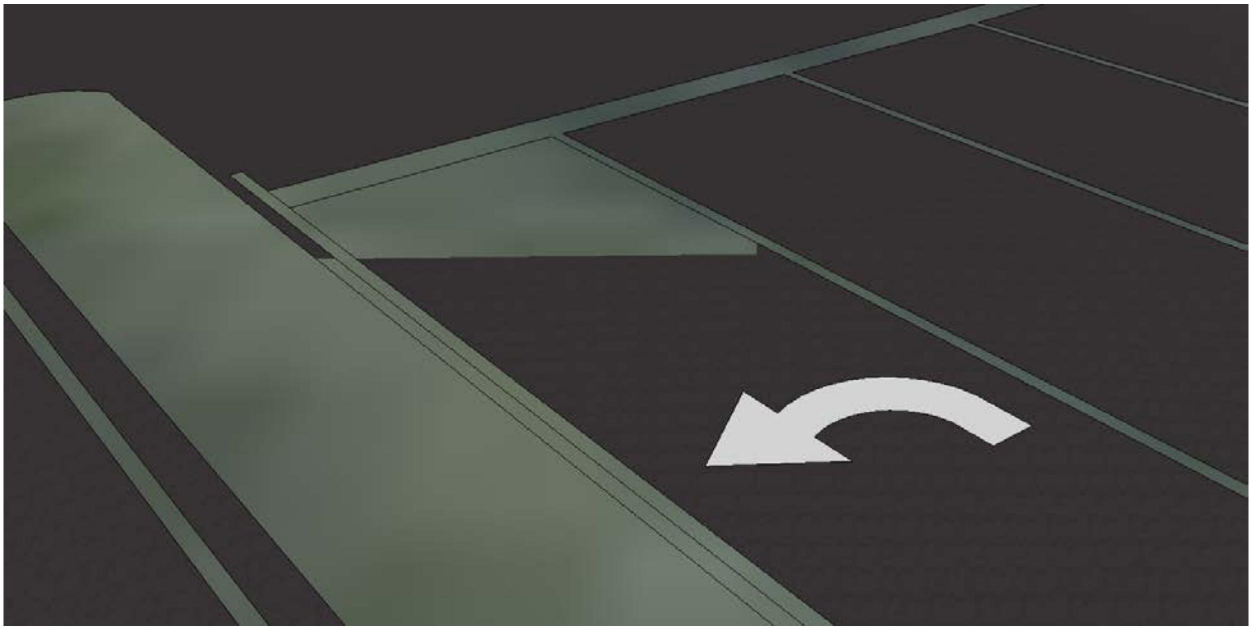


Figure 3.20. Re-Texturing of Left-Turn Pavement Marking after Closing of Shape

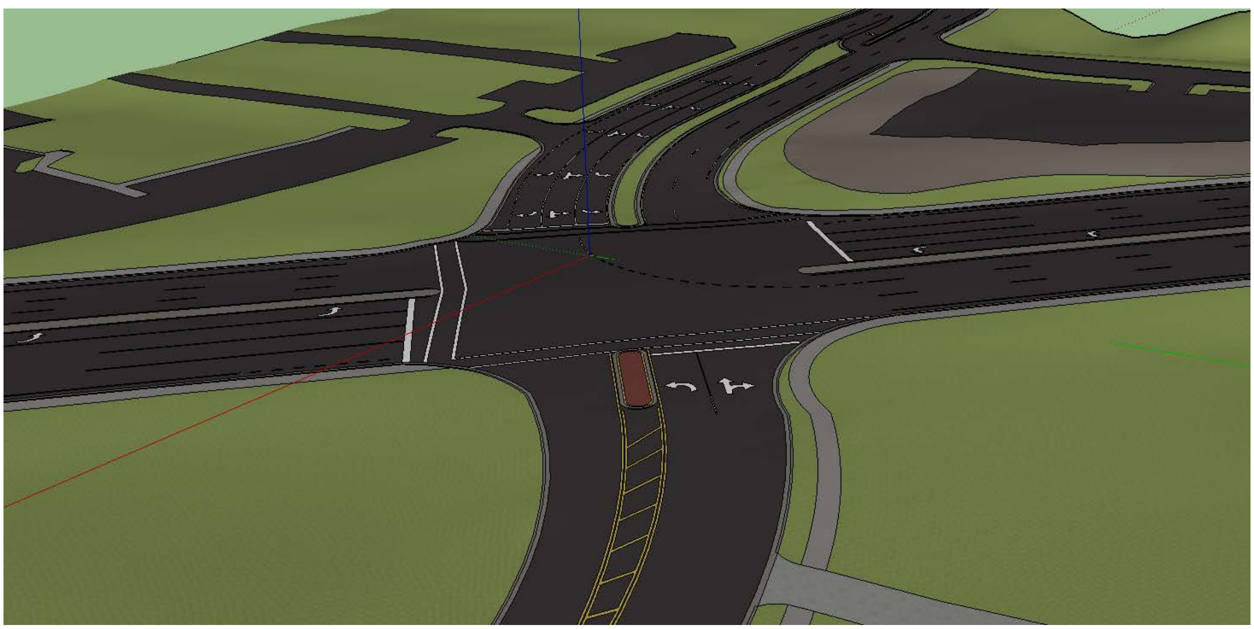


Figure 3.21. Roadway with Fully Textured Terrain Model

To fix the problem, the line work of the left-turn marking needed to be investigated to ensure that the cause of the error was gap related. After investigating the problem, the error was determined to be caused by a gap in the left-turn pavement marking. Figure 3.20 shows that upon closing the marking's gap, and therefore the closing the entire shape, the pavement marking was able to be filled in with a white texture that was independent of from the surrounding roadway's asphalt texture. Once similar errors were accounted, the model's 3D terrain was fully textured and looked similar to the 2D textured terrain model (Figure 3.21).

With the completion of the 3D terrain model, the final step of the model became moving the buildings, traffic signals, etc., to their appropriate locations to finalize the model. Due to the elements of the model being initially being placed according to the satellite image in the 2D model, the objects will not require much in the way of adjustments to their positions in the x and y axes; however, a great deal of movement will be required in the z-axis (elevation). Care was taken to ensure that the objects weren't floating in the air, rotated in a manner that was unrealistic, and had heights above ground that were acceptable when compared to their real-life counterparts. Figures 3.22, 3.23, and 3.24 display the finalized model and give one the understanding of how the model will look when it has been placed in a simulator.

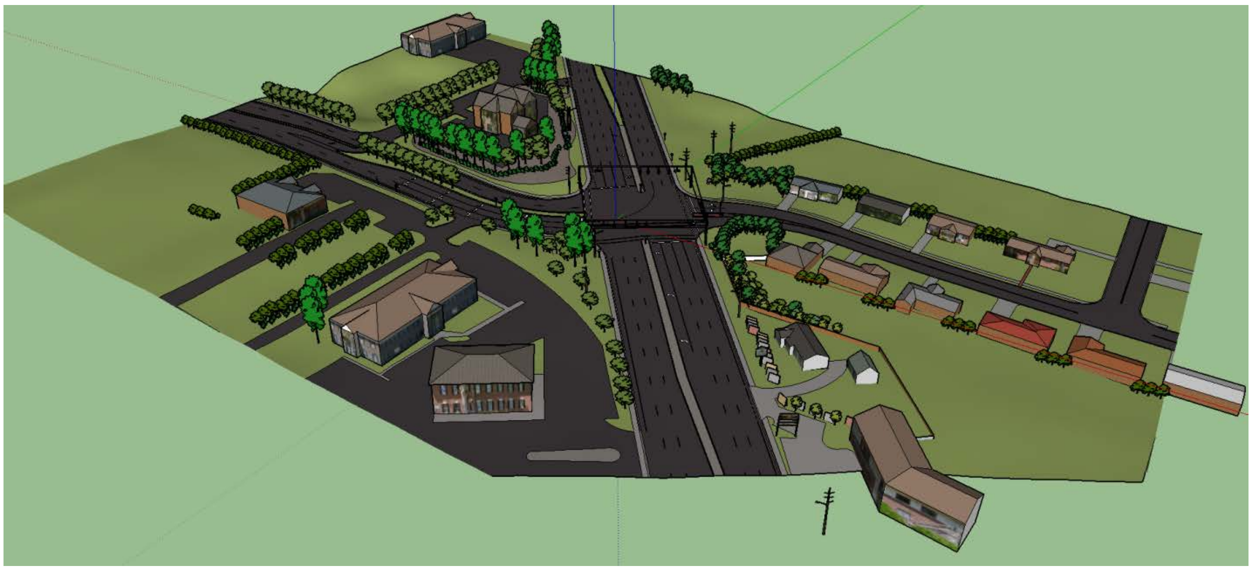


Figure 3.22. Overview of the Finalized Model

Figure 3.23 Eye-Level View of Left Turn Lane (NE Capital Circle Northbound on to Hermitage Blvd)

Figure 3.24. Eye-Level View of Left Turn Lane (Hermitage Blvd Eastbound on to NE Capital Circle)

Figure 3.22 gives an overhead view of the intersection and all of the elements within a 400 foot distance from the intersection. All terrain, after the region 400 feet from the intersection, will be generated as generic, roadway tiles. Figures 3.23 and 3.24 allow one to see the eye-level views taken from within the model. Figure S shows the left-hand turn from northbound NE Capital Circle to westbound Hermitage Blvd (which was described as the region where most of the left turn collisions at the intersection occur. The view in Figure 3.24 consists of an eye-level view from westbound Hermitage Blvd's left lane, which gives a visual of the region's topography. Upon viewing the image, one can see the steep gradient encountered by traffic heading eastbound on Hermitage Blvd. The region has a higher elevation west of the intersection and a lower elevation to the east of the intersection; however, the elevation remains quite constant along NE Capital Circle. Figures 3.25 and 3.26 are added to show a comparison between the SketchUp model and the actual image. Figure 3.25 consists of a view taken from northbound NE Capital Circle, which was taken from Google Maps. Figure 3.26 is a screenshot taken from the SketchUp model taken at roughly the same location.

