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Older Driver Support System (ODSS) Usability and Design Investigation

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Final Report

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Technical Report Documentation Page

1. Report No.	2.	3. Recipients Accession No.
CTS 18-01		
4. Title and Subtitle Older Driver Support System (ODSS) Usability and Design Investigation		5. Report Date January 2018
		6.
7. Author(s) Nichole L. Morris, Curtis Craig, David Libby, Jennifer Cooper		8. Performing Organization Report No.
9. Performing Organization Name and Address HumanFIRST Laboratory Department of Mechanical Engineering Roadway Safety Institute University of Minnesota 111 Church St SE, Minneapolis, MN 55455		10. Project/Task/Work Unit No. CTS # 2015054
		11. Contract (C) or Grant (G) No. DTRT13-G-UTC35
12. Sponsoring Organization Name and Address Roadway Safety Institute Center for Transportation Studies University of Minnesota 200 Transportation and Safety Building 511 Washington Ave. SE Minneapolis, MN 55455		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code
15. Supplementary Notes http://www.roadwaysafety.umn.edu/publications/		

16. Abstract (Limit: 250 words)

Older drivers represent a high-risk population on the road, due to age-related declines in cognition and perception. The present research investigated whether an Older Driver Support System (ODSS) smartphone application would be useful. The research presented here was comprised of (1) focus groups, surveys, and interviews, (2) simulated driving with video playback, and (3) on-the-road field-testing. The methodology centered on iterative re-design of the ODSS interface based on feedback and behavior of older drivers. This iterative re-design approach was successful at making the ODSS interface more usable when considering System Usability Scale (SUS) scores. Furthermore, older drivers during the field test reported minimal mental effort expended when using the smartphone application and many significantly positive statements about the application. The field test resulted in several final recommendations for the ODSS application. A promising final takeaway was a universal design approach preferred by the older drivers, as they did not want to be singled out for special attention.

17. Document Analysis/Descriptors		18. Availability Statement	
Driving, Aged drivers, Automobile travel, Safety, Intelligent speed adaptation, Field tests, Mobile applications, High risk drivers		No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312	
19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	74	

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January 2018

Published by:

Roadway Safety Institute
Center for Transportation Studies
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200 Transportation and Safety Building
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Minneapolis, MN 55455

ACKNOWLEDGMENTS

The funding for this project was provided by the United States Department of Transportation's Office of the Assistant Secretary for Research and Technology for the Roadway Safety Institute, the University Transportation Center for USDOT Region 5 under the Moving Ahead for Progress in the 21st Century Act (MAP-21) federal transportation bill passed in 2012.

Special thanks to the research assistants and other research support staff who assisted in this work: Peter Easterlund for simulation programming, Jacob Achtemeier for interview recruiting and data collection, Brady Patzer for simulation study data collection and analyses, and Pooja Bajjuri for focus group transcription and simulation study data collection.

Additional author notes: N.L.M.: Project supervision, overall experimental design, focus group data collection and analyses, interview and simulation analyses, and manuscript writing; C.M.C.: Controlled field test experimental design, data collection, and analyses, and manuscript writing: D.A.L.: Controlled field test data collection, and analyses, and manuscript writing; J.C.: Focus group interview data collection and analyses, interview data collection and analyses, and interim report writing.
The authors report no competing financial interests.

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EXECUTIVE SUMMARY

Older drivers represent a disproportionately high crash risk on our roadways, due to age-related declines in cognition and perception. The present research investigated whether a modification of the Teen Driver Support System (TDSS) smartphone application would be useful for older drivers, as an Older Driver Support System (ODSS). This smartphone application provided information about speed limits and upcoming road features such as curves, along with feedback about risky driving behaviors (e.g., speeding, excessive acceleration, sharp turn taking).

The research presented here was comprised of (1) focus groups, surveys, and interviews, (2) simulated driving with video playback, and (3) controlled field-testing. The methodology centered on an iterative re-design of the TDSS interface based on feedback and behavior of older drivers to create a customized ODSS to meet the needs and preferences of an older driver population. After synthesizing information gathered from the initial interviews, surveys, and focus groups, the design of the interface focused on effectively integrating multiple components of driving-related information, such as the speed limit and wayfinding or navigation. After the simulated tests, the design of the interface shifted toward simplicity and other universal design principles. The finalized design during the controlled field test resulted in an interface that primarily presented speed information with occasional alerts about risky driving behavior. This iterative design approach was successful at making the ODSS interface more usable, with an initial mean System Usability Scale (SUS) rating of 74.75 (average usability) during the simulated test, and a final mean SUS rating of 93.86 (highly usable) during the controlled field test. Furthermore, older drivers after the field test reported minimal mental effort expended when using the smartphone application, as measured through the Rating Scale Mental Effort, and most of the drivers made significantly positive statements about the application and expressed a likelihood of purchasing such a system.

The controlled field test resulted in several *final recommendations* for the ODSS application, now named RoadCoach.

- Ensure that the presented speed information is accurate and routinely updated.
- Give drivers the ability to change the speed warning threshold (within a set range) for personal driving preferences.
- Present different visual icons for braking and acceleration violations so that drivers can differentiate between these warnings.
- Remove application status information (e.g., GPS and Maps functioning) from the primary screen to further simplify the interface.
- Include a tutorial to explain Passenger Mode.

A promising final takeaway was the conclusion that the best approach to take in designing and marketing the driving application was through a universal design approach. This approach uses general design principles and user-testing to improve the experience and user-friendliness of the interface for both the general population and other high-risk populations, such as older drivers. The universal design approach was wholly accepted by older drivers, as they rejected the premise that they should be singled out for special attention more than any other driving group. Further, the design and functionality was perceived as an application that could help them remain independent and safe on the road.

