ROADWAY SAFETY INSTITUTE

Human-centered solutions to advanced roadway safety

HumanFIRST Driving Simulation Educational Development

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Final Report

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16. Abstract (Limit: 250 words)

The HumanFIRST Laboratory was recently awarded a grant through the University of Minnesota Office of the Vice President for Research to match funds to completely overhaul the laboratory’s driving simulators. This upgrade, which includes large touchscreen displays in the immersive simulators’ cockpit, will allow the laboratory to conduct innovative research in the fields of connected vehicles, in-vehicle technologies, and automated vehicles. In addition, the visibility of the laboratory’s increased capabilities is expected to boost an already frequent demand for educational and training partnerships (particularly around high-risk behaviors, such as distraction and speeding) from both government and private groups. In addition to the value in education and dissemination of knowledge regarding roadway safety to the greater community through demonstrations using the simulator, these partnerships often foster future opportunities for research partnerships and funding. Legacy driving scenarios will be updated to new simulator specifications. The creation of this new content is expected to allow new funding opportunities and will facilitate the research team to share its knowledge through educational and training opportunities within the regional community. This research leveraged the investment in the new simulator and propel the laboratory’s capabilities through the creation of three distinct simulated demonstrations focused on controlled hand-offs with automated vehicles, distracted driving via non-driving-related in-vehicle technologies, and speeding in pedestrian populated areas. These topics are key research focus areas for the Roadway Safety Institute and are core focus areas for the HumanFIRST Laboratory and its funding stakeholders.

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EXECUTIVE SUMMARY

Traffic crashes are a leading cause of death in the United States (CDC, 2017). The leading contributing factors to traffic crashes are linked to driver behavior and are preventable. Speeding and distracted driving are two prevalent factors associated with fatal crashes (NHSTA, 2019) that have been difficult to address despite years of public safety campaigns and enforcement and policy action. Education and outreach are essential tools to help reach drivers to prevent or reduce risky driving. A useful platform for engaged education and outreach is a driving simulator to simulate rare, but deadly scenarios to captive audiences. The HumanFIRST Laboratory at the University of Minnesota has a long history of inviting students, stakeholders, and community members into its immersive driving simulator for educational tours. The laboratory's simulator has overhauled with an updated computer, visual, and motion base, along with an updated interior interface. The upgrade offered an opportunity to enhance the educational activities to meaningfully reach audiences about risky driving behaviors, such as speeding and distraction while highlighting emerging topic areas such as pedestrians and automation. This project involved the creation of three educational demonstrations in the new driving simulator and utilized user-centered, iterative design to ensure the intended messages were properly communicated.

The research team created three simulated worlds including a rural highway scenario, an urban scenario, and an automated vehicles scenario. The rural highway scenario featured a three-mile segment of roadway on Scott County Highway 8 intersecting with Minnesota State Highway 13. The scenario was created to demonstrate the difficulty of maintaining lateral position and speed while engaging in an in-vehicle distraction. The demonstration ended with the average, minimum, and maximum values of speed and lane position of the driver's performance. The urban scenario featured a 3-mile urban grid of intersections on a four-lane roadway. The scenarios were designed to present a series of imminent collision events with vehicles and bicycles to highlight the difficulties of avoiding crashes when one is traveling even 5 miles over the speed limit. Finally, the automated vehicles scenario featured fifteen miles of US Highway 61 between Lacrosse and Winona, Minnesota in which simple instructions are provided in how drivers can initiate the autonomous mode (i.e., automated speed and lane position) of the vehicle and change lanes through a button press.

Five participants were recruited and participated in the usability assessments of the educational demos. Testing provided an opportunity to gather useful feedback on the design characteristics of each educational demonstration to use towards improvements in the design of the scenarios. General improvements were made to the initial design of the interface, based on the usability feedback. Large features, such as the position of the chassis to the projection screens and center stack luminance, were adjusted and feedback metrics were adjusted based on feedback.

Demonstrations of urban, rural, and automated driving scenarios were constructed to highlight these issues with speeding, distraction, and automation to interested stakeholders and the public using the driving simulator as a powerful educational tool (Backlund et al., 2010). Iterative usability testing was

employed to measure workload and user-friendliness as well as the overall perception and representativeness of the scenarios. The work demonstrates the importance of integrating user-centered design and iterative testing in educational tools and materials to maximize opportunities to reach drivers and ultimately improve driving safety.

CHAPTER 1: LITERATURE OVERVIEW

1.1 SPEEDING AND DISTRACTION CRASHES

There were 34,247 fatal crashes nationwide in 2017 (IIHS, 2018), and crashes are a leading cause of death in the United States (CDC, 2017). Furthermore, the number of crash deaths is relatively evenly split between urban (19,038) and rural (17,216) environments (IIHS, 2018). These deaths do not reflect the total cost of these motor vehicle crashes to society (see Figure 1.1). Speeding accounted for 9,717 traffic fatalities in 2017 (NHTSA, 2019) and distraction-related crashes accounted for 3,450 traffic fatalities in 2016 (NHSTA, 2019), with teenagers being at a disproportionate risk of distraction-related crashes (CDC, 2017). Furthermore, pedestrian fatalities are at a 28-year nationwide high (Calvert, 2019), which has been partially attributed to (1) distraction and (2) speeding. The impact of speeding on fatality likelihood is well-known, with up to 50% risk of death for pedestrians struck by a vehicle going 40 mph and a higher risk for older adults, approximately 75% at 40 mph (Tefft, 2011) (see Figure 1.2). The pedestrian crash data has indicated that the pedestrians most at risk for fatalities are older adults over the age of 65 and children (CDC, 2017).

Figure 1.1 Societal cost of motor vehicle accidents (CDC).

Figure 1.2 The impact speed on a pedestrian's risk of severe injury or death. Graphic from Denver Vision Zero Action Plan (Tefft, 2013).

1.2 AUTOMATION

One potential solution for managing speeding crashes, distraction-related crashes, and other forms of traffic fatalities is through increasing vehicle automation and connected vehicle technologies (West, 2016). However, implementing automation in the vehicle has significant challenges, particularly when automation fails, and the driver must take over the driving task (Hancock, 2019). Specifically, when automation controls the vehicle, drivers may be inclined to disengage from the driving task and become "out-of-the-loop" on what is happening in the driving situation, causing them to be slower, less effective, and more error prone when taking over the driving task when the automation hands the driving task to the human or automation fails, requiring manual take-over for safe performance (Endsley & Kiris, 1995).

1.3 CONCLUSION

Given these challenges, a sustained effort must be made to both research solutions to these challenges (e.g., Creaser, Edwards, Morris, & Donath, 2015; Seppelt & Victor, 2016) and educate stakeholders and the public on the nature of speeding, distraction, and automation promises and pitfalls. The use of driving simulators in education is understudied due to the relative scarcity of simulators, but these simulators are significantly effective at providing a safe environment to explore driving scenarios and preliminary research has suggested that the use of driving simulators leads to positive educational outcomes (Backlund, Engström, Johannesson, & Lebram, 2010). Speeding, distraction, and automation are key components in both roadway risk and potential mitigation through educational means. The HumanFIRST laboratory created three different educational demonstrations targeted toward speeding, distraction, and automation.

CHAPTER 2: SIMULATOR REPLACEMENT

2.1 LEGACY HUMANFIRST DRIVING SIMULATOR

The original HumanFIRST full-chassis simulator was based on a 2002 Saturn full-vehicle cab. The previous simulator offered 270 degrees total field of view through a total of 8 video screens (6 projectors, 2 LCD screens).

The original immersive simulator offered a showpiece for the university to demonstrate a mix of basic and applied research with significant face validity to stakeholders, prospective students, and state and federal legislators. Historically, the lab has hosted tours and even media events with high profile stakeholders who are integral in ensuring that funding continues to flow into the university. In May 2016, the laboratory hosted a joint media event with United States Senator Amy Klobuchar, teenagers, and bereaved parents to help her raise awareness about the fatal consequences of distracted driving.

To continue a legacy of advanced research conducted by the laboratory and to facilitate important interdisciplinary collaborations, there was an update to multiple components of the HumanFIRST driving simulator. When originally installed, the immersive simulator was state-of-the-art and among the best in the country. However, over time competing institutions had surpassed our capabilities and many primary components of the simulator were nearing their end-of-life. The computational power required to provide high fidelity simulated environments were great and required thirteen computers. These computers were nearly 10 years old and operated using Windows XP. Most notably, the age of the computer systems risked contract delays due to potential catastrophic failures. Furthermore, the computers in the immersive simulator no longer support the motion system, which had resulted in increased instances of simulation sickness in previous experiments. A system-wide replacement of all computer subsystems presented the wisest investment of funds rather than replacing individual computers, which would need to be compatible with outdated programming techniques and the software of the remaining system computers.

2.1.1 Saturn Simulator Specs

Figure 2.1 Legacy Saturn Simulator.

The original simulator consisted of a 2002 Saturn full-vehicle chassis featuring haptic feedback through vibration and a three-axis motion system (see Figure 2.1). One of the key competitive differentiating features of the simulator was a (later removed due to computer issues) partial motion system that helps to stimulate a driver's vestibular system and, importantly, reduce the risk of simulation sickness that is a common result of experiencing visual motion without vestibular motion. This also provided a realistic and immersive feel to the simulation, thus enhancing the validity of the experimental results. The driving environment was projected on to a five-channel, 210-degree forward visual field screen, projected on five discrete flat screens, with 60-degree rear views provided by a rear screen and side-mirror mounted LCD panels. This provided an immersive visual world to allow researchers to present realistic driving environments, such as rural intersections which are often the site of fatal crashes, and measure eye and head movements across the visual plane to better understand the information drivers use to make decisions, such as choosing gaps in traffic.

2.2 MODERN HUMANFIRST SIMULATOR

The new modern HumanFIRST full-chassis simulator was based on a 2016 Ford Fusion furnished by Realtime Technologies, a division of FAAC, in 2017. This simulator offers 360 degrees field of view through a total of six video screens (four projectors, two LCD screens).

The infrastructure rebuilds of the immersive simulator replaced the vehicle used in the immersive simulator with a new model vehicle, a Ford Fusion. The complete cab refurbishing replaced the worn seats and armrests and provided the simulator with a professional fit and finish. Furthermore, the new Ford Fusion cab enhance the facility and raise the face validity of the simulation lab. The new cockpit included a glass dash and a center stack with a touch screen system. The cab is prepped for proper air ventilation inside the cabin to allow cool air to be piped into the vehicle, ensuring a more comfortable driving experience for research participants, reducing the likelihood of simulator sickness.