Figure 3.25. Google Maps Street View Taken Along Northbound NE Capital Circle

Figure 3.26 Google SketchUp Screenshot Taken from Location Shown in Figure U

While the model for the Hermitage Blvd/NE Capital Circle intersection has been completed, a 3D model has only been created for one scenario, protected-only left turn phases (no permitted left turn phase). As the aim is to eventually compare protected-only against protected/permitted left-turns at intersections, it becomes necessary to model an intersection with traffic lights designed to provide protected and permitted phases for those hoping to turn left. Due to the fact that the case study intersection underwent a change of this nature in the past, the protected/permitted scenario's traffic light set-up could be modeled according to images of when the intersection had been designed to allow for a protected and permitted left-turn phase.

The changes between the already developed, protected-only left turn model and the alternate set-up mentioned above consists of the traffic lights along NE Capital Circle. The Protected/Permitted model consists of fewer lights along NE Capital Circle when compared to the Protected-Only model (two versus four). The Protected-Only model has four lights along each approach of NE Capital Circle, which consist of three traffic lights that don't control turning movement (one solid green, one solid yellow, and one solid red circle) and one signal in the left turn lane (consists of one green, one yellow, and one red arrow). The aforementioned set-up is similar to the one shown in Figure 4D-10 of the 2009 Edition of the MUTCD.

The Protected/Permitted model has only two lights along each approach of NE Capital Circle, which consist of one light that doesn't control turning movement (same was the one described in the Protected-Only model) and one that controls both the turning movements in the left turn lane and the through traffic in the center lanes. The set-up for this Protected/Permitted scenario can be visualized by viewing Figure 4D-11 of the 2009 Edition of the MUTCD. The traffic signal controlling both through and left turn traffic consists of one circular red light controlling both the through and left-turn movements. Underneath that light consists of a set of yellow and green lights consisting of an arrow and a circular light. The yellow and green arrows control the protected left turn phase, while the yellow and green arrows control the through movements of the center lanes and the permitted phase of the left turn lane. Figure 3.27 consists of a screenshot of the NE Capital Circle lighting set-up for the Protected-Only scenario, while Figure 3.28 displays an image of the NE Capital Circle lighting set-up for the Protected/Permitted scenario.

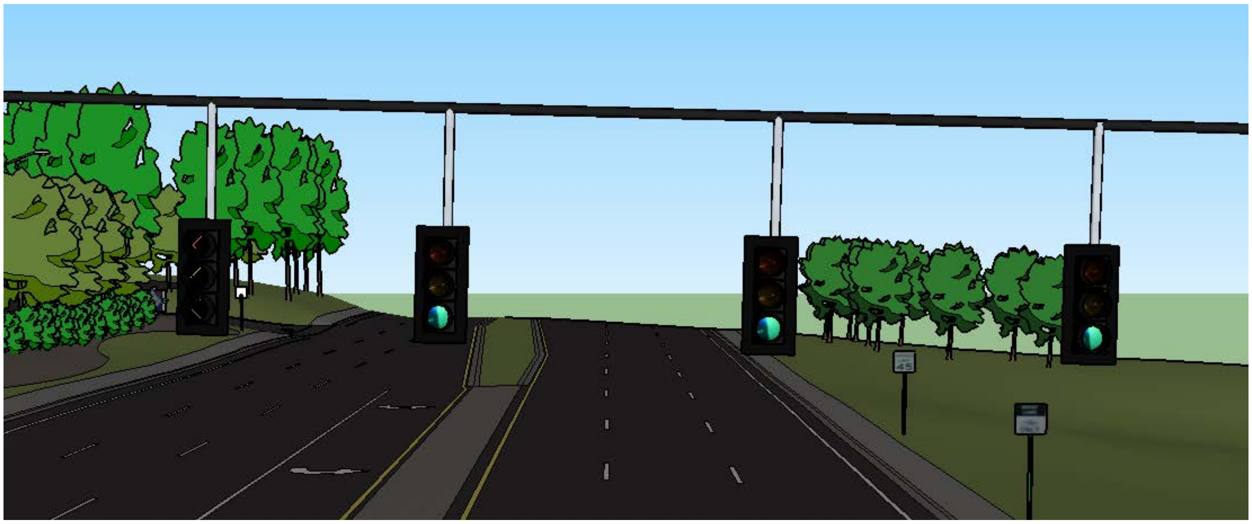


Figure 3.27. Lights along NE Capital Circle (Protected-Only Scenario)

Figure 3.28. Lights along NE Capital Circle (Protected/Permitted Scenario)

4. Development of Simulator Tile and Scenario

As mentioned previously, based on the analysis of crash patterns and crash reports, the intersection of Hermitage Boulevard and Capital Circle North East was selected as the intersection to import into the driving simulator. Thirty-nine police crash reports were obtained from the study period. Not all crash reports had all information, but we examined these reports for general patterns to determine the exact driving scenarios we would have younger and older drivers experience. 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).

Although the most typical crash at this location during the study period was a rear-end crash occurring during the day and under clear weather conditions, a decision was made to investigate left-turn crashes due to the much greater severity of these crashes, the fact that several left-turn crashes occurred during the study period, because of previously discussed age-related risk associated with left-turns, and due to technical challenges in simulator tile and scenario design outlined below. Within the set of 39 crash reports, one report closely matched the typical pattern for older drivers with respect to left-turn crashes. Our driving simulator scenario was modeled after this crash. This report described a driver (61 years of age) attempting to make a left-turn and being struck by opposing traffic (Figure 4.1). The driver was heading north on Capital Circle NE and turning left onto Hermitage Boulevard. The officer who authored the report noted "near elderly at fault for improper left turn," and the older driver was cited for failure to yield.

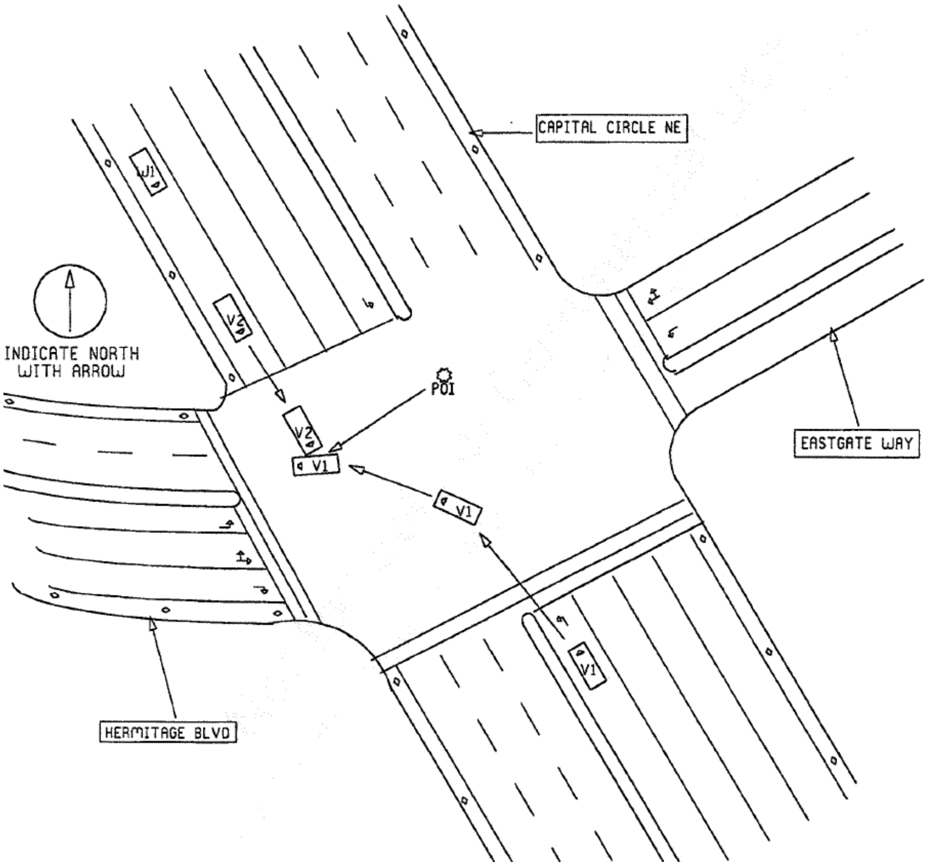


Figure 4.1. Police report diagram for left-turn crash at the intersection of Hermitage Blvd & Capital Circle NE.