The universal design of the RoadCoach application was modified to include a baseline, data collection only mode. The technology has been readied to expand the research to determine the efficacy of the driving application to reduce risky driving behaviors, such as speeding and hard braking, compared to those observed during baseline data collection periods among a larger group of older drivers in a multi-state field operational test. The results and implications of the upcoming research may help to better understand the types of risky driving prevalent among older drivers and whether real-time feedback can improve driving performance and driver confidence later in life.

LIST OF ABBREVIATIONS

GPS- Global Positioning System

LCD- Liquid Crystal Display

ODSS- Older Driver Support System

RSME- Rating Scale Mental Effort

SD- Standard Deviation

SME- Subject Matter Expert

SUS- System Usability Scale

TDSS- Teen Driver Support System

UFOV- Useful Field of View

CHAPTER 1: INTRODUCTION

This study sought to adapt the functions and interface design of a Teen Driver Support System (TDSS) smartphone application (Creaser et al., 2015) to an Older Driver Support System via consideration of the needs and limitations of the aging driver population. Advanced in-vehicle warning and sensing devices, like the TDSS, are well-positioned to offer tailored support for older drivers to help them safely maintain their driving independence. Reducing fatal crash rates among older drivers is paramount in working toward our goals of zero deaths on our nation's roadways. What follows is a review of older drivers and their capabilities.

1.1 LITERATURE REVIEW

An aging population introduces the need for understanding aging performance and limitations in various environments. This review will first present an overview of a few theoretical frameworks to generally understand aging and human performance (Charness, 2008; Salthouse, 1996), describe specific perceptuo-motor and cognitive characteristics of the aging population and extrapolate these characteristics to possible driving limitations (Smither, Mouloua, Hancock, Duley, Adams, & Latorella, 2004; Mouloua, Smither, Hancock, Duley, Adams, & Latorella, 2004). The review will conclude with an overview of specific research on older drivers.

1.1.1 Aging Frameworks and Age-Related Effects

Charness (2008) introduces several useful frameworks for understanding general cognitive performance across the aged population, including a processing speed framework (Salthouse, 1996), a neural noise framework (Welford, 1981), and two somewhat related frameworks: brain workload (Cabeza, 2002) and cognitive reserve (Stern, 2009). The processing speed theory (Salthouse, 1996) states that the speed of basic mental processes (e.g., perception, computation, reaction time) are slowed with age. This slowing means that older individuals will on average perform less information processing per unit of time, especially for *unfamiliar* tasks. Furthermore, because of this decline in processing speed, the products of this processing are less available for easily making connections or relationships between differing pieces of information, suggesting that managing *complexity* is a challenge for many older individuals. Welford (1981) postulated, using signal detection theory, that older adults had a lower signal-to -noise ratio in their neural functioning, resulting in slowed performance on perception and reaction tasks, as well as disruption in memory. This leads to downstream effects and design implications for memory performance, where older adults perform better if the environment supports their memory recall with *external cues*, effectively boosting the signal that would otherwise be lost in neural noise (Craik, 1986).

The other two related frameworks, brain workload and cognitive reserve, reflect the idea that the brain of older adults often must work "harder" to accomplish tasks relative to younger brains with both brain hemispheres contributing to tasks in older brains that were more lateralized in younger brains (Cabeza, 2002), and that older adults vary in the degree of cognitive reserve or resources available to compensate for age-related decline and more severe conditions (Stern, 2009). Both frameworks are detailed and beyond the scope of this review. The primary takeaway for these frameworks is that performing complex tasks are significantly *more demanding* for older individuals, and that the extent of this increase in mental demand *varies significantly* between older adults, with those high in cognitive reserve able to buffer the effects of age related decline for some time.

Smither et al. (2004) and Mouloua et al. (2004) outline specific changes in perceptuo-motor and cognitive capabilities for older adults and their potential challenges for driving. The specific changes for physical functioning are as follows: less motor response speed, less movement control, less mobility and strength, a decrease in height, slower eye movements, and degraded sensory information in vision and hearing (Smither et al., 2004). The driving related consequences of these motor declines include: less rapid response to driving situations (e.g., using brakes), longer time to initiate and carry out driving maneuvers, less strength to manipulate steering wheel and gauges, changes to the ability to see over the steering wheel and monitor position in traffic, limitations in head mobility to monitor traffic, and slower eye movements to fixate on moving objects (e.g., vehicles). For visual perception, age-related declines occur for visual acuity, contrast sensitivity, motion-in-depth, gaze stability, critical flicker frequency, and absolute thresholds (Smither et al., 2004). Furthermore, older drivers have changes in color vision and increased sensitivity to glare (Smither et al., 2004). These age-related shifts lead to the following concerns for older drivers: inability to see or easily discriminate highway information such as signs, difficulty seeing with low illumination, poor adjustment to glaring light, difficulty processing color-coded information on the road, impaired gap-judgment and propensity to rear-end vehicles, and impaired tracking of objects.

Fiorentino (2008) analyzed performance on visual and cognitive tests and compared it to performance on a test for monitoring the visual environment, particularly important in driving (i.e., useful field of view, UFOV). The study found that performance on cognitive tests, not visual tests, was associated with performance on the UFOV test for both younger and older drivers, suggesting that cognition is particularly relevant for driving. Mouloua et al. (2004) note the following age-related shifts in cognitive ability: decreased reserve capacity, less working memory capacity, diminished complex judgment, diminished spatial ability, less efficient mental rotation skill, diminished divided attention ability, reduced ability to switch attention between tasks and information sources, limited sustained attention ability, declining selective attention, and slowed processing speed. These changes lead to many potentially adverse driving implications, including: reduced ability to handle complex driving situations and environments, less ability to recall and remember driving relevant information (e.g., navigation, speed limits), problems in focusing on several pieces of traffic-relevant information at once and maintaining a mental picture of where other vehicles are in the environment, difficulty in translating information from side mirrors, challenges with long stretches of highway, inability to screen out irrelevant information (e.g., which car to pay attention to), and slower to detect and recognize traffic-relevant stimuli in the driving environment (Mouloua et al., 2004).