Finally, the upgrade replaced all the computers needed to program and build the simulated worlds and run the simulated driving scenarios for the immersive simulator. The computer upgrades for the immersive system replaced the 7 visual channels, one host, and one center stack computer with the latest generation computers incorporating the latest simulation creation software. Finally, a new simulator development workstation was purchased, enabling scenarios to be built while driving behavior studies are being run in the simulator, providing for efficient lab workflow.

2.2.1 Ford Simulator Specs

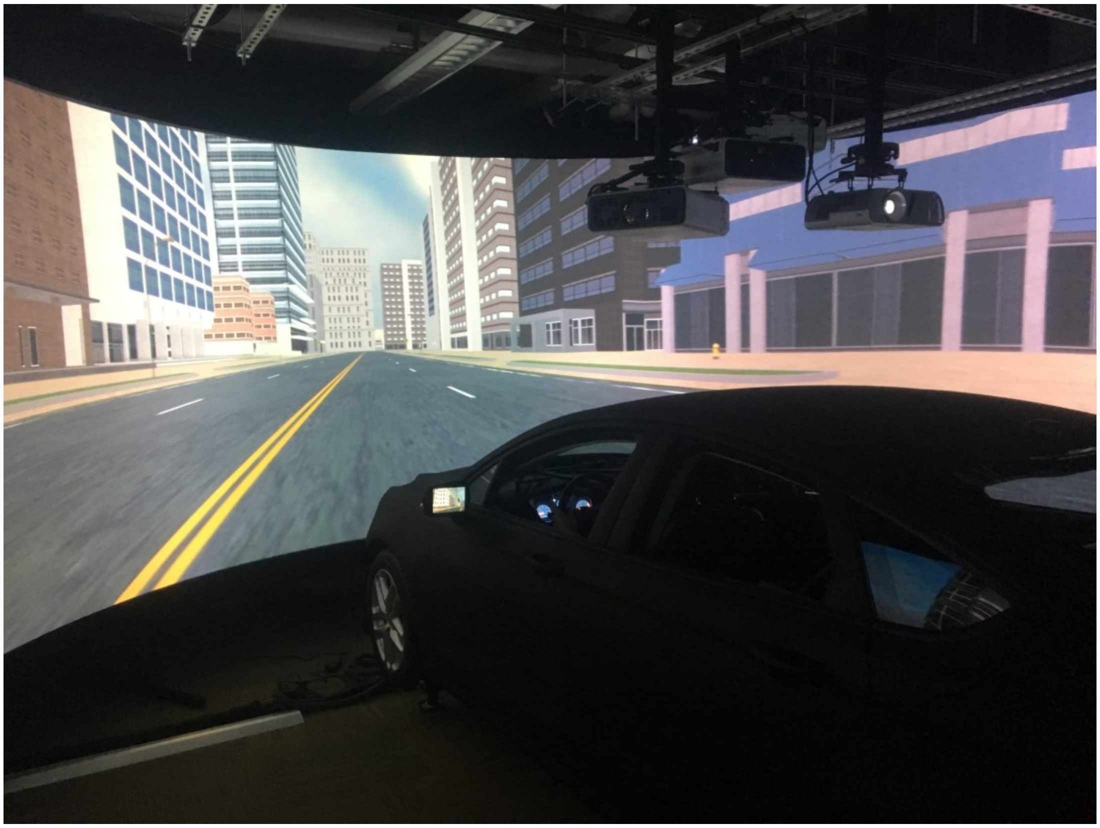

Figure 2.2 Modern HumanFIRST Simulator.

The modern simulator consists of a 2016 Ford Fusion full-vehicle chassis featuring haptic feedback through vibration and a three-axis motion system (see Figure 2.2). One of the key competitive differentiating features of the simulator was the partial motion system which helps to stimulate a driver's vestibular system and, importantly, reduce the risk of simulation sickness which is a common result of experiencing visual motion without vestibular motion. This also provided a realistic and immersive feel to the simulation, thus enhancing the validity of the experimental results.

The upgrade initially included five new, high lumen, high-resolution projectors and a seamless, cylindrical screen, maximizing horizontal field of view and fitting the current specifications of the present laboratory space. The screen spans a 210-degree forward field of view affording the ability conduct intersection studies in which the driver must make decisions on traffic approaching at a 90-degree angle.

Complimentary right and left LCD mirrors are embedded into the standard mirror housing of the new chassis for an OEM look. The mirror field of view can be dynamically changed using the electric mirror tilt controls on the driver's door, replicating the experience in an actual automobile. A rear projection screen is reflected in the rear-view mirror. An over-size projected image provides the driver the ability to adjust their mirror to capture their desired view angle.

Additionally, the upgrade included a new three-axis electric motion system. The vehicle chassis sits on four linear actuators, providing roll, pitch, and vertical acceleration (speed bumps, curb strikes, rumble strips) of the simulator vehicle. A frame-mounted transducer provides low-frequency vibration from road and engine noise.

The simulator contains two separate audio systems to replicate both external and internal vehicle sound sources. A 5.1 channel surround sound system is located behind the projection screens creating localized audio from other vehicles, pedestrians, and other environmental sources. The vehicle's original audio speakers are in place and controlled by the simulation software to provide in-vehicle warnings and entertainment system audio.

CHAPTER 3: INITIAL SIMULATION DESIGN

3.1 OVERVIEW

Historically, the HumanFIRST Program used experimental research scenarios for public tours and demonstrations. While these scenarios displayed actual research projects, they were often not ideal for a tour situation. Research scenarios are frequently too long, lack instruction, and provide little feedback to the driver.

A research drive scenario is typically thirty minutes or more in length, which is a long time for a demonstration and too long for most tours. Driving only a portion of the scenario might leave out important elements that are of interest to the audience. A research scenario also contains a significant amount of drive time without any event occurring. This is often wasted time in a demonstration. The newly created demonstration scenarios are designed to be five minutes in length.

Research scenarios do not contain automated instruction such as on-screen messages to explain novel control elements or scenario features. This is because research scenarios are typically evaluating how a driver reacts to these elements. A research experiment would also include training, if needed, prior to a participant beginning the drive. In the demonstration scenarios, concise on-screen instructions explain key controls and elements to the viewer.

Performance analysis in a research scenario is performed long after the drive is complete, without the participant knowing the results of their drive. The goal of research is to identify the natural behavior of a driver to events, not to evaluate or instruct them. This is opposed to a tour or class highlighting driver safety issues (such as distraction). In that situation, it is desired to provide the driver with information about how their performance has been affected. The demonstration scenarios will include immediate on-screen feedback for driving safety measures such as speed, lane-keeping, and collisions.

3.1.1 Rural Highway Scenario

The Rural Roadway will be used to demonstrate distracted driving effects in a low-volume rural environment. The rural environment drawn from a geo-specific database of ten miles of Minnesota State Highway 13 and twenty miles of Scott County Highway 8, see Figure 3.1 and Figure 3.2. Topographical data to construct the area was obtained from the Minnesota Department of Natural Resources' MnTOPO service, see Figure 3.3. Roadways in the area are two-lane rural highways. Shoulders are present only on major routes. Most intersections are two-way stop, with some four-way stop and a single-lane roundabout at CSAH 8 and Vernon Avenue.

The rural demonstration scenario is on a three-mile section of CSAH 8 between Texas and Panama Avenues, see Figure 3.3. The scenario begins on the side of the road, facing west. On-screen instructions tell the driver to proceed at the posted speed limit of 55 MPH, see Figure 3.4. When the driver stops at the intersection with Panama a variety of performance measures appear on the screen. These measures include mean speed, speed deviation, and lane position metrics, see Figure 3.5.

The scenario can be used to demonstrate the effects of distraction on a driver. The driver can be talking on a cell phone, texting, or engaging in other distracting tasks during the scenario. The end-of-drive metrics show the driver's performance was affected with lane deviation and inconsistent speed.

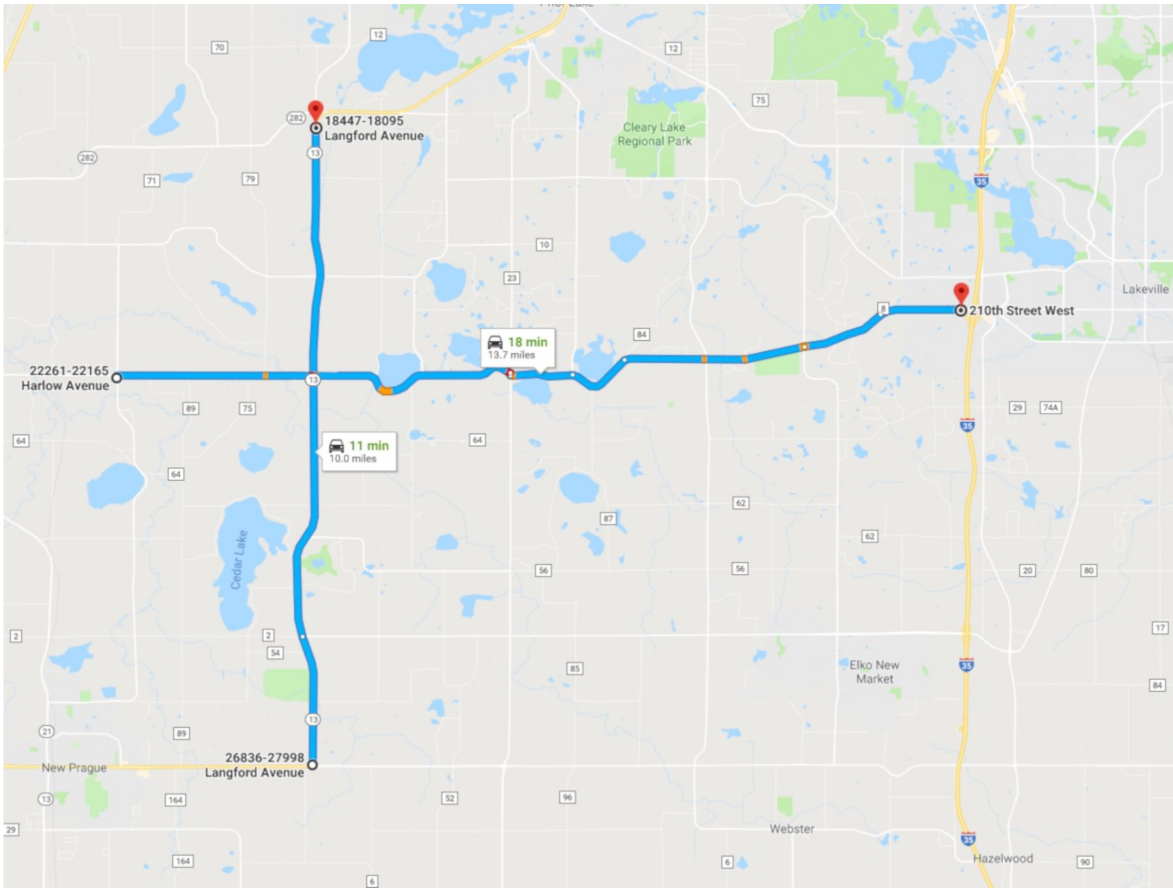

Figure 3.1 Google Map View of the Minnesota Geospecific Database Used for Rural Highway Scenario.