Furthermore, viewing the Google SketchUp model and from a detailed analysis of the roadway geometry, it was noticed that a curvature of the road to the north of the intersection, and the offset of left-turn lanes (negative offset), might make gap judgments especially challenging for older drivers, particularly if the opposing left-turn lane was occupied. This was particularly noted once the model was imported into the driving simulator and more of the roadway geometry was included (beyond 400 feet from the intersection). This configuration would block turning drivers' view of opposing traffic, forcing them to extrapolate the speed, distance, and location of traffic occluded by vehicles in the opposing turn lane. This may be particularly challenging for older drivers as a result of age-related declines in perceptual and cognitive abilities, especially declines in visuo-spatial ability. This approach of creating SketchUp models of an intersection under investigation may be a promising method to relatively quickly and inexpensively identify factors contributing to older adult crashes. Modeled intersections can be explored and viewed from a multitude of angles and under different viewing conditions. These models then might be modified to include geometric changes or other countermeasures and viewed again. Finally, these models can be converted to driving simulator scenarios to better understand driver behaviors that might contribute to increased crash risk, especially with respect to older drivers.

We aimed to recreate the left-turn scenario outlined in the crash report described previously in our driving simulator to observe younger and older drivers' behaviors at this intersection. The intent was to explore the extent to which we can understand differential crash risk associated with specific intersections rather than generic crash risk (e.g., left-turns). We provided the Google SketchUp model we created to the National Advanced Driving Simulator (NADS) lab at the University of Iowa to develop a simulator "tile" (section of drivable roadway within the simulator) matching the characteristics and dimensions of the Hermitage/Capital Circle NE intersection.

Challenges and Lessons Learned

Our experience with tile construction projects associated with previous studies caused us to underestimate the time and cost involved in replicating a complex, real-world intersection associated with crash risk. Previous tiles had depicted generic scenarios associated with increased risk rather than a specific risky intersection. Of particular challenge were the changes in elevation at and around the intersection of Hermitage Boulevard and Capital Circle (all previous tiles for other projects had no elevation changes). One solution would have been to leave these elevation changes out of the simulator tile, but elevation changes may be a contributing factor to what makes this intersection particularly risky for older drivers. As a result, we rejected this solution. Part of the experienced problem appeared to be a difference in model resolution between the Google SketchUp model and elevation map within the simulator. Since the SketchUp model contained a coarser resolution, this did not result in a smooth driving surface for the driver in the simulator. This caused the driver's simulated car to bounce up and down, which had the potential to induce even greater simulator sickness in our older adult participants already prone to this problem. Attempts by NADS to smooth the elevation map in the driving scenario were unsuccessful, and resulted in other undesirable properties (traffic floating significantly above the roadway). To recreate the visual model and elevation map of the simulator tile at higher resolution would have taken significantly more funds and time than allocated to this project. The ideal solution would be to custom program a simulation tile based on the simulator software code.

Our solution was to have participants, rather than turn left, judge whether it was safe to turn or not given the position of opposing traffic (i.e., perform a gap-judgment task). Participants monitored a continuous stream of traffic and pushed a button when they felt that the gap in traffic was large enough to turn safely. There are disadvantages to this approach in terms of understanding driver behavior (since no turn is executed), but there are also significant advantages in terms of understanding the drivers' decision process (which may be the more important factor contributing to left-turn crashes). Multiple turns would have almost certainly resulted in high levels of simulator sickness in many participants and numerous drop-outs (especially among older adult participants). In addition to drop-outs, data from participants who are experiencing simulator sickness are of questionable validity. Driving behaviors may not reflect natural behaviors after the onset sickness. In the past, due to concerns of simulator sickness, we have had participants perform at most four turns. However, in our gap-judgment task, we presented participants with 60 gaps in traffic in which they could have decided to turn or not turn. This allowed us to collect many more data points in our decision task compared to a turning task. Finally, one measure we are interested in exploring is participants' eye movements while they are deciding whether or not it would be safe to turn. A stationary driver vehicle makes it tremendously easier to code areas of interest in the simulator for eye-tracking analyses. Thus, although there are drawbacks to the design we were forced to adopt as a result of tile and scenario challenges, we may be able to learn more about the decision processes that contribute to left-turn crashes with this design.

5. Driving Simulator Experiment

Methods

Participants

A total of 64 participants completed the simulator study, including 31 younger drivers and 33 older drivers with a valid U.S. driver's license. Participants were recruited from the Tallahassee, FL region (see Table 5.1). Most completed the study in a single 1.5 to 2 hour session and received twenty dollars for their participation. Data from two participants were excluded from analyses, one due to simulator sickness, and the other due to experimenter error.

Table 5.1. Participant Demographics.

Age Group	Total n	Mean Age (sd)	Males / Females
Younger (18 – 35 years)	30	20.33 (1.65)	20/10
Older (66 – 82 years)	32	71.38 (4.35)	16/16
Total	62		

Materials and 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 developed by The National Advanced Driving Simulator at the University of Iowa (Iowa City, IA) 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 (Figure 5.1). The simulator is integrated with an SMI eyetracker to monitor eye and head movements (http://www.smivision.com/en/gaze-and-eye-tracking-systems/products/iview-x-hed.html).

Figure 5.1. Photograph of the FSU driving simulator and eye tracker used in the reported experiment.

Task 1: Simulator Tasks

The simulator task consisted of two practice scenarios (approximately 6-7 minutes each) 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 identified as problematic for older drivers through an analysis of crash reports. The two practice scenarios took a combined total of approximately 14-15 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 more well-informed 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. The eye-tracker was calibrated to the participant's left eye. After the calibration procedure the experimenter read the instructions for the main task. All instructions were read aloud by the experimenter who remained in the room throughout the task.

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. Note that this intersection currently features protected phasing for left-turn movements (so this left turn would not be allowed today), but at the time of the crash on which our scenario was modelled phasing permitted left turns. 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 (Figure 5.2).

Figure 5.2. The view of a driver in the left-turn judgment task.

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

An initial look at the data revealed that in some instances it was clear that participants intended to make a turn just after an oncoming vehicle cleared the intersection, even if it had not cleared the intersection yet. Counting this vehicle as the closest vehicle at the time of a button press would result in a severe underestimate of what participants considered a safe gap. To account for this problem an exclusion zone was created that began at the stop bar of the opposing traffic lane and continued into the intersection and beyond (Figure 5.3). If the button was pushed while one or more vehicles was within this zone, distance was calculated between the participant's vehicle and the closest vehicle not in this zone.

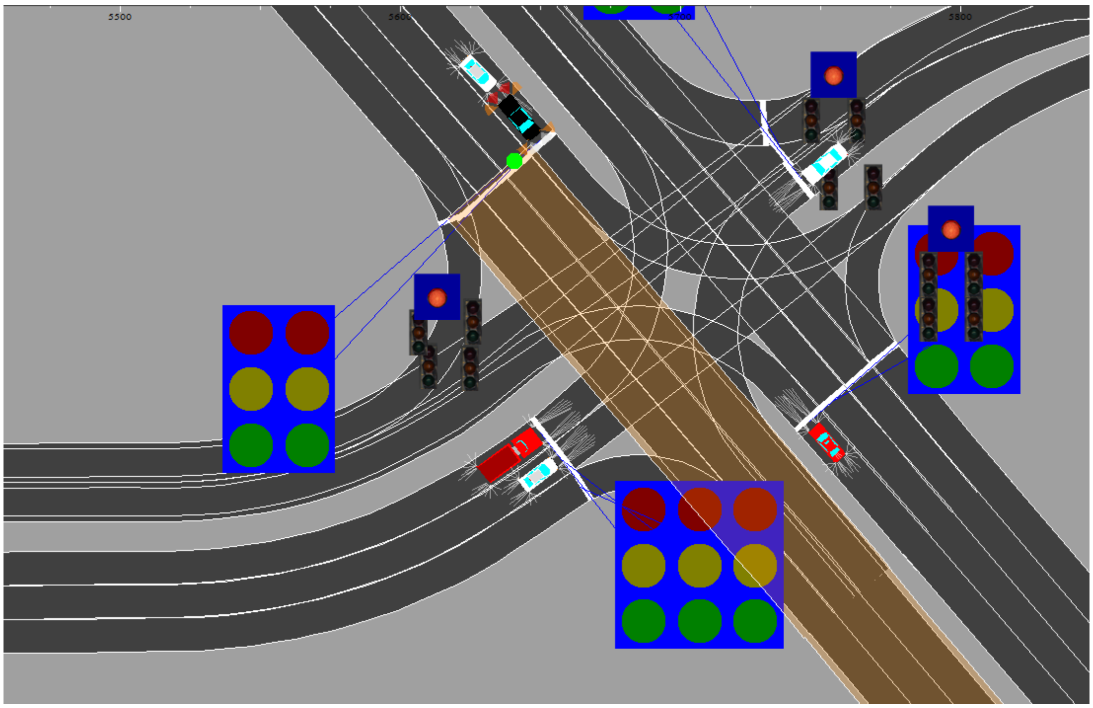


Figure 5.3. Highlighted area depicts the exclusion zone used to calculate distance between the participant's vehicle and the next closest vehicle at the time participants judged it was safe to turn.