1.1.2 Aging and Driving Research

Older drivers represent the second highest injury and fatality rate per 10,000 licensed drivers, next to teen drivers, and are first in fatalities per 100 million miles driven (NHTSA, 2010). This disproportionate fatality risk is linked to normal, age-related declines in information processing (Parasuraman & Nestor, 1991), visual search abilities (Dickerson et al., 2007), and overall fragility (Langford & Koppel, 2006). Risk is also associated with behavioral factors, such as failure to yield and lower seatbelt use (Koppel, Bohensky, Langford, & Tranto, 2011), and estimation errors, such as misjudging the speed of one's own vehicle or other vehicles (Hakamies-Blomqvist, 1993). Hakamies-Blomqvist, Mynttinen, Backman, and Mikkonen (1999) measured use of car controls during normal driving for older and middle-aged drivers, and found that unlike middle-aged drivers, older drivers tended to use less than four controls during complex driving scenarios, suggesting a shift to less cognitively complex movements in later ages.

Older drivers are at increased crash risk at intersections. As drivers age, they are more likely to be in a right-angle collision at an intersection crossing (Cooper, 1990) and these crashes make up 55% of older driver multi-vehicle collisions (Hakamies-Blomqvist, 1993). Collisions at intersections are more likely to occur when the older driver is engaging in a left turn rather than a right turn (Keskinene, Ota, & Katila, 1998). Older drivers tend to require more time to decide when a turn is appropriate and tend to require more time to complete a turn (Keskinene et al., 1998). This increased time is likely due to their slower and more frequent fixations in time-limited situations, such as completing a left turn against on-coming traffic, that tend to lead to misjudgments of vehicle speeds and distances (Ho, Scialfa, Caird, & Graw, 2001) as well as psychomotor slowing (Hakamies-Blomqvist, 1994). Older adults have also been found to have very high cognitive load when approaching or driving through an intersection (Keskinene, Ota, & Katila, 1998). A custom-designed driver support system could help to reduce cognitive load for older drivers when entering an intersection by notifying drivers that they are approaching an intersection by type (i.e., 4-way stop, traffic controlled, etc.) to improve expectancies and decrease workload. This reduction may allow more efficient fixations and faster decision making when engaging in a turn.

Merging into traffic also tends to be a high crash-risk situation for older drivers. Due to age-related declines in visual search, older drivers have difficulty detecting other vehicles that appear in their peripheral vision and are often surprised by other vehicles when merging into traffic (Kline, Kline, Fozard, Schieber, & Sekuler, 1992). This is another driving scenario that could feasibly be assisted through a support system that could prepare older drivers with what actions are needed when a merge is imminent.

Environmental factors such as time of day or weather tend to be rarely connected to older driver fatal crashes. Older drivers have fewer nighttime crashes and inclement weather crashes (Hakamies-Blomqvist, 1994). This is likely due to the fact that older adults avoid difficult driving situations, such as nighttime or poor weather condition driving. Furthermore, there has been no difference found between older and younger driver crashes relating to the purpose of trip (Hakamies-Blomqvist, 1994). Older drivers, however, are more likely to be severely injured in dark or unlit areas than younger drivers (Khattack et al., 2002).

Low vision is a common contributing factor to older drivers' high crash risk. Speed and distance become more difficult to judge (Langford & Koppel, 2006). Older adults tend to be slower to recognize traffic, are more likely to misidentify or miss altogether traffic signs (Ho et al., 2001), and their problems reading signs are related to low vision issues (Klein et al., 1992). Failing to detect a posted sign could result in issues ranging from missing a turn or exit to missing a posted reduction in the speed limit. The first may result in a minor hassle for the driver and the latter could result in a catastrophic error leading to crash. Older drivers also appear to avoid driving at night due to deteriorating vision (Langford & Koppel, 2006). An ODSS could help drivers to recognize important signs, such as major roadways and speed changes, through auditory warnings.

Such a system may also aid in navigation and way-finding on the road. The quality of decisions made by older drivers is equivalent to those of younger drivers, but the speed at which those decisions are made vary as a function of age, with older drivers taking longer (Walker, Fain, Fisk, & McGuire, 1997). On the road, decision-making time may be limited, and a system such as the ODSS, while not specifically a way-finding system, may significantly reduce monitoring and scanning time for speed and speeding related information, freeing up mental resources for a decision-making task related to navigation. A related note is that older drivers are more prone to fatigue and may get tired on long journeys (Langford & Koppel, 2006), and a system like the ODSS that takes over some of the mental requirements of the driving task may be beneficial for longer or unfamiliar routes that older drivers find challenging (Burns, 1999).

Given both general behavioral research and concrete driving research have demonstrated problematic issues with older drivers on the road, addressing these issues has become a focus of technological intervention (Ball 2006). Ball (2006) notes that technology can assist the needs of aging drivers through improvements in driving assessment (e.g. UFOV test) and rehabilitation (i.e., vision, education, and cognition). The ODSS reflects both such advancements for in-vehicle technologies and highway enhancements as it utilizes vehicle location information and mapping services to provide both immediate and predictive information to the drivers for support.