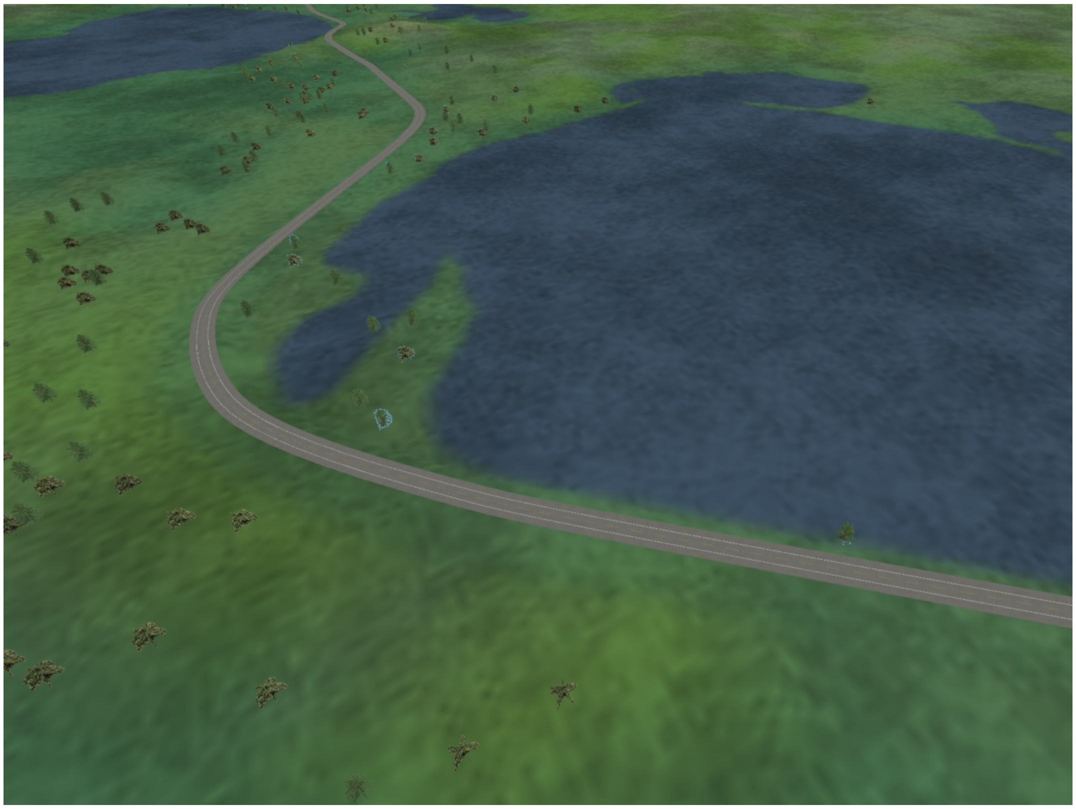

Figure 3.2 Simulation Software Bird's Eye View of Rural Highway Scenario Simulation Route.

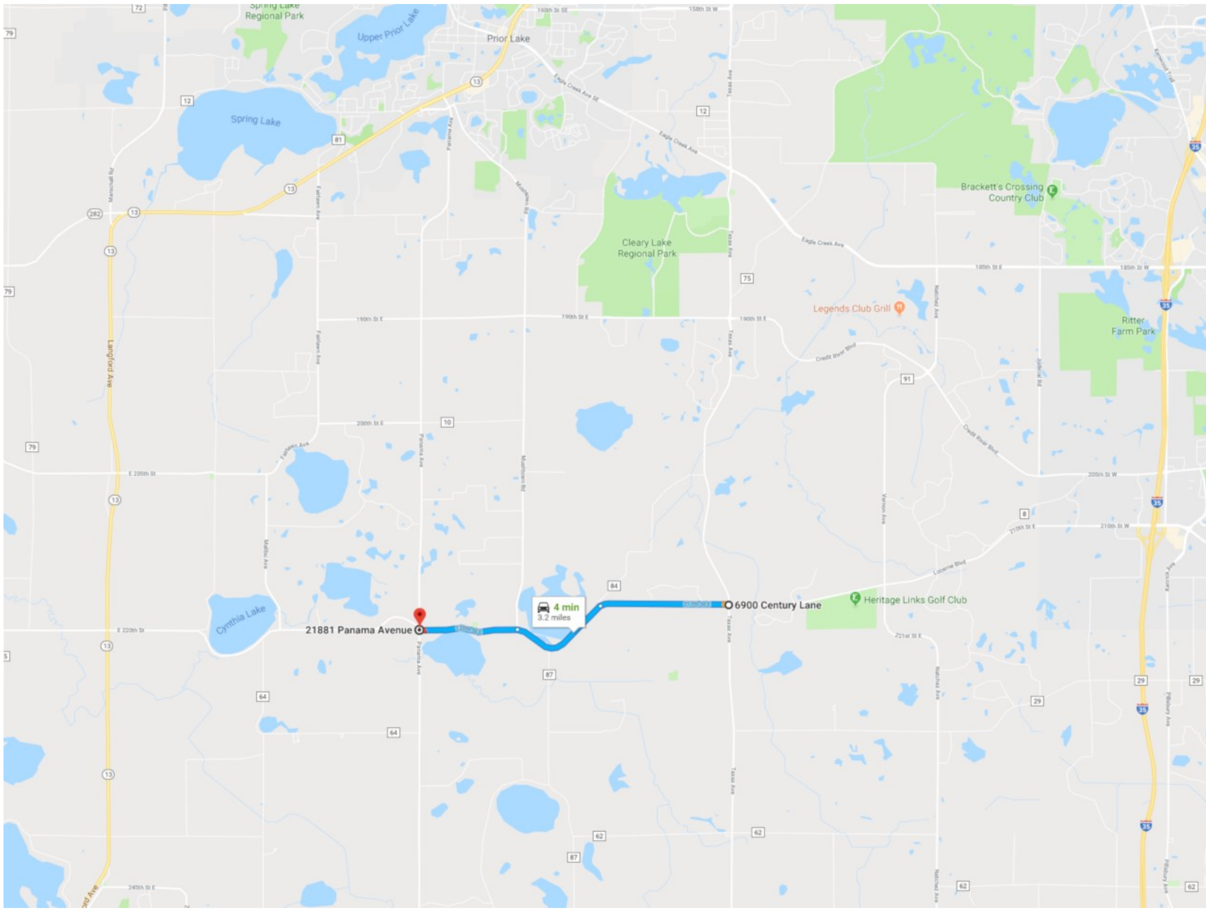

Figure 3.3 Google Map View of Rural Highway Scenario Simulation Route.

Figure 3.4 Start of the Rural Highway Demo

Figure 3.5 End of the Rural Highway Demo

3.1.2 Urban Scenario

The Urban Scenario's environment is based on the Minneapolis street grid, although no specific part of the city is represented. A three mile by one and one-half mile section of city is modeled, see Figure 3.6. Arterial roads are four-lane, undivided with sidewalks and commercial storefronts on both sides, see Figure 3.7. Minor roads are two-lane with on-street parking and sidewalks. Alleys bisect the blocks along the long axis. Intersections are controlled by stop lights.

The Urban Scenario creates a series of accident-likely conditions involving both bicycles and vehicles. A car pulls out from a cross street, turning right on red in front of the driver, see Figure 3.8. A bicycle crosses against a red light, see Figure 3.9. Additionally, an oncoming bicycle makes a left-hand turn, requiring the driver to stop quickly.

The Urban roadway has been used to create accident-likely scenarios and evaluate the subject's ability to respond in a congested environment. Incidents may include pedestrians in the future to address issues with pedestrian crashes.

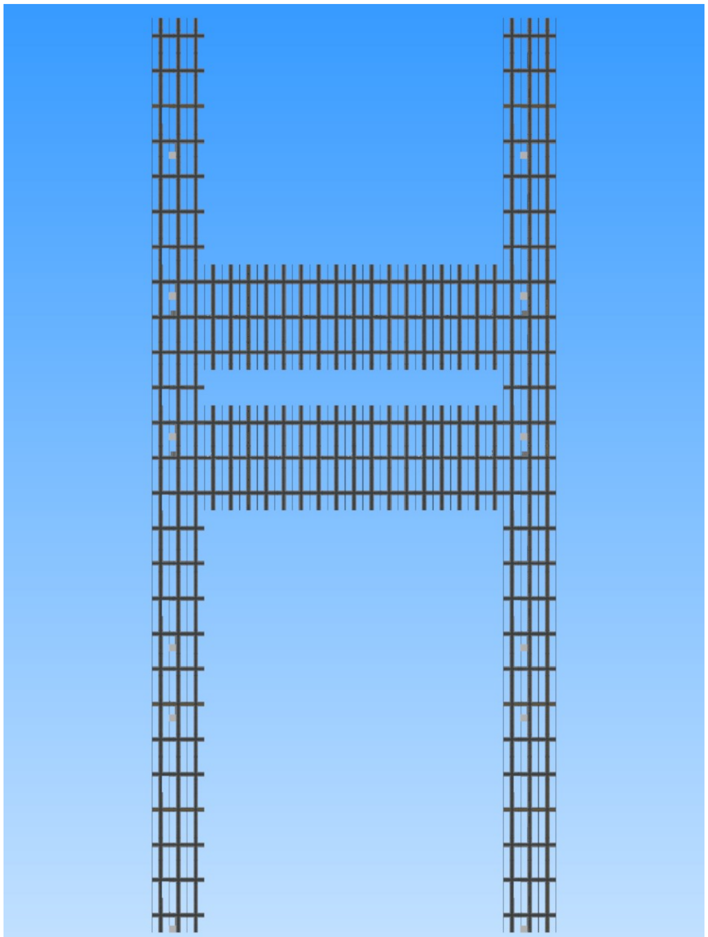

Figure 3.6 Urban Grid.

Figure 3.7 Tested Urban Simulation Scenario.

Figure 3.8 Urban Simulation Vehicle Collision Scenario.

Figure 3.9 Urban Simulation Bicycle Collision Scenario.

3.1.3 Autonomous Vehicle Scenario

The Autonomous Vehicle Demonstration scenario will be used to demonstrate high-speed automated driving in on a limited-access freeway. The highway will be used to evaluate drivers' responses to automated driving situations, specifically the hand-off between manual and automated driving modes. The driver starts driving the vehicle and then engages an automated driving system. At a later point, the system deactivates, forcing the driver to re-take control. This scenario aims to serve as an educational aid for researchers when describing the trends in automation during demonstrations for both research stakeholders and educational outreach.