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 50.2 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.

Task 2: Cognitive Battery

Spatial Ability: The battery of cognitive tasks included two measures of spatial ability: Mental Rotation and the Judgment of Line Orientation (JoLO) task.

Mental Rotation. Participants completed a computerized mental rotation task patterned after the test developed by Shepard and Metzler (1971). They were shown two figures which appeared side-by-side on the screen and were asked to judge whether the two figures depicted the same object or different objects (Figure 5.4). Critically, one of the objects was rotated so spatial working memory was required to mentally rotate the two figures to the same orientation. Participants were required to respond “same” or “different” with a keyboard press and the speed and accuracy of participants’ responses was recorded (with the task instructions placing an emphasis on fast but accurate responses). Participants completed 24 practice trials, followed by 128 actual trials.

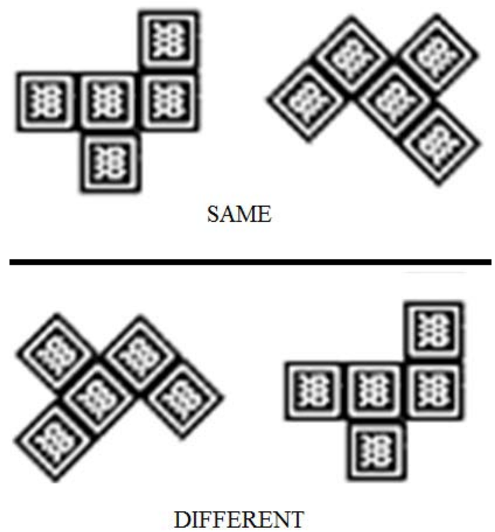


Figure 5.4. Two trials of the mental rotation task.

The first trial (above) requires a “same” response. If the two figures were rotated to the same orientation they would be identical. Below, a "different" trial. The figure on the left could never be rotated to the left or right to match the figure on the right. They are mirror images of one another.

<u>Judgment of Line Orientation (JoLO) Task</u>. The Judgment of Line Orientation task was a second measure of visuo-spatial processing. Participants completed a computerized version of the task developed by Benton, Varney, and Hamsher (1978). This task consisted of 55 items and did not include a time limit. For each item, an array of lines paired with numbers to identify each line appeared at the bottom of the screen, and two lines of different orientations appeared at the top of the screen. The participant’s task was to select which two lines from the array matched the orientation of the two unmarked lines (Figure 5.5). Participants entered a response by clicking on the numbers corresponding to the lines they wished to select. The speed and accuracy of participants’ responses was recorded.

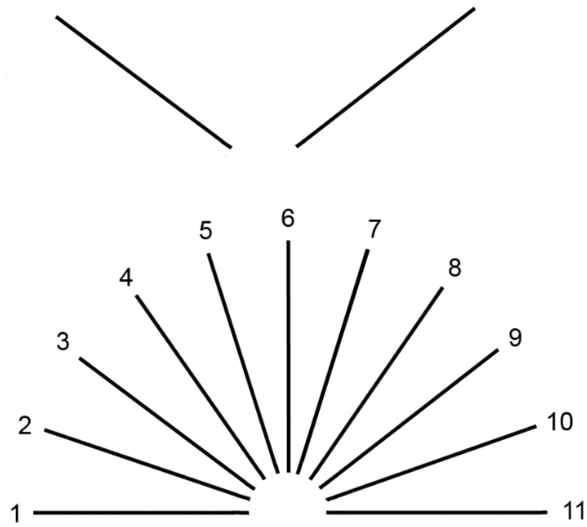


Figure 1.5. Example item from the judgment of line orientation task.

Participants selected the two lines from the bottom array that matched the orientation of the lines shown above. In this case, the correct responses are 3 and 9.

Processing Speed: The battery of cognitive tasks included two measures of processing speed: Digit Symbol Coding and Simple/Choice Response Time.

<u>Digit Symbol Coding</u>. This task was administered following the standardized instructions of the Wechsler Adult Intelligence Scale, Third Edition (WAIS-III, The Psychological Corporation, 1997). Participants were shown an array of numbers paired with arbitrary symbols (Figure 5.6) and below the array were boxes with numbers but no symbols underneath. The participant's task was to fill in the missing symbols for as many of the 133 empty boxes as possible within the 120 second time limit. The participant's score was calculated as the total number of items completed within the time limit. This task is intended to measure processing speed and perceptual speed, but also taps short-term memory (Hoyer, Stawski, Wasylyshyn, & Verhaeghen, 2004; Joy, Kaplan, & Fein, 2004).

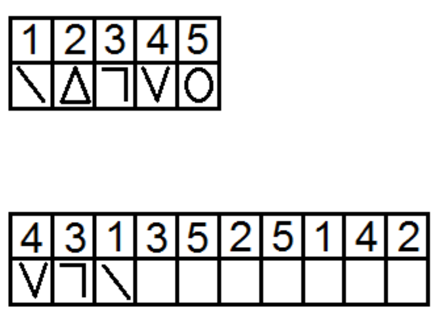


Figure 5.2. Example of the type of items found on the digit symbol coding task.

<u>Simple/Choice Reaction Time.</u> For the simple reaction time task, participants saw a square on the screen and had to push a button on the keyboard as quickly as possible in response. In the choice reaction time task, the square appeared either to the left or the right of the center of the

screen, and participants were required to push one of two keys depending on the location of the square. Participants completed 60 simple trials and 60 choice trials. Response speed was the primary measure of interest.

Reasoning Ability: The battery of cognitive tasks included one reasoning ability test: Letter Sets.

Letter Sets. Participants completed the first set of items of the Letter Sets task (Ekstrom, French, Harman, & Dermen, 1976). Participants were presented with fifteen test items. Test items included 5 sets of four-letter strings. Four of those letter strings conformed to a common rule, and one letter set did not follow that rule. Participants were asked to select the one letter set that did not belong. Participants were allowed 10 minutes to complete the test, and score was calculated as the total number correct.

Crystalized Knowledge: Finally, the battery of cognitive tasks included one measure of crystalized knowledge: the vocabulary portion of the Shipley Institute of Living Scale.

Shipley Institute of Living Scale. This test consisted of 40 items, with each item having a prompting word and four choices (Zachary, 1986). The task was to select which out of the four words was closest in meaning to the prompting word.

Results

Simulator Task

Number of responses. 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 wait and respond only when there are 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 smaller gaps in traffic. As is has been found in other types of tasks, we expected older participants to make fewer responses overall and for these responses to be at times when there was a larger gap in traffic.

Before any analyses were conducted, invalid responses were excluded from the data set. A response was considered invalid if it occurred before any oncoming traffic would have been visible to the participant. The first vehicle in the stream of oncoming traffic was generated at 9 seconds into the scenario, but would have first been visible to the participant at 12.85 seconds into the scenario. Thus, any response made prior to that point was excluded from the data file. Only two trials, both of which were from younger adult participants, were excluded for this reason, leaving a total of 945 button responses from 62 participants.

The scenario lasted for a total of 310 seconds (5 min, 10 seconds), and during that time a total of 60 vehicles passed the participant in the oncoming lanes. Participants had been instructed to respond only once per gap in traffic, so 60 responses would the maximum number of valid responses for any one participant. However, because about one third of trials would have been gaps that should have been too small to safely turn, we expected very few, if any, participants to have more than about 40 responses.

Across all participants, the group median was 13.5 responses, with a range of 1 to 57 responses. To test whether younger and older adults differed in the number of responses they made during the scenario, the total number of responses was calculated for each participant, and the median number of total responses for each age group was compared using a Mann-Whitney U test. As predicted, younger adults made significantly more responses overall (Median = 18, range = 6 – 57) than did older adults (Median = 10, Range = 1 to 39), $U = 771$, $Z = 4.11$, $p = .00004$, $r = .52$ (see Figure 5.7). Consistent with other work, older adults were far more conservative when judging when it was safe to go compared to younger adults.