Finally, the use of technologies to provide driving feedback have been shown to be particularly helpful for older adults, suggesting that the ODSS has the potential to positively affect driving behavior outside of the immediate driving situation (Ackerman, Crowe, Vance, Wadley, Owsley, & Ball, 2011). Older drivers were scored on the UFOV test and given feedback on whether their scores qualified them for an insurance discount. Their feedback was found to be related to their avoidance of difficult driving conditions, with those not receiving the discount due to poor UFOV scores being less likely to drive in more dangerous driving scenarios (Ackerman et al., 2011). This suggests that the ODSS can provide relevant feedback about questionable driving behavior, and older drivers can use this information to help inform appropriate driving strategies and moderate their involvement in dangerous driving environments.

1.1.3 The Present Research

The present study tests whether the function of a Teen Driver Support System (TDSS) generalizes to an older population with unique limitations and capabilities, as an Older Driver Support System (ODSS). The TDSS provided real-time and continuous monitoring of known driving risk variables, such as speeding and vehicle maneuvers (Creaser et al., 2015). If the Older Driver Support System (ODSS) proves effective and usable for older drivers, it could prove to be a significant technological aid for road safety while helping older drivers maintain driving independence and mobility in their later years.

The research study uses a mixed methods approach (Creswell & Clark, 2007; Creswell, 2013) by building on previous work and information collected through the HumanFIRST laboratory's previous studies (i.e., Safe Teen Car and the Teen Driver Support System) through sequential activities to collect both qualitative and quantitative data to enhance and modify the TDSS into an ODSS. The two main purposes of this approach were to first, complement the work of the previous TDSS (Creaser et al., 2014) and Safe Teen Car (Manser, et. al, 2013) projects, and second, to develop the technology through a deliberate research structure by which each step informs the next (Greene, Caracelli, & Graham, 1989).

CHAPTER 2: FOCUS GROUPS & INTERFACE DISPLAY SURVEY

2.1 FOCUS GROUPS AND INTERVIEW SESSIONS

The first task of this study involved designing multiple icons for each warning and alert that researchers planned to use for the interface. The initial framework for driving alerts and warnings was adapted from the Teen Driver Support System (TDSS), developed in 2012 by HumanFIRST and ClowdLab. The team from HumanFIRST eliminated icons which were not relevant for older drivers (e.g.., seatbelt warning from a separate sensor) and added new information not previously used in the TDSS (e.g., driving under speed limit notification). Some warnings or alerts discussed extended beyond the current capabilities of the TDSS application, but were not outside the realm of what is possible for the software if better integrated into other systems or databases. Two categories of alerts emerged as necessities in the system. The following list describes the two categories and presents which items are included in each.

Maintenance alerts:

- Check mirrors
- Seatbelt reminder
- Speed Limit Reminder

Contextual Warnings:

- Exceeding speed limit
- Driving below speed limit
- Aggressive driving maneuver
  - Braking
  - Steering
  - Turning
- Prepare to merge
- Sharp curve ahead
- Upcoming change in Speed Limit

Older drivers (age 65-85) were recruited to participate in focus groups and one-on-one interviews to discuss the system and to identify their preferences among the multiple icons. By soliciting feedback through focus groups and one-on-one interviews, researchers were able to understand the typical older driver's perception of an in-vehicle smartphone application. Feedback on icons were tallied across all participants (i.e., tech-savvy and non-tech-savvy focus groups, interviews) and presented in Tables 2.1 and 2.2. Qualitative data related to concerns expressed by participants were analyzed separately by group membership and research setting. Additionally, one subject matter expert (SME) on aging was interviewed to assist in shaping the system adequately using feedback from an unbiased expert.

2.1.1 Older Driver Focus Groups

Two focus groups of technologically savvy older drivers (ages 65-85) were recruited to provide feedback on the icons and alerts. They were contacted via participant contact lists from both the research laboratory and an online recruitment site, ResearchMatch.com. Participants were surveyed to determine if they met eligibility requirements (i.e., had a current driver's license, were age 65 or older, and owned a smartphone, mobile navigation device, or tablet pc). These participants were operationally defined as "technologically savvy". In total, eight participants (ages 65-79) were involved in both focus groups (10 scheduled and 2 no-shows). Participants were asked exploratory and probing questions about potentially challenging aspects of their driving experience and were asked to provide feedback on the icons and warnings that were being considered for the application.

In addition to the received responses from interested participants who met the "technologically savvy" eligibility requirements, a number of older adults inquired to participate who did not own a smartphone, navigation device, or tablet PC. The high response rate of the operationally defined "non-tech-savvy" older drivers presented an opportunity to examine how they may respond to the technology given their lack of engagement in mobile technologies. To understand potential differences in opinion between tech-savvy older and non-tech-savvy older drivers, a third focus group was conducted with a sample of five older adults who had no previous experience using smart devices (e.g., smartphone, mobile navigation, or tablet). Older adults tend to have lower usage rates and adoption of newer technologies so it was important to take into consideration the significant proportion of older drivers who never or rarely interact with smartphones and similar technologies. The non-technology savvy group consisted of five participants (ages 65-85). This group helped to provide ideas for designing and marketing an application that may entice non-smartphone users to purchase and download a driving assistive application.

2.1.2 One-on-One Older Driver Interviews

Five one-on-one interviews were conducted with older drivers who were categorized as being technologically savvy. The interviews took place in a private room where participants were given more specific questions about their driving behaviors and aspects of their road experience that could be changed for the better with technology. Feedback was solicited regarding the icons and alert messages which were under consideration for use in the application. Interviewees were shown paper prototypes with mock-ups of all potential icons and warnings, including the phrasing to be used for voice notifications.