The highway environment used in the Automation Scenario is a geo-specific database consisting of fifteen miles of US Highway 61 between Lacrosse and Winona, see Figure 3.10. Topographical data to construct the area was obtained from the Minnesota Department of Natural Resources' MnTOPO service, see Figure 3.11. The roadway is a divided four-lane highway, see Figure 3.12. The road consists of twelve-foot lanes, a ten-foot right shoulder, and a three-foot left shoulder, see Figure 3.13. The opposing directions are separated by a twenty-foot wide grass median.

The highway scenario demonstrates the autonomous driving capability of the simulator. The vehicle starts on the right shoulder of the road. On-screen instructions describe the operation of the autonomous driving mode: steering wheel buttons are used to engage/disengage and change the set speed. Lane changes can be accomplished using the turn signal.

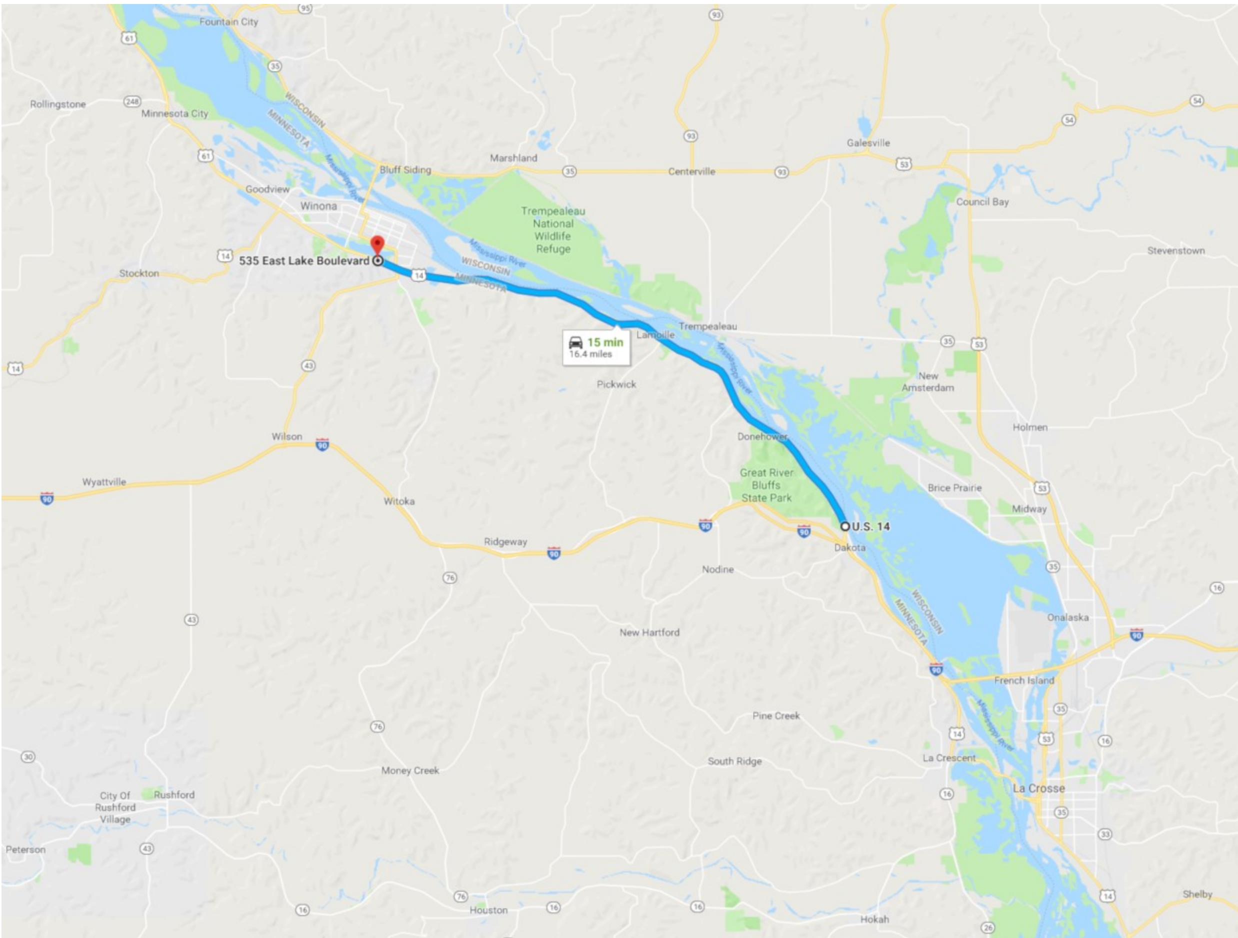

Figure 3.10 Google Map View of Automation Scenario Simulation Route.

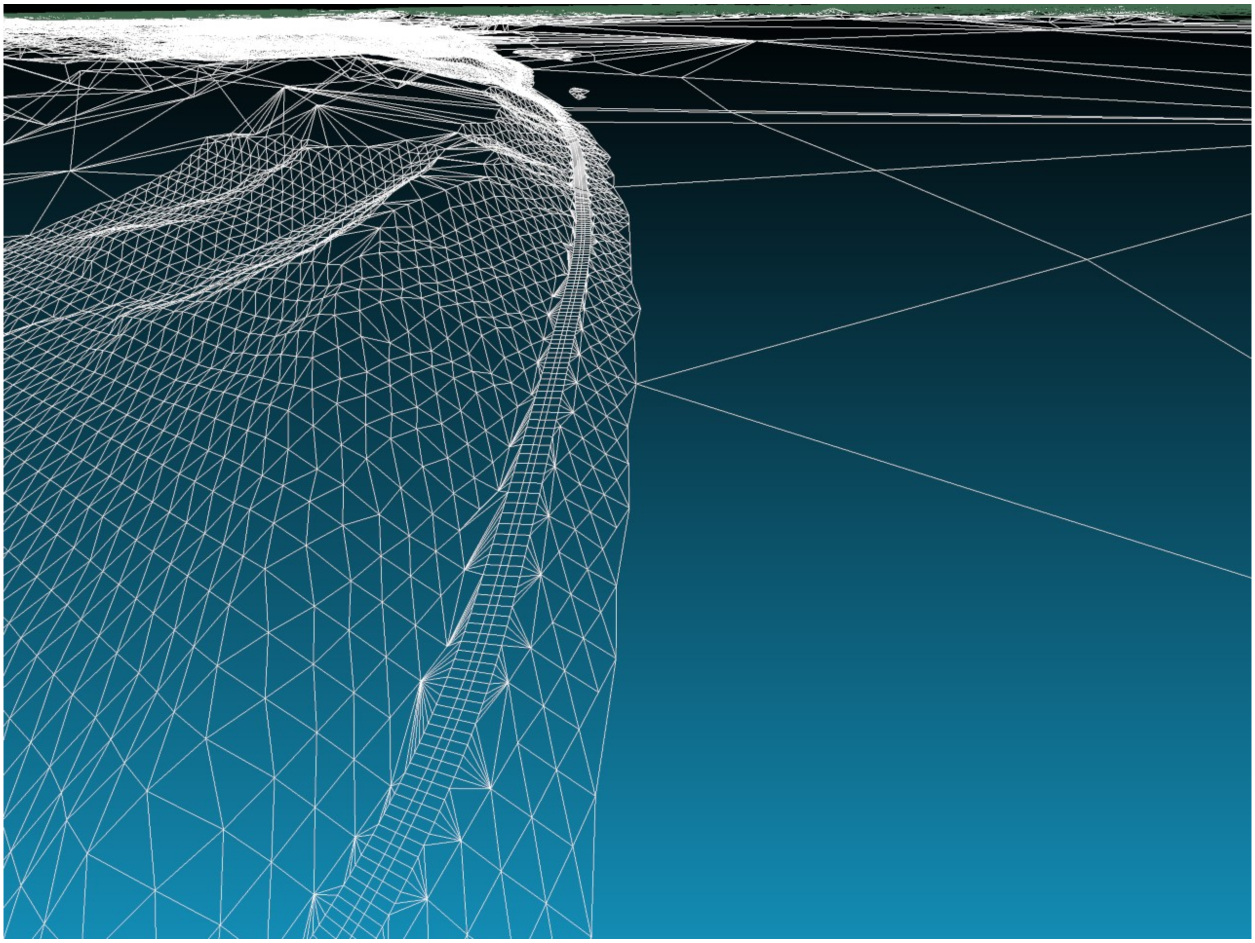

Figure 3.11 Automation Wireframe Simulation Route.

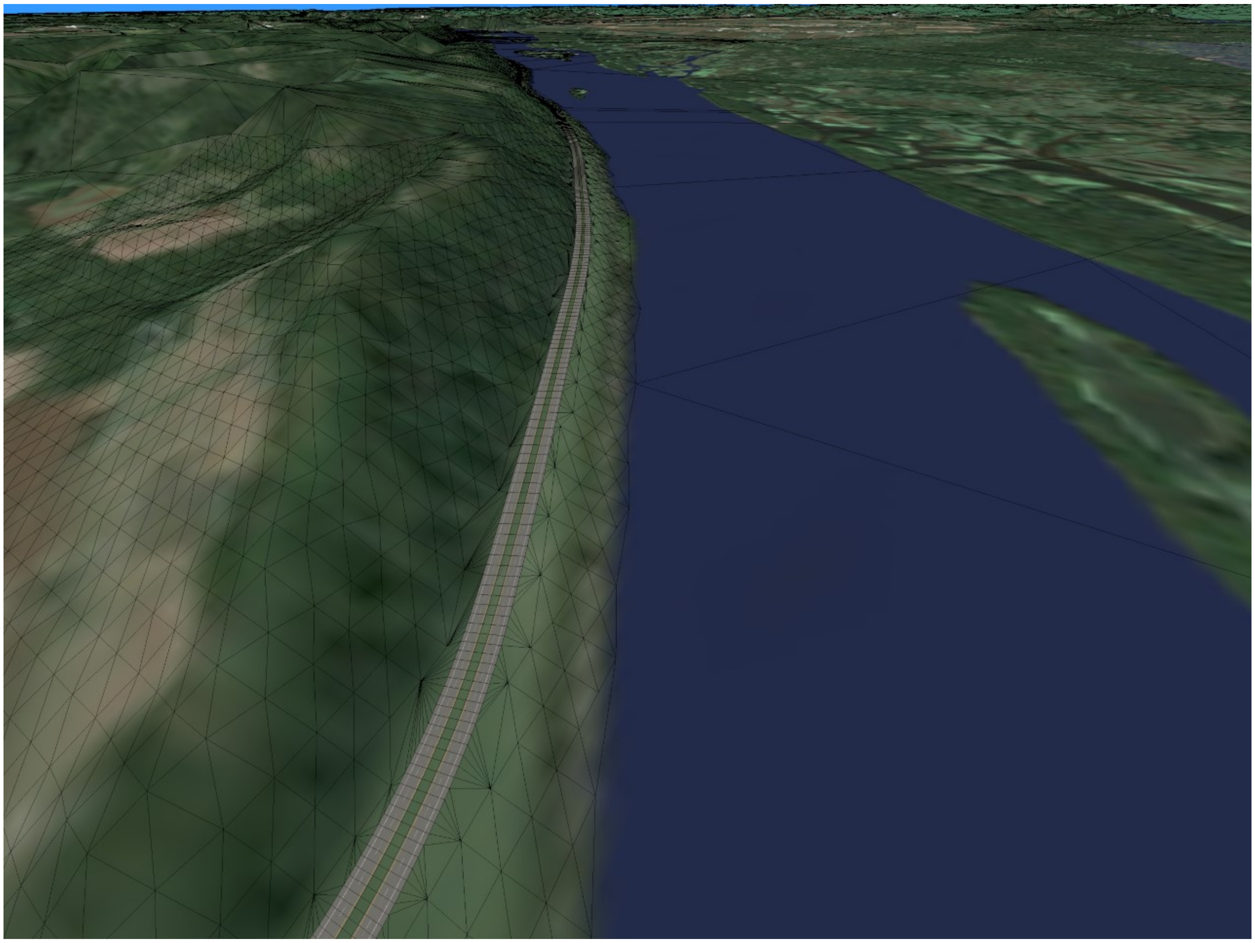

Figure 3.12 Development of Bird's Eye View of Automation Scenario Simulation Route.