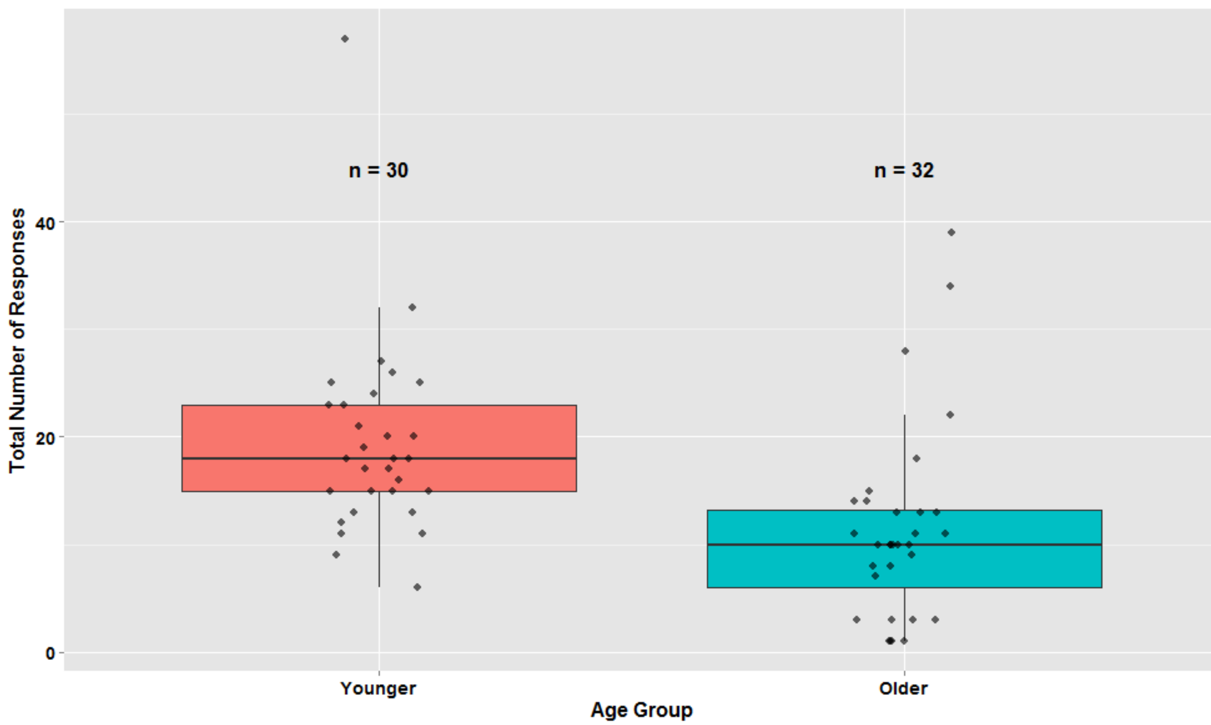


Figure 5.7. Total number of responses made during the simulator task by age group. The horizontal line in each box represents the median total number of responses for each group, and the points represent the total number of responses for each participant.

Intersection wait times. Intersection wait times are another indicator of conservative responding; more careful participants are more likely to wait longer before making an initial response. In our task, the first response a participant makes represents the first time in the scenario when they felt it was safe to make a left turn and could be considered an indication of how long that person would have waited to turn at an intersection with a similar layout and amount of traffic to the one used in the current study. A separate data file was created containing only the first valid button press for each participant. For the two participants whose first response was considered invalid because it occurred before any oncoming traffic was visible, the second button response was included instead.

We expected older participants to take longer than younger participants to make their first response. Across all participants, the median time until the first response was 38.14 seconds. To test whether intersection wait times differed significantly between age groups, a Mann-Whitney U test was conducted comparing median intersection wait time between younger and older adults. Indeed, wait times did differ significantly between age groups; 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 seconds) for older participants, $U = 149$, $Z = -4.43$, $p = .000003$, $r = .57$ (see Figure 5.8). Also, as can be seen in Figure X, not only was the median wait time longer for older adult participants, older adults' intersection wait times were more variable than younger adults'. While no younger adult took more than 66.43 seconds to make their initial response, There were several older adults who took much longer to make a first response, some taking over 300 seconds to respond, indicating that they may have only had time to make a single response before the scenario ended.

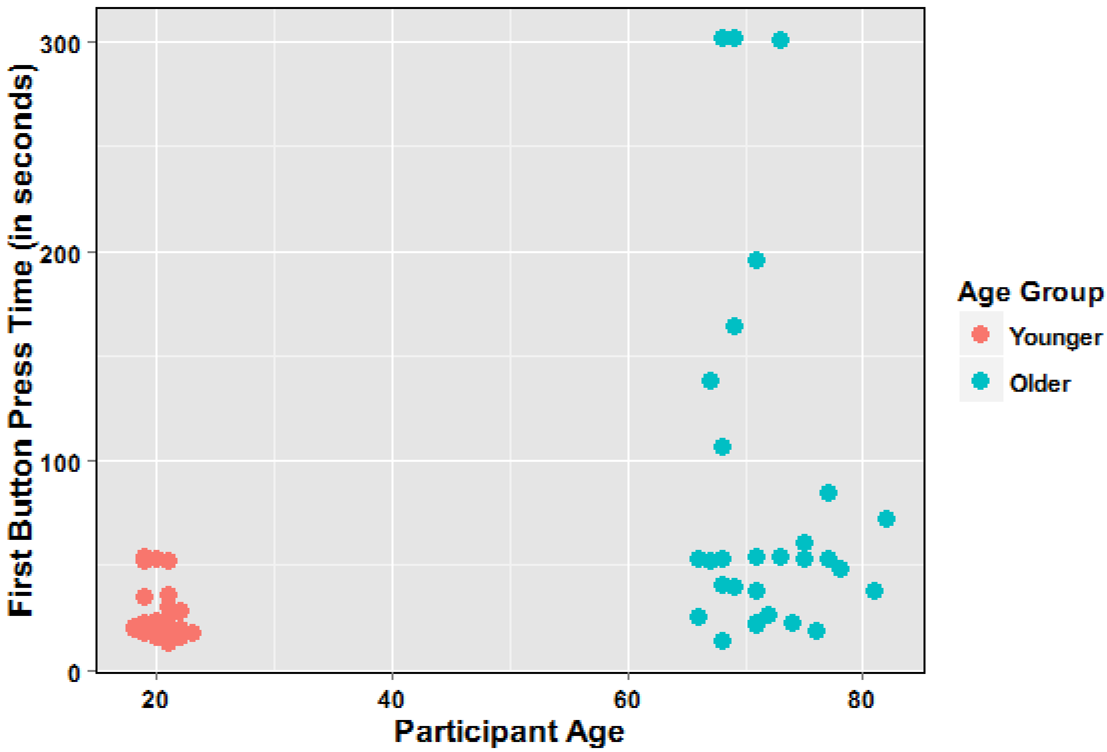


Figure 5.8. Time to first button press response by participant age.

Gap Size and Oncoming Vehicle Distance

In our analysis of the total number of responses made during the scenario, we found that older adults made significantly fewer responses than younger adults. However, that analysis only demonstrated that older adults less often felt that it was safe to turn and did not include information about whether older adults' limited number of responses were, on average, safer (e.g. chose to turn across only larger gaps in traffic) than younger adults'. To examine this, we computed two additional measures. First, we calculated gap size, which was defined as the distance between the two oncoming vehicles present at the intersection for each button response.

The tail vehicle in each gap was defined as the vehicle in the oncoming traffic lanes that was nearest to the participant but had not yet crossed the stop bar to enter the intersection. The lead vehicle for each gap was the first vehicle ahead of the tail vehicle (see Figure 5.9).

Even if one opts to turn only during large gaps in traffic, it is still possible to make an unsafe turn if one waits too long during the in-progress gap to initiate the turn. As a metric of whether older adults wait longer to initiate a turn, we also computed the distance between the participant's vehicle and the tail vehicle in the gap during which the participant made a response. This measure corresponds to the line of sight between the participant and the oncoming vehicle (see Figure X). Shorter oncoming vehicle distances in comparison to gap size indicate longer delays in initiating a response during that gap.

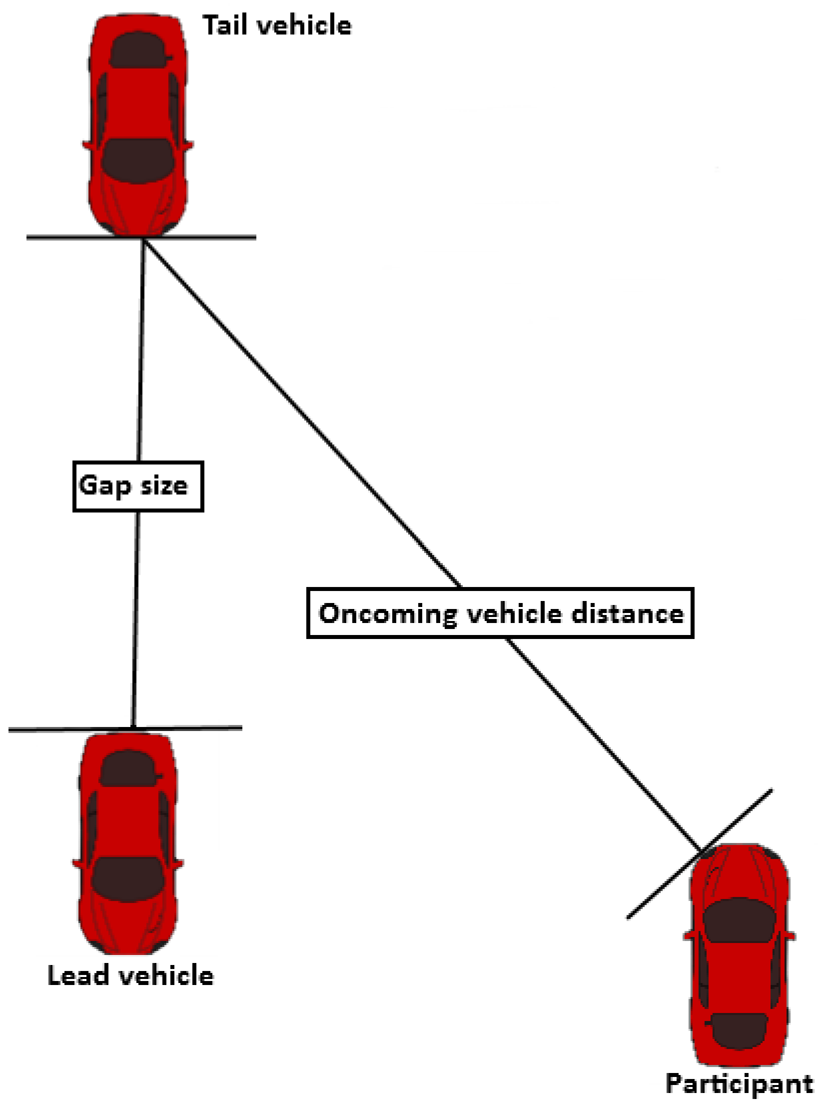


Figure 5.9. Calculation of gap size and oncoming vehicle distance for the simulator task.