2.1.3 Subject Matter Expert Interview

A gerontologist from the University of Minnesota was interviewed to provide a deeper understanding of potential issues that had not been considered. The Subject Matter Expert (SME) was knowledgeable in geriatric cognition and perception, as well as having interest in preventing cognitive decline in older adults. The recommendations given during the interview is as follows:

- Ranking curves by degree of sharpness will help older drivers better understand the risk
- Defining specific units and parameters around alerts will help older drivers with context (e.g., "In 5 miles, Reduce Speed")
- Programming context-specific alerts will be optimal (e.g., only alert for check mirrors when the driver is changing lanes)
- Be sure to only introduce one icon at a time rather than layering multiple alerts at once or immediately back-to-back (e.g., be sure to space alerts out)
- As people age, all color is yellowed, be sure to account for color blindness
- Include a pictorial representation of "too slow" condition (i.e., turtle icon) to reinforce the warning

2.1.4 Focus Group and Interview Results

Upon transcription of the interviews and focus groups, multiple features emerged for the list of the older driver preferences, wants, and desires. Transcripts were reduced and counts were taken of mentions of key features, safety topics, or otherwise applicable elements. Table 2.1 describes the results and the number of participants interested in each feature. The response rate includes those who mentioned the feature during an interview or focus group as well as those who agreed with fellow members of their focus group on that particular feature. Lack of response does not necessarily mean that a participant disagreed with the feature, instead they may have remained silent or agreed without expressing their view. Overall, three themes emerged that the majority of users indicated that they would like to see integrated into the application. The first was information associated with the users getting to their destination (e.g., exit information, integration of navigation into the application, context-aware alerts, traffic alerts). Second, there was a desire for real-time speed readouts, which included warnings about speeding violations. Third, participants wanted notifications geared toward accident avoidance (e.g., lane departure warning, tailgating warning, bicycle warnings, blind spot check, and connected vehicles warnings). Besides these application features, issues related to speed were the most prominent feature discussed by participants, as maintaining a desired speed often led drivers to feel stressed during heavy traffic or complicated driving scenarios.

Table 2.1. Common themes that users indicated would be ideal for the application to have.

Application Features (Themes)	Response Rate
Real-time speed readout	8
Integration of navigation into application	8
Context-aware alerts (when in unfamiliar areas)	6
Exit information	5
Bicycle warnings	5

Connected Vehicles	4
Traffic alerts (e.g., collision, jam, incident)	4
Additional Signage	3
Lane Departure Warning (Curve Ahead Warning)	3
Tailgating Warning (aimed at follow vehicle)	3
Weather alerts	3
Blind spot check	3

Table 2.2- Table 2.8 presents the different categories of icons and options within each category (e.g., icons, colors, contrast, etc.) that participants were shown and asked for feedback on. For each icon(s), participants were asked if they **liked** or **disliked** the icon(s). They were also asked to deduce what message the icon(s) were intending to convey to drivers. Table 2.2 - Table 2.8 also list general sentiments from participants anytime most of the group felt a certain way about the icon or something related to it.

Table 2.2. Speed Limit Visual Feedback

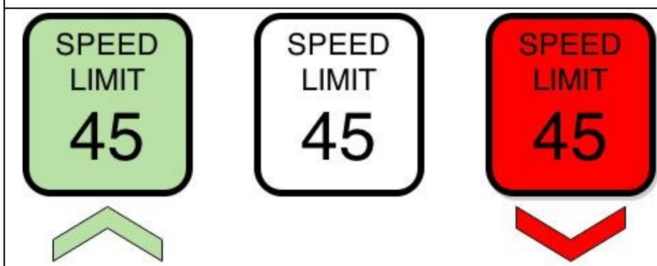
Speed Icon Options (3)	Results	Comments
	Like – 1 Dislike – 4	Green was not agreed upon as a sign of "too slow"
	Like – 5 Dislike – 4	
	Like – 3 Dislike – 4	Chevrons were not well-received

Table 2.3. Speed Limit Change Visual Feedback

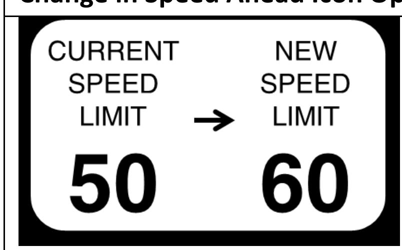
Change in Speed Ahead Icon Options (2)	Results	Comments
	Like – 8 Dislike – 4	Terms Current and New create some confusion
	Like – 1 Dislike – 5	Too vague

Table 2.4. Seat Belt Reminder Visual Feedback

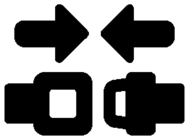
Seat Belt Reminder Icon Options (3)	Results	Comments
	Dislike – 4	Too vague
	Like – 8 Dislike – 2	Red on black is difficult to see
	Like – 5 Dislike – 1	

Table 2.5. Aggressive Driver Warning Visual Feedback

Aggressive Driving Maneuver Icon Options (3)	Results	Comments
	Dislike – 10	Too vague
	Dislike – 5	Better, but still vague
	Dislike – 5	Looks like slippery when wet

Table 2.6. Advance Sundown Notification Visual Feedback

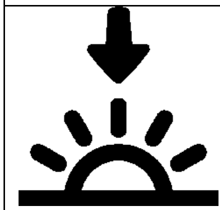
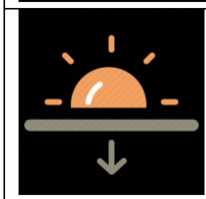
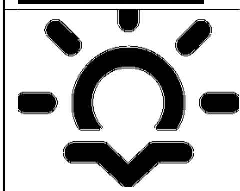
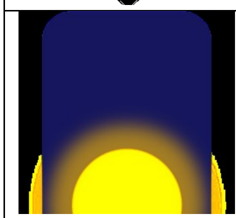
Sunset Icon Options (4)	Results	Comments
		No need for sunset warning at all
	Like – 4	
	Dislike – 2	
	Like – 3	Looks tranquil and sleepy (no indication of whether this was good or bad)