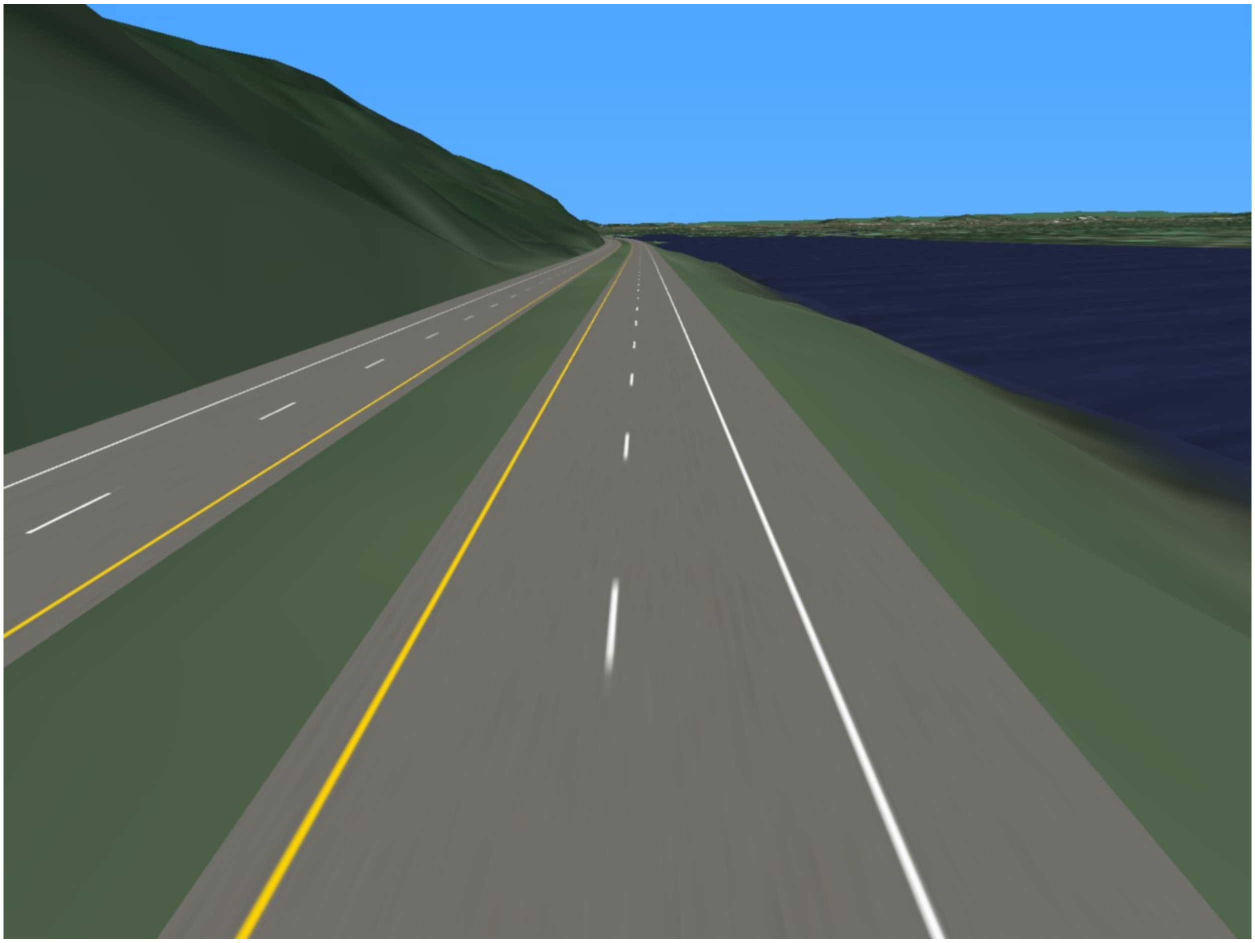

Figure 3.13 Tested Automation Simulation Scenario.

CHAPTER 4: USER-CENTERED ITERATIVE DESIGN PROCESS

4.1 OVERVIEW AND USABILITY TESTING

To evaluate the three demonstration simulations (i.e., Urban, Rural, and Automation), five usability tests were conducted with five study participants using the modernized full-chassis driving simulator at HumanFIRST. Usability testing provides an opportunity to gather useful feedback on design characteristics of each educational demonstration to use towards improvements in the design of the scenarios for the most user-friendly and informative demonstrations.

Usability tests on the original demonstration scenarios were conducted to evaluate their usefulness, appropriateness, and depth of educational quality. In total, five participants engaged in usability tests for each scenario: A Rural Highway scenario with cell phone-based distracting tasks, an Urban Scenario environment with varying participant vehicle speeds, and an Automation drive featuring autonomous vehicle controls. Please see Appendix A for a description of the usability testing plan.

4.2 METHOD

4.2.1 Participants

Five participants were recruited and participated in the usability assessments of the educational demos. Typically, a significant majority of issues are found with a sample size of five study participants, in addition to gathering common attitudes from users. Of the five participants, three were men and two were women, with a mean age of 25 years (*SD* = 4). All had driver's licenses for over 5 years (*M* = 9 years, *SD* = 4), and reported an average annual miles traveled of approximately 15,000 miles.

4.2.2 Procedure

Prior to engaging in the study, researchers solicited verbal consent that participants were interested in the study and understood the tasks needed to complete the study. Candidate participants were screened for study eligibility (See Appendix C), which first included their histories with symptoms or episodes of motion sickness in order to avoid motion sickness occurring in the driving simulator during the suability studies. Participants also were required to have had a driver's license for over two years to ensure the study sample was representative of drivers in Minnesota. Following consenting and eligibility screening, experimenters briefed the participants on each educational demonstration scenario (e.g. Urban, Rural Highway, Automation drives) and the corresponding driver distraction tasks (e.g. Text message to your mother and view social media feed tasks). Participants were also briefed on the subjective measures data that experimenters would ask for between each simulation scenario, with the Urban environment having two such collection interventions.

The simulation study began with the Urban educational demonstration and participants were instructed to drive at 20MPH throughout the urban environment. Driving at 20MPH would afford participants the ability to avoid threats from intruding vehicles or bicyclists that rapidly appeared in the immediate lane of travel from the participant's perspective. Following the completion of the Urban demonstration at 20MPH, participants were instructed to complete the drive at 35MPH, which made evasive maneuvers much less likely to succeed at avoiding crashes with intruding vehicles and bicycles. Both speeds are representative of speeds drivers take in urban environments, and this demonstration can be used to highlight the risk of driving at higher speeds.

The Rural Highway scenario featured a secondary distractor task requiring participants to initiate a text message and refresh a social media smart phone application while travelling on the 55MPH roadway. The roadway featured frequent horizontal and vertical curves. At the end of the drive, participants were provided with their driving performance in terms of speed error and lane keeping performance.

The final scenario in the usability study was the Automation drive, which required participants to engage with the Autonomous vehicle capabilities programmed into the simulation experience. Participants were instructed to engage and disengage with the automation system once at speeds of approximately 25MPH and perform various lane changes using the automated system. Participants were encouraged to engage and disengage at least twice.

4.3 DEPENDENT VARIABLES

4.3.1 Quantitative usability metrics

4.3.1.1 Rating Scale of Mental Effort (RSME)

The Rating Scale of Mental Effort (RMSE) is a subjective measures inventory used to determine a participant's extent to which they felt cognitive effort was required in order to meet the demands of a task. In the context of the educational demonstration scenario usability tests, the RSME provided a general sentiment of how difficult and cognitively intuitive each scenario was. Establishing a baseline for mental effort is helpful for determining the appropriateness of when to use a demonstration, in addition to providing feedback on how scenarios can be changed to reduce mental workload if necessary when experiencing them. Appendix B contains the Rating Scale of Mental Effort response form.

4.3.1.2 System Usability Scale (SUS)

The System Usability Scale (SUS) provides participants with opportunities to evaluate ten usability characteristics related to the system being assessed by users, in this context being the task demands and driving experiences of the scenarios. The SUS scores can guide researchers with an understanding on how participants viewed general system usability during their drives. General characteristics of system usability include the intuitiveness, difficulty, consistency, and degree of technicality each educational demonstration scenario exhibited during their drives. The SUS provides researchers the opportunity to understand which system characteristics were satisfactory in the opinion of the users in the usability assessments, as well as identify potential problems or shortcomings with the scenarios that can be forwarded on to team members responsible for iterative design of the scenarios. Appendix D contains the System Usability Scale document.

4.3.2 Post-Scenario Follow-up Validity Questions

At the end of each educational demonstration drive, experimenters asked semi-structured format questions after participants gave their initial impressions. The questions considered the urban drive (*Is this scenario representative of speeding experiences in urban environments in the real world? Is this scenario representative of distraction experiences in urban environments in the real world?*), the rural drive (*Is this scenario representative of distraction experiences during rural highway drives in the real world?*), and the automation drive (*To what degree was this scenario an informational model of automated vehicles?*). See Appendix E.

Participants were shown a 7- point Likert scale response form (see Appendix E) that ranged from "Not at all" to "Completely" and were asked to provide the answer that best fit their judgment of each evaluation question for the respective scenarios. Participants reported their specific rating for each question to the experimenter and the response was recorded.