Gap Size. Gap size could not be computed for button responses made before the first vehicle, because there would have been only a tail vehicle present and no lead. Additionally, no gap size could be computed for instances where the participant responded to after the final vehicle in the scenario had passed, as there would be only a lead vehicle and no tail vehicle. Across all participants, valid gap size calculations could be done for 834 out of 945 valid button responses. Calculated gap size among these 834 trials represented a range of gap sizes (107.43 ft to 713.93 ft), which included some that would have been very risky to try to turn within, some that were clearly a safe distance, and others that should have been large enough that even very cautious drivers would have felt safe to turn within (see Appendix for full list of gap sizes/durations).

For the analyses that follow, a risky turn was defined as a turn made during a gap of less than 300 feet, a safe turn is one made during a gap of between 300 and 400 feet, and a cautious turn was defined as one made during a gap of 400 feet or greater. Although an equal number of gaps in each gap category would have been presented to each participant, we expected participants to be more likely to respond to safe and cautious gaps than to risky gaps. Figure 5.10 (see also Table 5.2), shows the distribution of responses by calculated gap size across all participants. As is evident in the figure, participants made fewer responses to gap sizes that would have been categorized as risky (< 300 ft).

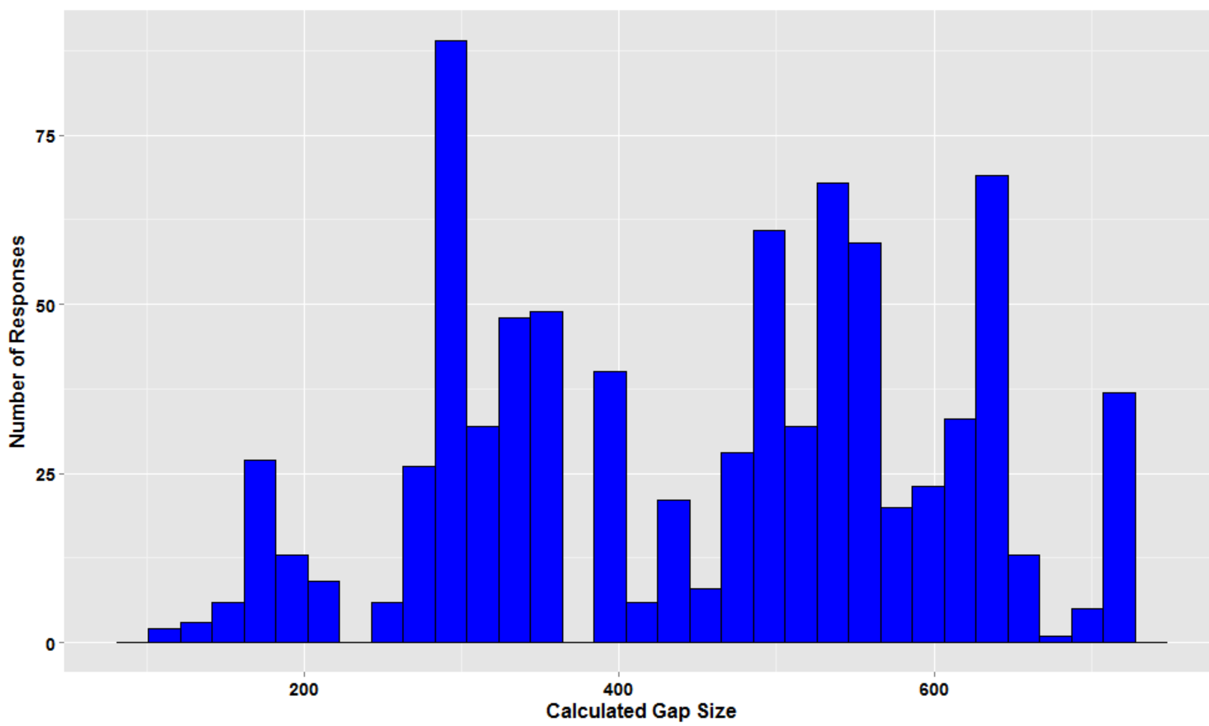


Figure 5.10. Histogram showing the distribution of calculated gap sizes across all participant responses.

However, there was evidence that older and younger adults differed in which gaps they selected as safe to turn within. Table 2 gives the total number of responses in each category for each age group. Older adults made a little more than half as many total responses as younger adults, which suggests that older adults might have been responding more cautiously and conservatively than younger adults. However, the distribution of responses within age groups suggests that this may not be the case. Not only did older adults make more total responses to gaps of less than 300 feet, despite making fewer responses overall, responses to small gaps represented 34.7% of responses within the older adult group. For younger adults, risky responses represented only 12.9% of younger adults' total responses. Age differences were smaller in magnitude for safe and cautious gaps. Responses to safe gaps represented a similar proportion of both older and younger adults' responses, while a greater proportion of younger adults' total responses were made during cautious gaps.

Table 5.2. Number of responses by response category by age group. Row percentages given in parentheses after each value.

Age Group	Risky	Safe	Cautious	Total
Younger	67 (12.9%)	91 (17.5%)	362 (69.6%)	520
Older	109 (34.7%)	43 (13.7%)	162 (51.6%)	314
Total	176 (21.1%)	134 (16.1%)	524 (62.8%)	834

The median gap size across all responses was calculated for each of the 62 participants in the current data set. No value was recorded for two older adult participants, who each had made only one response during the scenario. For the 60 remaining participants, a Mann-Whitney U test comparing median gap size between older and younger participants revealed a significant difference in median calculated gap size between age groups, $U = 621.5$, $Z = 2.54$, $p = .01$, $r = .33$. The median observed gap size for younger adult responses was 492.86 ft, while the median observed gap size was almost 100 ft smaller for older adults at 395.12 ft.

Distance of Oncoming Vehicle at Response. If one waits too long to begin turning, it is possible to make an unsafe turn during a large gap in traffic. In addition to being more likely to respond to risky gaps compared to younger adults, we were interested in whether older adults also waited longer to initiate a response once they had decided it was safe to turn. In the current task, an indication of how early or late within a given gap a participant might have initiated their left-turn action is the difference between gap size and oncoming vehicle distance. For each button response (at the time when the press was first initiated), the distance between the participant's vehicle and the tail vehicle for the in-progress gap was calculated.

Our previous analyses showed that older adults made fewer responses overall, indicating that they less often judged it to be safe to make an unprotected left turn, and when older adults did judge it safe to turn, they tended to select smaller gaps in traffic. Of interest in the current analysis is, given responses to gaps that are of similar size, whether older adults tend to wait longer before initiating their response. Longer wait times within a gap are indicated when the distance from the participant to the oncoming vehicle, the tail vehicle in a given gap, is closer. A linear mixed-effects model predicting oncoming vehicle distance with age group as a between-subjects factor, gap size category as a within-subjects factor, and their interaction. The only random effect in the model was an intercept for each subject. There were significant main effects of age group, $F(1,58) = 47.35$, $p < .0001$, such that the oncoming vehicle was closer when older adults responded than was the case for younger adults, suggesting that older adults take longer to respond to the same size gap in traffic. There was also a significant main effect of gap size category, $F(2,770) = 519.79$, $p < .0001$. As expected, the oncoming vehicle was closer when participants, regardless of age group, responded to smaller gaps than when they responded to larger gaps. The interaction between age group and gap size category did not reach statistical significance, but there was a trend toward larger age differences between observed oncoming vehicle distances for smaller gap sizes than for larger gap sizes, $F(2,770) = 2.05$, $p = .13$. Figure 5.11 shows the median oncoming vehicle distance at response for each gap size category for both younger and older adults. For the smallest gap size category, which corresponds with the most risky turn decisions, older adults responded when the oncoming vehicle was nearly 100 feet closer than it was when younger adults' responded to gaps of about the same size. Figure 5.12 displays the distribution of oncoming vehicles distances when participants indicated when they would turn as a function of age.