Table 2.7. Advanced Merging Notification Visual Feedback

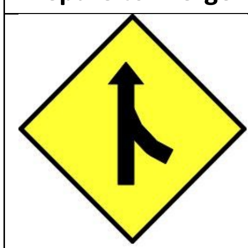
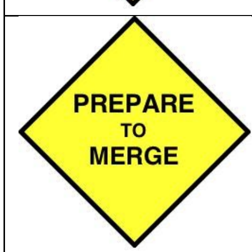
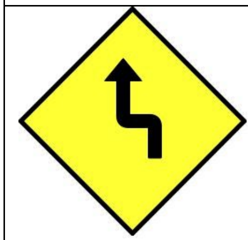
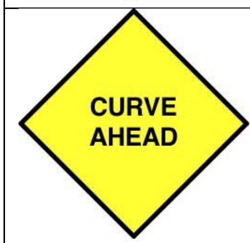
Prepare to Merge Icon Options (2)	Results	Comments
	Dislike – 5	Unclear of meaning without auditory message
	Like – 5	Simple and recognizable

Table 2.8. Advanced Curve Notification Visual Feedback

Advanced Curve Notification Icon Options (2)	Results	Comments
	Dislike – 3	Unclear of meaning
	Like – 3	Simple and recognizable

Outside of the specifications of features and functions of the application, a number of concerns about the safety of the application were mentioned during the focus groups and interviews. Table 2.9 describes the expressed concerns of participants from the sessions. The main concerns that arose were related to privacy of the data collected by the application, driver distraction, and the application coming off as “naggy,” meaning they did not want to feel annoyed by the application’s notifications.

Table 2.9. Safety concerns users had about using the RoadCoach while driving

Concerns	Non-Tech-Savvy Responses	Tech-Savvy Responses
Block calls/texts features	1	2
Customization opportunities		3
Auditory alerts that are annoying		2
Privacy	1	3

Both the focus group and the one-on-one interviews involved a long list of potential auditory messages for various warnings or notifications. Most of the options did not result in absolute likes or dislikes, but rather ended with discussions about the circumstances surrounding the potential use of each message. The most prevalent theme that came from the focus groups was that drivers did not want a system that came across as “bossy” or “naggy” when giving feedback about their driving as they felt this may lead them to get annoyed at the system and ignore it.

When designing an interface, it is important to understand the user from a holistic perspective. Feelings and emotions are key to uncovering the optimal system that will help achieve the goal of better driving performance. Table 2.10 lists the feelings and emotions that focus group and interview participants often experience when driving. These feelings were most often a result of errors or feelings of being overwhelmed during driving. The fact that getting overwhelmed elicited such negative feelings from drivers indicates that an application that helps monitor the driving environment may be of great value to these users in alleviating some of the stress that comes along with many types of driving scenarios.

Table 2.10. Emotions that drivers indicated they commonly experienced when driving

Feelings about Driving (Themes)	No. Responses
Stupid/Dumb	4
Frustrated	6
Afraid	2
Confused	5

Aside from discussing individual aspects of the application, researchers also queried participants regarding potential names for the system. It was important to the researchers to choose a name for the application that would be met with acceptance by older adults and convey its purpose and functions. During the focus groups and interviews participants were asked about their preferences for names, in addition to which words they felt should be left out. The most overwhelming response that participants had was that they would appreciate an application that is catered to *all* drivers rather than the senior population only. Drivers were very explicit that they did not like the idea of including the word "aging" in the title or any words synonymous with aging (e.g., senior, seasoned, older, etc.). The most favorable naming choice at the time of the focus groups was "Driver Support System."

Finally, the TDSS had a feature that allowed the application to automatically send a text message to the teen driver's parents or legal guardians when a risky driving maneuver (i.e., speeding, running a stop sign). This allowed parents to have real-time feedback and detailed information about when and where risky driving events occurred. This feature was discussed with the older drivers as something that could be adapted to be shared with other secondary parties for whom their driving safety or risks would be a concern. Participants were nearly unanimously opposed to sharing this information with their adult children. Some reported an openness to share with a physician, but more commonly limited a close, trusted friend as the only recipient they whom they would feel comfortable sharing their driving performance.

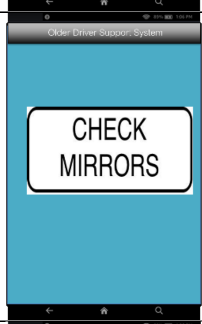
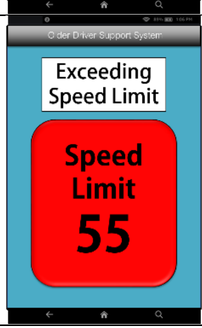
2.2 INTERFACE DISPLAY SURVEY

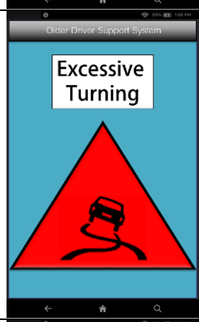
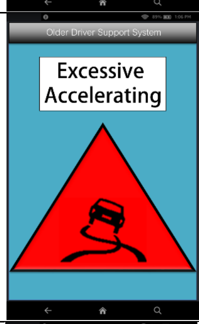
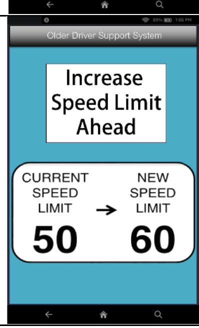
The results of the first task were used to inform the Interface Display Survey, completed in Task 2. The icons that were unpopular, based on feedback from focus groups and one-on-one interviews, were removed from the potential interface. Additionally, direct feedback from the SME interview was used to determine a path for providing adequate information to users without overloading them cognitively.