Responses to these questions were noted. Appendix E also details the notes and scoring document used by experimenters to capture representativeness and observational data points following each educational demonstration scenario.

4.3.3 Participant Feedback and Exit Interviews

4.3.3.1 Researcher observations of participants' attitudes and comments

The purpose of the attitude and behavior observations was to document participant responses to the educational demonstration scenarios. Experimenters performed observations of participants' behavior during the usability study and recorded notable events. Examples of behaviors that would be recorded would include utterances or statements about the drive during the simulation experience, overall driving behavior, and driving maneuvers viewed as unnecessary or erratic (e.g. quick jerk of the steering wheel, collision, hard brake event).

4.3.3.2 Participant comments and feedback regarding scenarios

Following each scenario conclusion, experimenters prompted participants to share their general feedback regarding their experiences in each of the educational demonstrations in the simulator. Initial comments were solicited from participants in an unstructured think-aloud manner, which gave participants freedom to report their thoughts on any aspect of the educational demonstrations.

4.4 DEBRIEFING

Following the conclusion of the usability test, experimenters debriefed study participants on the characteristics of the educational demonstrations and the future research that their participation could improve. Final comments on any of the scenarios and their educational qualities as learning tools were solicited. Participants were compensated $25 and were given a Wellness Assessment (see Appendix F). The Wellness Assessment was administered to ensure participants were not feeling ill or experiencing symptoms of motion sickness before they left the research site. No participants reported any symptoms of motion sickness or physical, cognitive, or emotional discomfort.

CHAPTER 5: USABILITY TEST RESULTS

5.1 SUBJECTIVE MEASURES

5.1.1 Rating Scale Mental Effort

5.1.1.1 Urban Scenario

In terms of mental exertion required to complete the driving simulation task, participants rated the Urban scenario at a speed of 20MPH as approximately “A Little Effort” (*M* = 26.4, *SD* = 15), see Figure 5.1. The variability in standard deviation scores for this rating suggest some participants experienced nearly “No Effort”, while others experienced “Some Effort”. When the travelling speeds increased to 35MPH in the Urban scenario, participants rated higher mental effort to complete the driving task between qualitative statements of “Some Effort” and “Rather Much Effort” (*M* = 49.4; *SD* = 6.9).

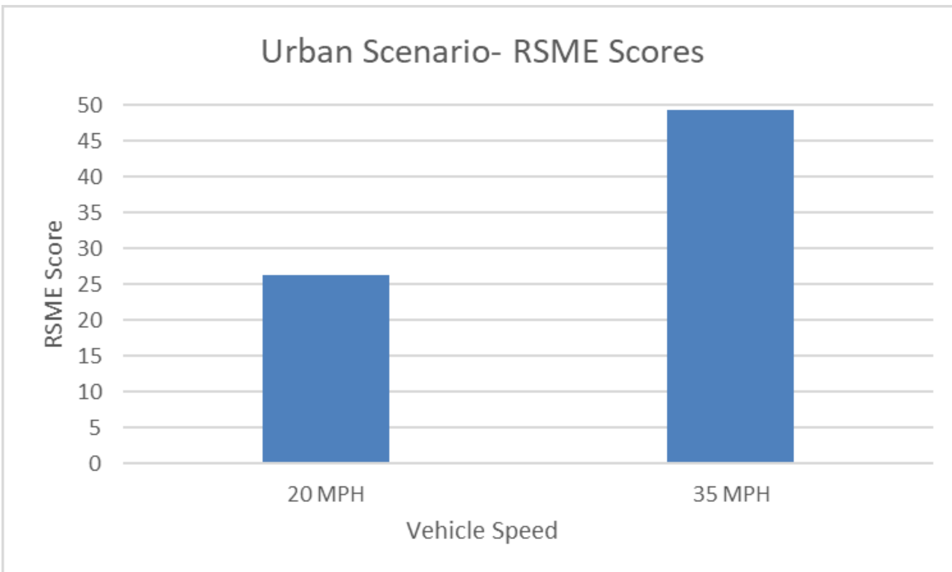

Figure 5.1 Urban Scenario Average RSME Scores by Vehicle Speed.

5.1.1.2 Rural Highway Scenario

The Rural Highway Scenario RSME results indicated that participants thought the driving task in combination with the distractor tasks were approximately “Some Effort” (*M* = 34.4, *SD* = 18), see Figure 5.2. This suggests that while the task demands did require focus and cognitive effort to complete, the relative workload imposed by the education demonstration in the simulator did not overwork participants, which is a key consideration for public tours and educational purposes for HumanFIRST.

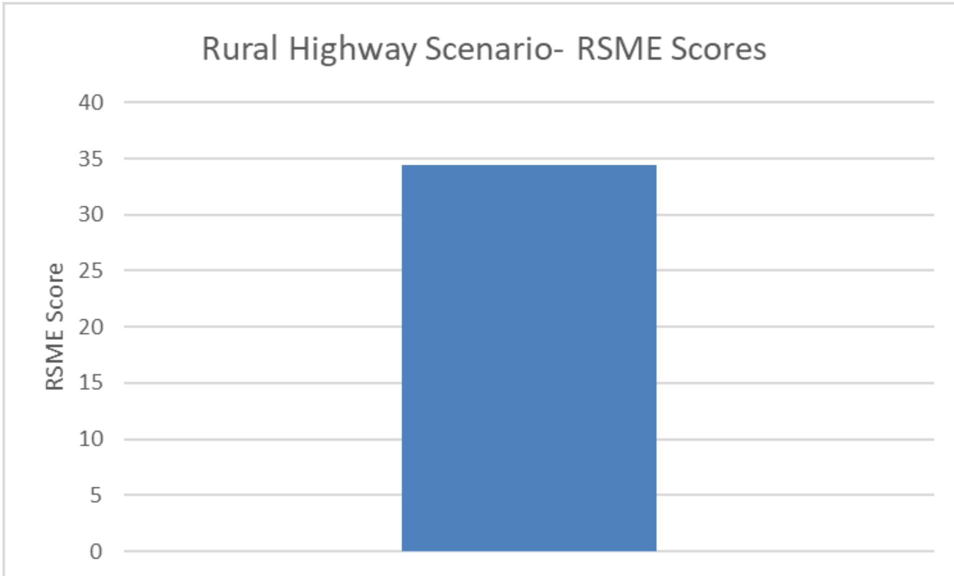

Figure 5.2 Average Rural Highway Scenario RSME Scores.

5.1.1.3 Automation Scenario

RSME scores were calculated for the three measured interactions participants made when completing the Automation scenario: 1) Engaging the automation, 2) Disabling the automation and take-over of vehicle control, and 3) Performing a lane-change using the automation system.

Participants rated the lane-change task in the Automation scenario the most mentally demanding, rating it as approximately “Some Effort” (M = 31.4, SD = 15.1), suggesting some degree of cognitive effort was required to interface with the lane-changing controls of the automated system. Interestingly, this action required only one lever press, which involved pushing the turn-signal stalk up or down to initiate the lane-change.

Engaging the automation control was the second-most difficult task reported by participants, which took approximately “A Little Effort” (M = 22, SD = 10.3), indicating that while some effort was required to successfully initiate autonomous driving features, the degree of mental effort was quite minimal, see Figure 5.3.

Disengaging the automation control, or performing a take-over to manual driving, was the least-difficult task in terms of mental workload, scoring at “Almost No Effort” (M = 10.4, SD = 15.5). However, some variability in scores was apparent (SD = 15.5), suggesting that while relatively little effort was exerted at maximum, the perception of mental effort exertion during the take-over task differed by participant.

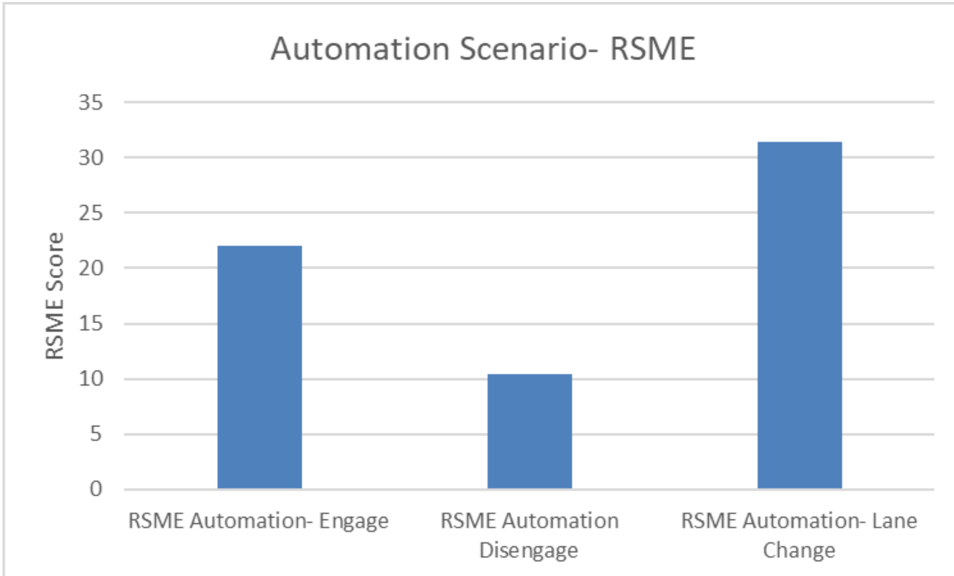

Figure 5.3 Automation Scenario Average RSME by Task.

5.1.2 System Usability Scores

Average system usability for interactive products is in the mid-60s, so scores significantly over 70 indicate a very usable system on average.

5.1.2.1 Urban Scenario

SUS scores were calculated for Urban scenarios at 20 MPH and 35 MPH conditions. Mean ratings of system usability for the 20MPH speed limit was 83.5 (*SD* = 15.1), and the 35MPH scenario mean SUS rating was 84 (*SD* = 15.1), suggesting participants thought this educational demonstration scenario was high in general usability, see Figure 5.4.

5.1.2.2 Rural Highway Scenario

The Rural Highway Scenario's mean ratings of system usability as reported by participants was 86.5 (*SD* = 5.4). These results indicate participants thought this educational demonstration scenario was high in system usability characteristics.

5.1.2.3 Automation Scenario

The Automation Scenario's mean ratings of system usability was 90 (*SD* = 7.9). These results indicate participants thought this educational demonstration scenario was very high in system usability characteristics, and this scenario was rated the highest on average among all educational demonstrations.