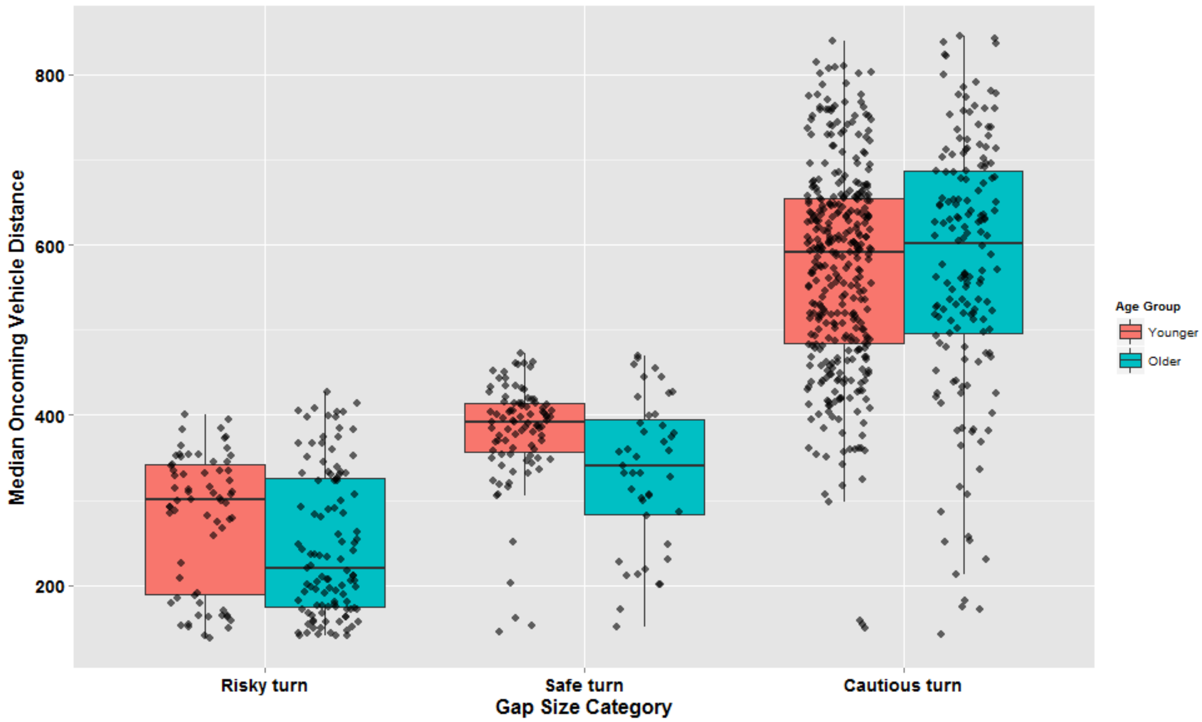


Figure 5.11. Median oncoming vehicle distance at response by gap size category and age group.

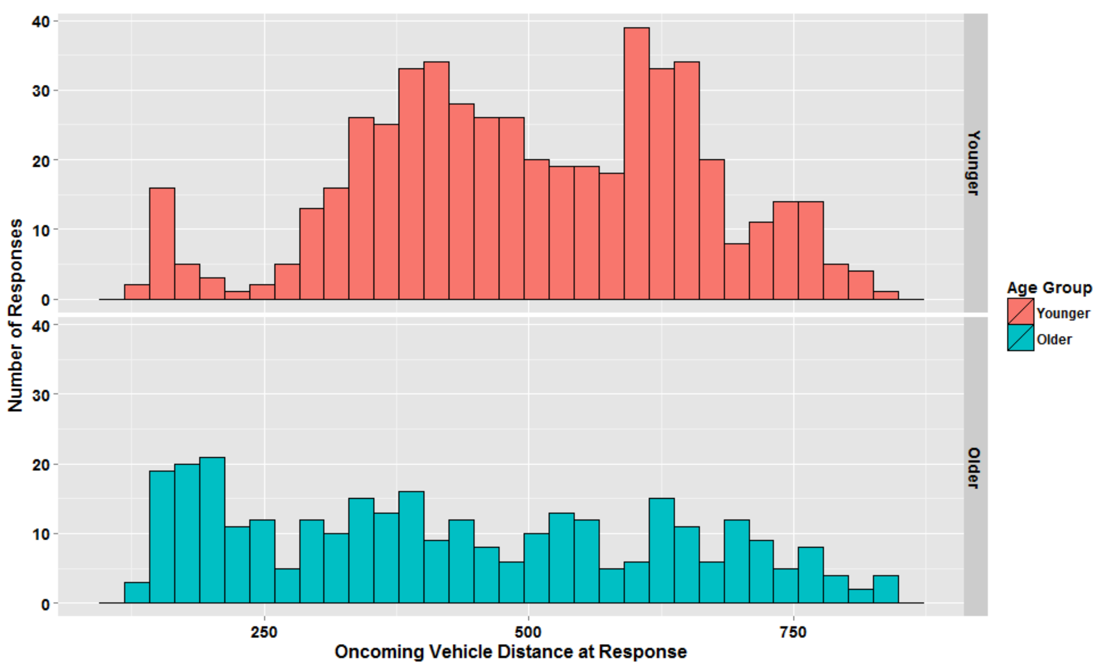


Figure 5.12. Median oncoming vehicle distance at button response for older and younger adults.

Eye Tracking

Eye movement data was recorded during the left-turn decision task. For each button press, we examined the 2.5 seconds before and after the initiation of the button press. For each 5 second period, two summary statistics were generated, the average fixation duration and average fixation dispersion. Participants were excluded from these analyses if their tracking data was incomplete or of poor quality, leaving a total of 647 observations from 40 participants (23 younger, 17 older).

First, we examined the dispersion of fixations over the screen area in the 5 second period in which a button press occurred. Because the distance of oncoming vehicles would be expected to affect fixation dispersion (further away = less area occupied on screen), all analyses control for oncoming vehicle distance. To test this, a linear mixed-effects model predicting fixation dispersion with oncoming vehicle distance and age group revealed a small main effect of oncoming vehicle distance on fixation dispersion, $t = 2.64$, $p = .01$, but fixation dispersion did not differ significantly between age groups, $t = -1.49$, $p = .14$.

A similar analysis was conducted for average fixation duration for the 5 second period during which a button press occurred. As was the case for fixation dispersion, oncoming vehicle distance at button press significantly predicted average fixation duration, $t = -3.53$, $p = .0004$, but there was no difference in average fixation duration between age groups, $t = .37$, $p = .71$. Overall, there was no evidence from these analyses that younger and older drivers were scanning the roadway any differently in the period before they made a decision to turn.

Age-Related Differences in Cognition

As a first step in understanding potential age-related changes that might be associated with increased crash risk in the left-turn paradigm, we examined whether age was associated with differing performance on tasks in our cognitive battery (see Table 5.3). Confirming expectations, there was a strong association between age and processing speed. An ANOVA was performed on each outcome measure with age and gender as between-participant factors. Older adults were significantly slower to make responses in both the simple ($F(1, 56) = 26.79$, $p < .001$, $\eta_p = .32$) and choice response time tasks ($F(1, 56) = 51.15$, $p < .001$, $\eta_p = .48$). Performance was also significantly worse for older adults compared to younger adults on the Digit Symbol task ($F(1, 58) = 66.01$, $p < .001$, $\eta_p = .53$). In terms of effect size, age-related differences in processing speed were largest compared to other measures included in the battery.

Older adults also performed significantly worse on one of the two measures of spatial processing. We quantified performance on the mental rotation task by creating a composite measure of speed and accuracy. Correct response times were divided by the proportion of correct trials for each participant, which penalizes participants for fast but inaccurate responding and reduces the impact of potential speed-accuracy tradeoffs. Higher scores represent less efficient spatial processing. Older adults performed worse on this task compared to younger adults ($F(1, 58) = 4.09$, $p < .05$, $\eta_p = .07$). The Judgment of Line Orientation task, which is scored as the total number of problems answered correctly out of 55, suggested age-equivalence, with older adults performing similarly to younger adults ($F(1, 57) = 2.24$, $p = .14$, $\eta_p = .04$). This was the only task in which a significant gender effect was observed, with females performing worse than males ($F(1, 57) = 10.53$, $p < .01$, $\eta_p = .16$; $M_{male} = 46.69$, $SD = 6.62$; $M_{female} = 37.32$, $SD = 13.76$).

Table 5.3. Summary of Spatial Ability Measure Scores as a Function of Age

		Younger Adults		Older Adults	
Ability Measures:		Mean	SD	Mean	SD
Processing Speed	Simple RT (ms)	282	36	349	56
	Choice RT (ms)	326	37	406	46
	Digit Symbol	84	13	58	13
Spatial Processing	Mental Rotation	1720	413	6059	11358
	JoLO Task	45	10	41	12
Other Measures	Letter Sets	0.70	0.16	0.59	0.18
	Shipley Vocab	31	3	34	4

Note. JoLO = Judgment of Line Orientation, ms = milliseconds, RT = Reaction Time

Letter Sets, a measure of reasoning ability, was scored as the total number of correct answers within the allocated time. Analysis also indicated significantly worse performance for older participants compared to younger participants ($F(1, 58) = 7.09$, $p < .05$, $\eta_p = .11$). In contrast to most cognitive measures, and consistent with the literature, older adults performed better on the Shipley Institute of Living Scale of vocabulary ($F(1, 57) = 13.50$, $p < .01$, $\eta_p = .19$). This is consistent with a common finding that crystalized intelligence is either unassociated, or associated positively, with age.