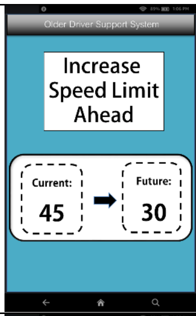
Seven participants (age 65-85) were brought in for one-on-one interviews regarding their preferences for the latest iteration of icon designs and potential corresponding audio messages. Users were shown images for all the different warnings that the ODSS system would potentially use along with either two or three possible auditory messages that would go along with the images and asked to select which auditory message they preferred most. The images were shown on an iPad tablet. Table 2.11 shows the images that were used for the interface in the display survey as well as the possible auditory messages with the number of users who preferred each message.

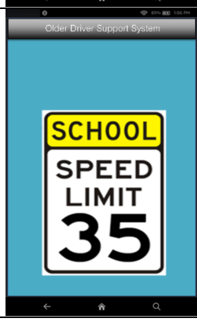
The results of the interface design survey informed the next iteration of design changes. The next phase of research would be to test the interface under a simulated driving scenario to see how users felt about the interface during more realistic road use.

Table 2.11. User preferences for auditory messages and their corresponding images

Visual Information	Auditory Information & Number of Users Who Preferred it
	1. “Buckle seat belt” = **4** 2. “Reminder: Buckle seat belt” = **3**
	1. “Check mirrors” - **5** 2. “Reminder: check mirrors” - **2**
	1. “Slow down, exceeding speed limit” - **1** 2. “Slow down” - **2** 3. “Warning: Exceeding speed limit” - **4**

	1. “Warning: Excessive braking detected” - **2** 2. “Aggressive braking detected” - **5**
	1. “Warning: Excessive steering detected” - **2** 2. “Aggressive steering detected” - **5** 3. “Warning: Dangerous steering maneuver” - **0**
	1. “Warning: Excessive turning detected” - **2** 2. “Aggressive turning detected” - **5** 3. “Warning: Dangerous turning maneuver” - **0**
	1. “Warning: Excessive acceleration detected” - **2** 2. “Aggressive acceleration detected” - **5**
	1. “Increased speed limit ahead” - **3** 2. “Speed limit increase in 1 mile” - **0** 3. “Approaching new speed limit, (pause) 60 miles per hour, (pause) 1 mile” - **4**

	1. “Reduced speed limit ahead” - **3** 2. “Speed limit reduction in 1 mile” - **0** “Approaching new speed limit, (pause) 30 miles per hour, (pause) 1 mile” - **4**
	1. “Caution: Merge ahead” -**2** 2. “Prepare to merge” - **5** 3. “Merge ahead, (pause) increase speed to traffic flow” - **0**
	1. “High traffic density ahead” - **0** 2. “Slow traffic ahead” - **2** 3. “Congestion ahead” - **5**
	1. “Caution: sharp curve ahead” - **4** 2. “Curve ahead (pause) reduce speed” - **3**
	1. “Warning: Stop sign violation” - **2** 2. “Failure to make complete stop” - **2** 3. “Stop sign violation detected” - **3**

	1. "Entering work zone, (pause) reduce speed" - **3** 2. "Approaching work zone, (pause) 40 miles per hour, (pause) 1 mile" - **4**
	1. "Entering school zone, (pause) reduce speed" - **2** 2. "Approaching school zone, (pause) 35 miles per hour, (pause) 1 mile" - **5**

2.3 CONCLUSIONS AND IMPLICATIONS

The combined results of the interface display survey, as well as the preceding focus groups and interviews, suggested that far more information and context should be provided with each alert or notification to meet the needs and preferences of older drivers compared to the system which was designed for novice, teen drivers. While the contextual information concerns are valid, the previous literature regarding the mental workload and cognitive declines of older drivers (e.g., Mouloua et al., 2004) would suggest that an even more simplified system would be best to provide support to older drivers. In the pursuit of creating a user-centric system, however, the feedback and preferences were taken seriously as viable options for the re-design of the TDSS to create a highly usable ODSS. The recommendations and icons and messages with the greatest preferences among study participants were integrated into a simulated version of the application to test whether their preferences would remain consistent when observing the icons and messages in a more immersive driving context rather than in a hypothetical discussion.

CHAPTER 3: SIMULATION TEST

3.1 OVERVIEW

The research team conducted a driving simulation study is to assess older drivers' (age 65-85) perception and acceptance of the in-vehicle interface (ODSS) created through an iterative design process to assist them while driving. The focus groups and interviews determined the needs and priorities of older drivers, the results of which informed the design of the interface used in the simulation study. The main goal of the Older Driver Support System (ODSS) was to provide a simple, non-distracting interface that has high user acceptance and easy-to-understand icons and alerts. The simulation study extended this goal by giving older drivers the experience of how the ODSS interface looks and feels while driving in a vehicle. To provide a controlled and safe experience, participants did not drive a vehicle, but instead were seated in the driver's seat of an immersive driving simulator while the vehicle drove itself in an automated vehicle mode.

3.2 METHOD

Ten older drivers, with an average age of 69.80 years (*SD* = 3.99) and a range from 55 to 80 years participated in this study. Seven participants were female and three were male. The research design was a within-subjects mixed-method approach (observational and descriptive). Observations were recorded by the researcher during each participant's driving session. The simulated driving world contained a variety of roadways (two-lane county highways and four-lane divided state highways) recreated from a real route in Minnesota. The simulator's vehicle was programmed to operate in an automated driving mode so that it each participant would be exposed to the exact same warnings and alerts based on the pre-programmed way in which the vehicle was commanded. For example, the vehicle drove over the speed limit, ran stop signs, and braked excessively in the same locations for each participant, which triggered specific warnings/icons on the interface. While participants were able to place their hands on the steering wheel or feet on the brake or accelerator pedals if it was comfortable for them to do so, they could not take over control of the vehicle or change its speed or trajectory in any way. A brief post-drive questionnaire recorded user preference along with general perceptions and opinions about the interface design.