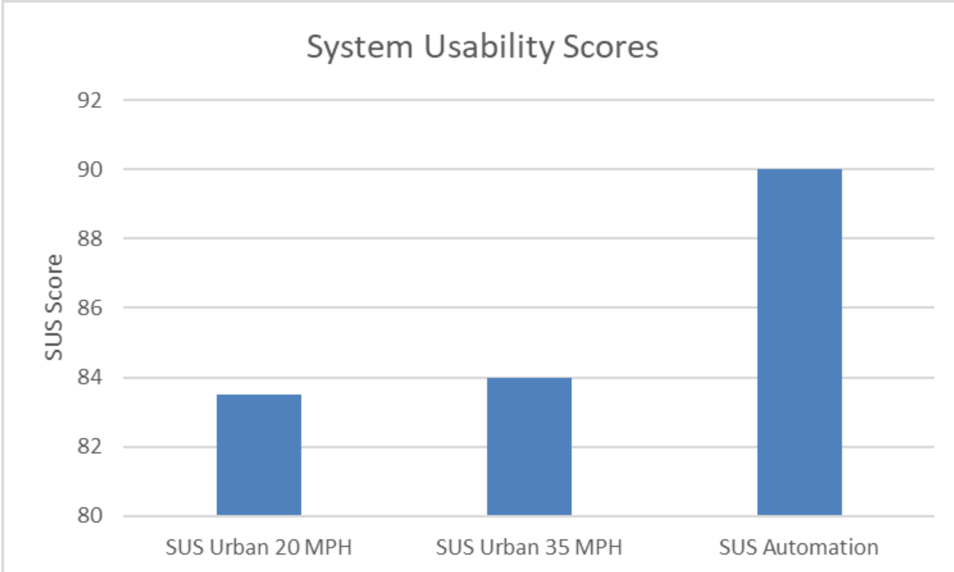

Figure 5.4 Average System Usability Scores for Educational Demonstrations.

5.2 POST-SCENARIO FOLLOW-UP VALIDITY QUESTION RESULTS

Results were calculated from collection of 7-pt Likert-scale responses based on the participants' experiences following the end of each scenario.

5.2.1 Urban Scenario

The scoring of representativeness scores was on a 1-7 scale, with 1 indicating "Not at All" and 7 "Completely". Participants reported high representativeness scores of the simulation scenario to Speeding Experiences (*M* = 6, *SD* = 1.5) and Distraction experiences (*M* = 6, *SD* = 1.55) in real-life generalizability during 35 MPH scenarios, indicating that the educational demonstrations in these scenarios scored highly at an average rating of "Very Much" in terms of their validity, see Figure 5.5. Ratings for the 20 MPH scenarios were slightly lower, with Speed Experiences and Distraction Experiences at "Moderately" representative levels (*M* = 3.8, *SD* =1.47; *M* = 4, *SD* = 1.67). Overall, these scenarios provided acceptable levels of real-world validity to urban driving environments featuring mixed-traffic.

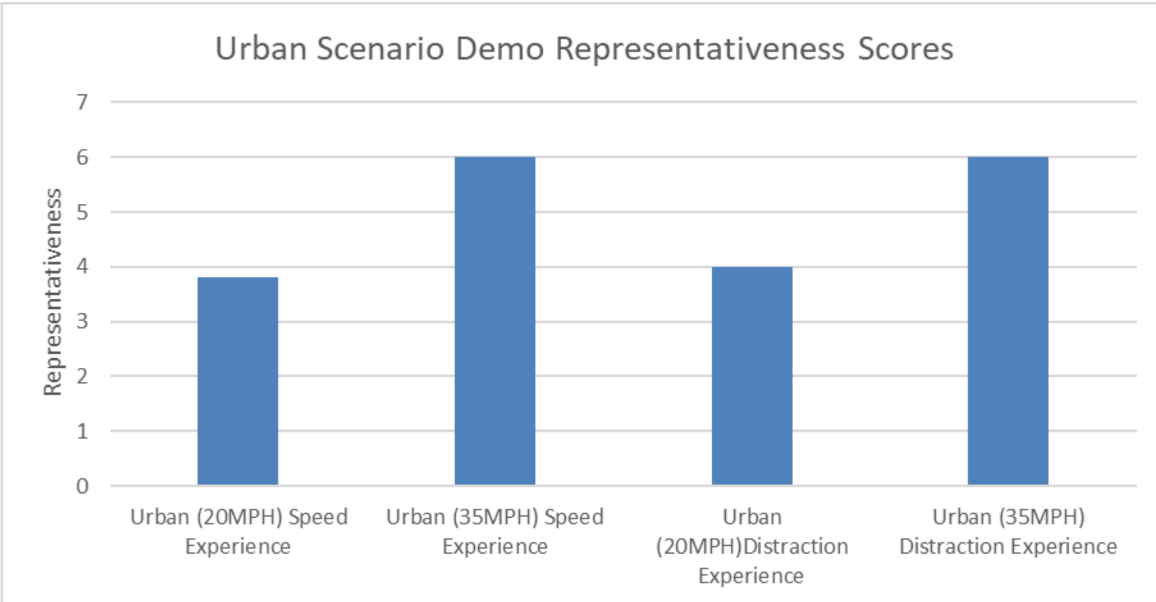

Figure 5.5 Urban Scenario Speeding and Distraction Representativeness Scores.

5.2.2 Rural Highway Scenario

When asked if the rural highway drive while performing the distractor tasks had a realistic impact on their driving performance relative to the real world, participants responded with a mean rating of 6.5 (*SD* = 0.44), which placed their sentiments between "Very Much" and "Completely" realistic. This result suggests the Rural Highway educational demonstration would be useful in future HumanFIRST implementations for target audiences.

5.2.3 Automation Scenario

While the Automation Scenario featured three RSME scoring intervals based on task-specific responses, only one composite SUS score was recorded due to the scale's multidimensional scoring procedure. Additionally, researchers were interested in understanding the participant's experiences with the autonomous features in whole, rather than as segments. Overall, participants reported that the Automation demonstration served as a good model for learning about autonomous vehicle operations and human-computer interface tasks, rating it between "Very Much" and "Completely" (*M* = 6.4, *SD* = 1.2). Researchers interpreted these scores as sufficient evidence the Automation Scenario would be beneficial for learning workshops and simulator capability demonstrations.

5.3 PARTICIPANT FEEDBACK AND EXIT INTERVIEW FINDINGS

5.3.1 Researcher observations of participants' attitudes and comments

Researchers identified commonalities across participants regarding their driving behaviors and attitudes during observations. Comments were solicited for each educational demonstration scenario.

5.3.1.1 Urban Scenario Observations

Researchers found that all participants were surprised when threat vehicles entered the roadway, which typically resulted in collisions due to participants' inabilities to avoid the vehicle. Following the first event that a threat vehicle entered the roadway and presented a safety hazard, participants were observed to be more cautious and employ more visual scanning of the environment in efforts to detect threats. During the 15MPH increase in speed as directed by experimenters (35MPH condition), participants reported driving experiences having more similarities to the real-world city environments and circumstances, which made them feel more at-risk during these drives. Some participants reported the scenario was very similar to Minneapolis or Chicago city driving, citing the abundance of bicyclists and aggressive drivers associated with those regions on the roadway.

All participants thought that the Urban Scenario was an excellent learning tool for young teen drivers with little experience, older drivers that may not experience mixed-traffic interactions in dense city traffic, and any driver unfamiliar with a city roadway that lacks a mental model of expectancy for both vehicle presence and driver behavior in city environments.

5.3.1.2 Rural Highway Scenario Observations

The Rural Highway Scenario afforded researchers with a variety of observational data points and qualitative feedback from participants, as difficulty of the driving and secondary tasks was higher than the Urban and Automation Scenarios, in addition to the fun nature of the secondary tasks: text messaging a parent and browsing social media material was quite unexpected from the participants' point of view when they signed up for the simulation study. Indeed, a wide array of observations, some in the form of gaffes and laughter from the participants were documented. In terms of driver behavior during the driving task, horizontal curves meeting the lowest point of a vertical curve with some rough road conditions was somewhat disorienting for participants, which may have caused them to over-correct steering input or reduce speeds. Some participants misjudged their approach speed at a horizontal curve, causing a slight run-off-road event that was quickly corrected and accompanied by a profanity exclamation. Researchers noticed a pattern of increased willingness to engage in cell-phone use when exiting horizontal curves and driving on straight sections of the road; however, no similar pattern for vertical curves was observed, potentially indicating lower risk perceived with hill features relative to curves on rural highways.

Participants reported that while the texting and driving scenario appeared rather contrived and counterintuitive for a transportation safety educational demonstration, the general opinions were that the scenario could afford teens and middle-aged drivers with an "eye-opening" experience via the diagnostics upon study completion regarding secondary task engagement when driving on rural highways. Specific emphasis was placed on the propensity for lane departures at curves and head-on collisions when interacting with a cell phone while driving, which provided lane keeping performance feedback.

5.3.1.3 Automation Scenario Observations

The first common theme across all participants involves the severity of force and rapidness of the Automation Scenario's lane-changing feature. During this participant-initiated event, researchers observed participants as being rather surprised or shocked at the rate by which the vehicle moved to the adjacent lane. Some participants were hesitant to complete an additional lane-change maneuver using the automation system after experiencing the event.

Additionally, two participants reported having the urge to override the automation during the lane change in order to correct what was perceived as an exaggerated steering maneuver. Three participants kept their hands positioned over the steering wheel during lane changes, as well as during a majority of the simulation. Researchers suspect that these hand-hovering behaviors are indicative of uncertainty with the automation's ability to keep the driver safe, which reflects on their degree of trust with the autonomous driving characteristics in the Automation Scenario. Hand-hovering was commonly exhibited by most participants when the autonomous mode negotiated horizontal curves, especially when the Mississippi River was most proximal to the roadway.

When prompted on the perception of trust with the automation, most participants acknowledged that while they felt no real-world consequences of harm could be realized by the system going off-road, they did feel the automation did make them feel somewhat uncomfortable and, at times, uncertain about how the drive would end in terms of safety in the simulated world. Participants noted that the strong lane-change maneuver did not meet their expectations or mental model of how an autonomous vehicle should perform such a maneuver. However, the overall experience with an autonomous vehicle met their mental model and expectations of how a "self-driving car should act."

Overall, participants expressed their appreciation for the "cool-factors" of the Automation Scenario and were interested in how further developments in both simulation experiences and real-world autonomous vehicle developments could be realized. Some participants stated that one effective way to understand an advanced modern vehicle's safety features before purchasing or driving the vehicle could be to experience the features in a simulator experience using the HumanFIRST Lab. Participants also thought that older drivers and drivers that are hesitant to "hand-over their keys to self-driving cars" could significantly benefit from the Automated Scenario simulation.