Overall it appears that advanced age in our sample was strongly associated with decreased processing speed, and was more weakly associated with poorer spatial and reasoning ability. Next we turn to the question of whether these cognitive abilities relate to participants' performance in the gap judgment task.

Additional analyses were conducted to determine whether any of the cognitive measures included in the current study significantly predicted either the number of left-turns or the distance to oncoming vehicles when a participant indicated it was safe to turn. Of the measures included in the current study that indicated a significant age effect, performance on the mental rotation task, the task that most strongly taps visuo-spatial processing, significantly predicted the number of turns, $r(58) = .32$, $p = .01$, and the distance to oncoming vehicles at the time when a response was made (safe to turn), $r(58) = -.37$, $p = .003$. That is, those with poor spatial skills felt that a greater number of gaps were safe, and indicated that it was safe to turn when vehicles were closer to their own vehicle.

For mental rotation scores, age group was entered into a linear mixed-effects model predicting the total number of responses. When age was included in the analysis, mental rotation scores no longer predicted the number of responses made during the simulator task, $t = .65$, $p = .52$. A similar analysis was conducted on the other primary dependent measure in the simulator task, oncoming vehicle distance at response. Again, once age group was entered into the equation, mental rotation scores no longer predicted oncoming vehicle distance at response, $t = .94$, $p = .35$. Thus while spatial ability was predictive of turning behavior, spatial ability did not predict performance over and above the effect of age.

Summary of Simulator Results

In some respects, younger adults were riskier than older adults in that they responded to more gaps overall. 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. However, in other, potentially more important respects, older drivers made risky decisions. They judged a greater number of small (risky) gaps in traffic to be acceptable. Another factor that may put older drivers at risk is that when they make a decision to turn, this decision may be reached and executed too late to allow enough distance between their vehicle and oncoming traffic. This is 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. It is unclear why older adults responded less to the largest (cautious) gaps in our scenario. In the future, process-tracing data such as the collection of verbal protocols, might provide insight into this strategy.

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 until this vehicle turned and their view was unobstructed before making a decision to turn. This was consistent with insights gained from the SketchUp 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, and behavior in the simulator, suggest that a switch from allowing protected and permitted left turns to only allowing protected left turns was a wise decision.

Clear age-related differences in cognition were observed between younger and older drivers in our study. Out of all the cognitive measures, only the measures of spatial ability seemed to predict aspects of turning decisions. However, ignoring age-related changes in cognition, and how these may (or may not) impact driver safety, it is important to recognize that older adults may largely be at risk due to increased fragility. Any countermeasure that reduces crash risk (such as protected turns) differentially benefits older drivers because the same crash that might injure a young driver might kill an older driver.

6. Project Conclusions

Within this project we illustrate 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 an intersection that appeared to be problematic with respect to older adult crashes. Next, we modeled this intersection in SketchUp 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.

While we were limited with what we could do in terms of budget and scope, this approach might be extended in a number of important ways. SketchUp and simulator models allow great flexibility to implement existing and experimental countermeasures into models of real-world, high-risk intersections. SketchUp models allow for a greater ability to visualize exactly how a change might impact factors such as visibility. Once imported into the driving simulator, participants (young and old) could be asked to navigate the same intersection with and without additional countermeasures to ensure that countermeasures are having their intended effect.

Once imported into the simulator other 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). All of these changes are easily implementable within driving simulator scenarios.

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 vehicle speeds and locations due to better visibility. Additionally, as mentioned in the FHWA Older Driver's Handbook, 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.

To further alleviate issues regarding the determination of gap distances when trying to perform a left-hand turn at an intersection, the intersection can be developed into one that only allows for protected left turn phases. By eliminating permitted left turn phases, the driver no longer has to make decisions on whether or not it is safe to perform a left turn maneuver, excepting the decision of whether or not to turn due to the phase ending. By eliminating this phase, older drivers avoid the difficulties of having to perform the maneuver as well as the stresses about whether they may be taking too long to make the turn.

Although the study could only make limited use of the SketchUp model, future studies that work through the limitations encountered by this study will be able to take advantage of being able to investigate specific intersections. While the models may not be a complete substitute for the actual intersection, depending on the level of care and detail placed into the generation of the model, an accurate model can be developed that will have only minor errors when compared with the actual intersection. Additionally, efforts can be made into identifying aspects of the actual intersection that the team considers vital to replicate as close as possible in the model. Upon doing so, the modelers can understand where to focus their efforts so that the any errors in the model (when compared to the actual intersection) are primarily found in non-vital elements, thereby reducing the importance of some of these errors.

Utilizing modeling software, such as Google SketchUp, also allows for the investigation of specific intersections where one may be interested in modifying the existing intersection with the intent on increasing driver safety. By developing the original intersection in SketchUp, modelers can then develop scenarios where the intersection is remodeled but with key differences from the original that are anticipated to produce a safer environment. These scenarios can then either be tested by converting the model into a drivable tile and having it be placed in a driving simulation or simply by allowing for one to gain an insight into how the proposed alternative(s) will look, differ from the original, and whether they perform the needed function before construction ever occurs. Since, in this scenario, one would be interested in investigating a specific intersection, it would behoove one to examine a model or driving tile that is bespoke to the intersection of interest, rather than a generic tile.

While the difficulties in modeling the SketchUp model's elevation proved to limit the model's usability, should this problem be nullified, the use of SketchUp or other 3D models will allow for one to model intersections or other driving scenarios with their elevations taken into account. This can allow for the investigation of how elevations can affect the sight distances of drivers attempting to perform a maneuver at an intersection, how it affect drivers' behaviors leading up to an intersection, etc.

An area where further investigation of this method can prove of great use is in the testing of importance of the FHWA's Older Driver's Handbook's Promising Practices. By developing driving simulator tiles that take these promising practices into account, research can begin to confirm or reject the validity of utilizing these strategies for reducing elderly driver collisions. By generating models depicting these scenarios, one can not only ensure that the level of detail is as desired but also ensure that the tile performs the function exactly as expected (i.e. designing the reduced left-turn-conflict intersections to verify that the driver behaviors/reactions being tested for will be captured as desired). Other practices (both promising and proven) may be made easier/possible with the integration of 3D software. The introduction of scenarios with and without high visibility signage, lane assignment controls, high visibility crosswalks, etc., may have either been unobtainable or required additional simulation tiles in order to test before the introduction of 3D modeling. While the purchasing of generic tile might be cheaper than a full 3D model, if one performs a good deal of the modeling work, the bespoke tile may be somewhat cost comparable and will better replicate the actual scenario; and therefore, give more accurate and meaningful results.

Limitations

Due to errors in trying to implement the model into the driving simulator, the major challenge that the study faced was in its inability to utilize the model exactly as intended. While the model could be used for testing when participants felt they would be able to perform a left turn, the team was unable to integrate it into a driving simulation scenario involving turn maneuvers due to the aforementioned problems. Despite the ability of the team to maneuver around this problem, it did prove to be a major limitation to the project. Further research will need to be conducted into determining methods that can alleviate this problem and allow for 3D models to be integrated with a driving simulator regardless of whether or not the model has a complex 3D topography or not.

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8. Appendix

Oncoming traffic in the current study was generated at a set pace for each participant so that each participant would see the exact same gaps at the exact same time during the scenario. All oncoming traffic traveled at a constant speed of 50.2 miles per hour. The 30 gap durations (10 risky, 10 safe, 10 cautious) shown below were repeated twice during the scenario.

Order	Gap Type	Duration (seconds)	Distance (feet)
1	Cautious	9	NA
2	Safe	4.11	302.62
3	Cautious	8.2	603.77
4	Risky	1.4	103.08
5	Risky	3.75	276.11
6	Risky	2.13	156.83
7	Safe	4.04	297.47
8	Cautious	7.6	559.59
9	Cautious	6.9	508.05
10	Cautious	5.6	412.33
11	Risky	3.7	272.43
12	Risky	1.6	117.81
13	Safe	4.08	300.41
14	Safe	4.2	309.25
15	Safe	4.24	312.19
16	Risky	2.11	155.36
17	Risky	2.94	216.47
18	Safe	4.6	338.70
19	Risky	1.77	130.33
20	Safe	4.3	316.61
21	Cautious	7.08	521.30
22	Cautious	6.4	471.23
23	Cautious	5.6	412.33
24	Safe	4.47	329.13
25	Safe	4.17	307.04
26	Cautious	9.4	692.12
27	Risky	2.14	157.57
28	Cautious	7.8	574.31
29	Safe	4.08	300.41
30	Risky	2.48	182.60