CHAPTER 6: IMPLEMENTATION AND FUTURE STEPS

6.1 SIMULATION ITERATIVE DESIGNS BASED ON USABILITY TEST FINDINGS

6.1.1 Current Revisions

The initial HumanFIRST educational demonstration scenarios were revised using feedback and insights gained from the Usability Testing tasks in Chapter 4. General improvements were made to the initial design of the interface, based on the usability feedback. The vehicle chassis was moved forward approximately 1.5 meters to be positioned closer to the projection screen. The modifications to the chassis position improved driver viewpoint of the roadway. In addition, the luminance of the center stack display was reduced for comfortable viewing under ambient, low-luminance conditions.

6.1.1.1 Automation Scenario

Based on feedback from participants and internal discussions, the automated drive was adjusted to include an end-of-route detection capability. Initially, it was assumed the simulation would be ended by experimenters before the end of the simulated route was reached. In practice, it was discovered that experimenters remained engaged with visitors during some tours and demonstrations after the route ended, resulting in the automated vehicle to lose navigation, drive off road, and crash. The scenario was modified to detect end-of-route and bring the vehicle to a stop prior to this point.

6.1.1.2 Urban Scenario

The urban drive initially provided several accident-likely conditions but little diagnostic feedback to the driver. While the driver could see that they had crashed with another car, no information was provided as to the severity. Automated feedback was added to report the severity of impacts to let drivers know how their reactions mitigated the event. Researchers hypothesize that participants will score these scenarios higher in terms of system usability and overall satisfaction and benefits.

6.1.2 Future Simulation Iterative Design Characteristics and Features

6.1.2.1 Driving performance diagnostics on scenario completion

Based on feedback from participants who received driving performance metrics at the conclusion of the Rural Highway scenario, researchers will add a similar set of driving behavior scores to current and future educational demonstration simulations to better inform participants on their performance under driving and secondary task demands. Descriptive statistics describing driving performance such as speed characteristics (e.g., average, standard deviation, and maximum speeds), lateral vehicle control characteristics (e.g., lane position mean, standard deviation, steering angle, and force), and event-related actions such as collision rates and evasive maneuvers will be implemented to simulation scenarios to improve participant experiences. In turn, researchers anticipate increased educational benefits and improved satisfaction with completing the demonstration scenarios, as well as overall quality of experience sentiments after touring the HumanFIRST Lab.

6.1.2.2 Pedestrian traffic

Currently, pedestrians were only staged on sidewalks placed parallel to the simulated lane of travel in the scenario. Based on internal discussion as well as participant feedback gained from the Usability Test task, researchers wish to implement pedestrian traffic into the Urban Scenario to examine a host of research questions related to transportation safety. For example, drivers' visual attention while driving the urban route and performing a secondary task may differ significantly when pedestrians enter the roadway. In addition to understanding visual scanning behaviors while driving in the presence of pedestrians who enter the roadway, researchers can create scenarios that assess drivers' performance metrics in both their inability to detect pedestrians, leading to collisions, as well as their ability to avoid collisions with pedestrians when detected. As pedestrian safety becomes an increasingly ubiquitous area of concern for transportation safety and public stakeholders, incorporating pedestrian activity in the roadway during simulation studies is necessary.

6.1.2.3 Weather factors

Participants suggested that sunny days are excellent examples to use in an educational setting or quick tour but much could be gained by introducing inclement weather such as rain, snow, or poorly lit environments to the simulations. The current simulator scenario sets do not use any of these weather factors, but the simulator affords rain, hail, fog, and the ability to customize friction factors potentially to simulate lowered traction found in snowy or icy conditions. Researchers anticipate vetting the quality of simulation during these weather and lighting changes using the new RTI, Inc. simulation software installed with the new Ford chassis.

6.2 CONCLUSIONS/IMPLEMENTATION

Speeding accounted for 9,717 traffic fatalities in 2017 (NHTSA, 2019) and distraction-related crashes accounted for 3,450 traffic fatalities in 2016 (NHSTA, 2019), while automation shows promise to resolve some of these problems, it has pitfalls of its own concerning hand-offs between the automation and the driver (Hancock, 2019). Using the driving simulator as a powerful educational tool (Backlund et al., 2010), demonstrations of urban, rural, and automated driving scenarios were constructed to highlight these issues with speeding, distraction, and automation to interested stakeholders and the public. Iterative usability testing was employed to measure workload and user-friendliness as well as the overall perception and representativeness of the scenarios. Based on the Usability Test results, which were largely very positive, improvements were made to the scenarios to enhance their educational impact. Future implementations may include pedestrians and inclement weather.

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APPENDIX A
USABILITY TESTING PLAN

Goals

Empirically test and record observations on the educational effectiveness of the immersive simulation demos with representative users.

Participants

Representative user sample: Participants should have enough driving experience, be “naïve” to the demos, and not prone to motion sickness.

Recruitment method: Snowball sampling method.

Tasks

Screening: Ask if participants are prone to motion sickness, exclude if “YES”.

Consent & questionnaires: Participants must provide verbal consent. Participants will report how long they’ve had their driver’s license and how often they drive in a year (Appendix A).

Demo tutorial: One researcher explains within 1-2 minutes the reason for the demos. For **each demo**, explain the demo and what the participant should expect and what driving phenomenon it is intended to illustrate.

Usability test(s): Participants will drive for about 5 to 15 minutes with each demo. Once finished with a demo, one researcher conducts post-test follow-up assessments for that demo, while the other sets up the next demo.

1. **Urban Demo**
2. **Highway Demo**
3. **Rural Demo**

Follow-up questionnaires for each demo: Participants will now fill out post-test forms indicating their mental workload (Appendix B), and system usability scale (SUS, Appendix C).

Follow-up interview: After exposure to all demos, participants will be asked unstructured follow-up questions about their experience while driving with each demo, during which they will be asked to provide their perspective on the usefulness and issues with the demo world, what they liked or disliked, and any suggestions they may have for improvement of build (Appendix D).

Measures

Usability test quantitative measures for each demo

Effectiveness: Relevant scores from the system usability scale (SUS).

Efficiency: Relevant scores from the system usability scale (SUS).

Satisfaction: Relevant scores from the system usability scale (SUS).

Workload: RSME scale scores for each demo.

Usability test qualitative measures

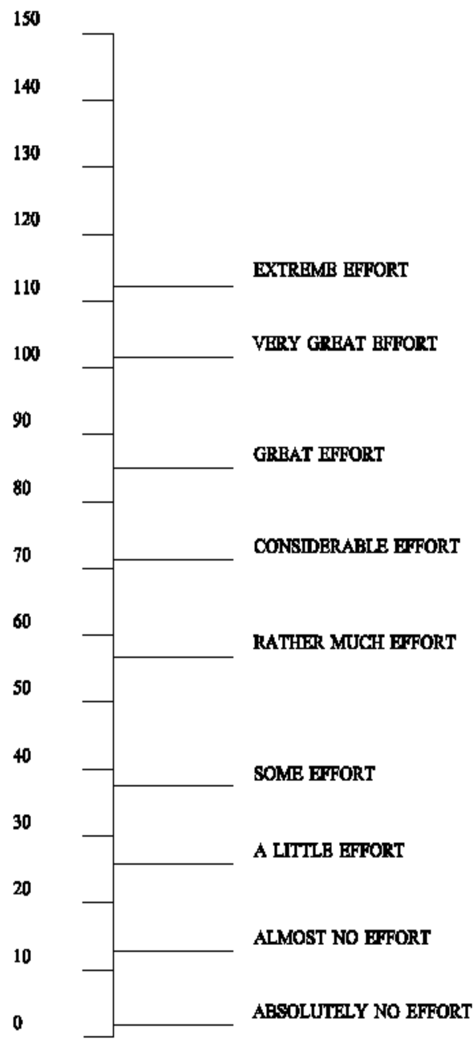
Attitude observations: Researchers note any particular attitude or emotional responses while sitting in each demo and reacting.

Interview responses: Notes for each demo should be taken (Appendix D).

APPENDIX B
MENTAL WORKLOAD SCALE

Rating Scale Mental Effort

Please indicate, by marking the vertical axis below, how much effort it took for you to complete the task you've just finished



APPENDIX C

MODIFIED SCREENING / DEMOGRAPHICS QUESTIONNAIRE

This questionnaire will be administered during the recruitment process to determine eligibility for participation.

1. What is your age?

2. How long have you had your driver's license?
   - EXCLUDE IF NO DRIVERS LICENSE

3. How many miles do you estimate you drive per year?

4. What is your gender?

   ☐ Male

   ☐ Female

   ☐ Self-report:______________________

5. Do you have a history of motion sickness? (e.g., back seat of car, boats, amusement park rides, etc)
   - EXCLUDE IF YES

APPENDIX D
SYSTEM USABILITY SCALE (SUS)

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the System	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

APPENDIX E
INTERVIEW NOTES

1. **Urban Demo- RSME (20MPH) - _______________ RSME (35MPH)- __________________**

Representative of speeding experiences in the real world?

Not at all	Very little	Somewhat	Moderately	Significantly	Very much	Completely
O	O	O	O	O	O	O

Representative of distraction experiences in the real world?

Not at all	Very little	Somewhat	Moderately	Significantly	Very much	Completely
O	O	O	O	O	O	O

Attitude observations by researcher:

Notes/Comments by Participant:

2. **Highway Demo RSME -______________________**

Representative of distraction experiences in the real world?

Not at all	Very little	Somewhat	Moderately	Significantly	Very much	Completely
O	O	O	O	O	O	O

Attitude observations by researcher:

Notes/Comments by Participant:

3. **Rural Demo RSME -______________________**

To what degree was this scenario an informational model of automated vehicles?

Not at all	Very little	Somewhat	Moderately	Significantly	Very much	Completely
O	O	O	O	O	O	O

Attitude observations by researcher:

Notes/Comments by Participant:

APPENDIX F
WELLNESS ASSESSMENT

Participant ____________ Researcher______________ Date_____________

Wellness Assessment Questionnaire

Instructions: Circle how much each symptom below is affecting you right now.

1.	General Discomfort	None	Slight	Moderate	Severe
2.	Fatigue	None	Slight	Moderate	Severe
3.	Headache	None	Slight	Moderate	Severe
4.	Eye strain	None	Slight	Moderate	Severe
5.	Difficulty focusing	None	Slight	Moderate	Severe
6.	Salivation increasing	None	Slight	Moderate	Severe
7.	Sweating	None	Slight	Moderate	Severe
8.	Nausea	None	Slight	Moderate	Severe
9.	Difficulty concentrating	None	Slight	Moderate	Severe
10.	Fullness of the Head	None	Slight	Moderate	Severe
11.	Blurred vision	None	Slight	Moderate	Severe
12.	Dizziness with eyes open	None	Slight	Moderate	Severe
13.	Dizziness with eyes closed	None	Slight	Moderate	Severe
14.	*Vertigo	None	Slight	Moderate	Severe
15.	**Stomach awareness	None	Slight	Moderate	Severe
16.	Burping	None	Slight	Moderate	Severe

*Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.