Recruitment involved a pre-screening questionnaire for participants who had expressed interest in the study. Upon entering the lab for the study, participants were presented with the informed consent process; once consent was given, participants' visual acuity and color vision was tested. The study goals and the features of the older driver support system interface were explained by the researcher prior to the start of the simulation video. Participants completed a driving history questionnaire, which contained basic demographic and driving-related questions. The researcher explained that the participant will not be in control of driving the simulator at any point, but instead will be seated while they observe the simulated world on the screens around them as the automated vehicle drove through it, during which the interface would present various notifications/icon/warnings.

Once the participant had expressed that they are prepared to begin the simulation part of the study, the researcher instructed them to sit in the simulator and adjust the seat to their comfort. The driving sessions were performed using a 2002 Saturn SC2 complete chassis driving simulator furnished by Realtime Technologies, Inc. (see Figure 3.1). Participants were instructed to turn their head and look upstream onto any new roadway in which the simulated vehicle was maneuvering a 90 degree turn onto, in order to reduce the effects of "visual wash" and simulation sickness. The researcher then began the simulation of the driving route, synchronized with the alerts and warnings that are displayed on the interface docked in the vehicle. Participants were reminded to "look into the turn" just before the vehicle executed each turn during the simulated drive. The time spent in the simulator was approximately 20 minutes.

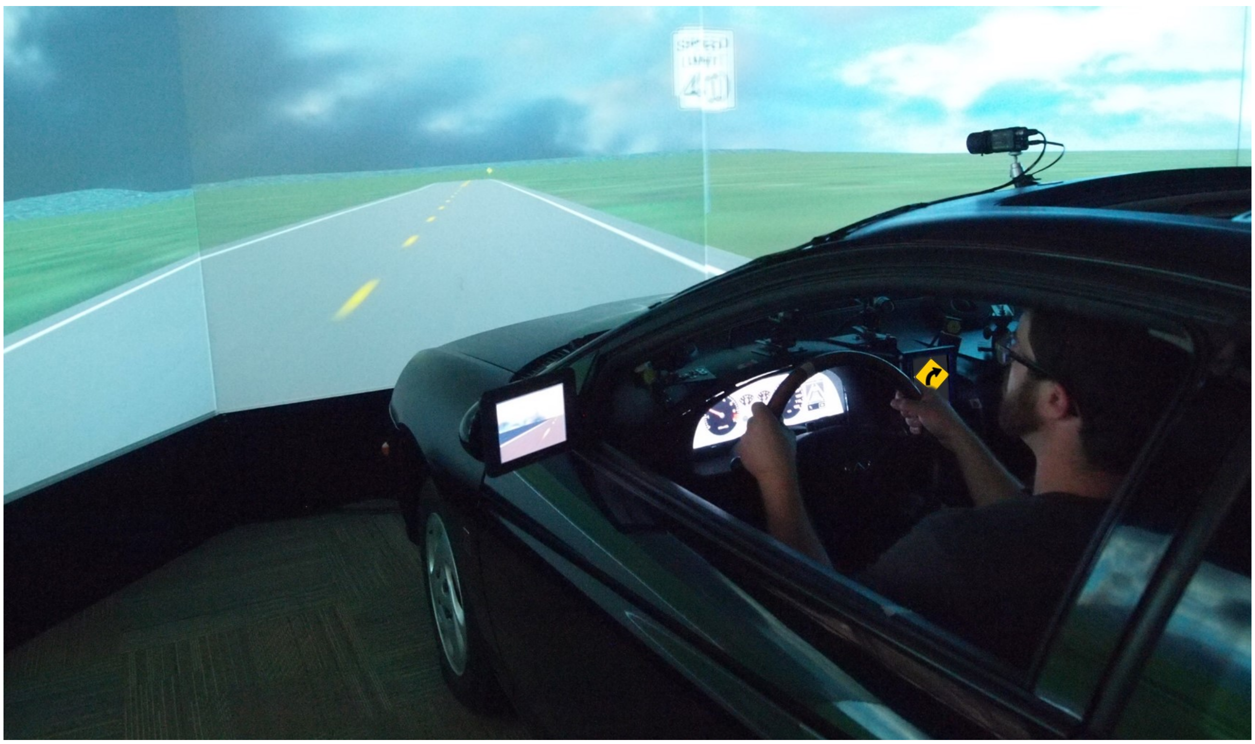


Figure 3.1. HumanFIRST Immersive Driving Simulator with curve warning icon

Upon completing the simulation part of the study, the participant was led to a desk where they answered questions about their mental workload, technology and usability preferences, and a wellness assessment to ensure they were not experiencing effects of simulation sickness. No participants reported symptoms of simulation sickness upon the completion of the drive. The duration of the study, beginning to end, was an hour.

3.2.1 Simulated Autonomous Driving Route and Scenarios

A 24-mile long route was identified southwest of the Minneapolis-St. Paul, MN metro that incorporates expressway, rural and local roads to accomplish the goals of testing the ODSS alerts, notifications, and warnings (see Figure 3.1). This route was chosen because it included the types of zones that were of interest for this study. The driving route took about 25 minutes to complete and was driven in a clockwise direction (see Figure 3.2). The drive included segments of two-lane rural driving, town driving, and freeway driving. The simulation was designed to be automated so drivers were not responsible for any maneuvering to allow them to evaluate the messages from the interface. Notifications and alerts were displayed to drivers on an LCD screen, presenting an image of an Android cellular phone, that was mounted to the center console of the vehicle within the driver's view. Oncoming traffic was presented in the simulation to that represented light traffic flow. Scenario features, such as road striping, buildings, trees, grass and hills were incorporated into the drive to approximate the environmental landscape of the real-world route.

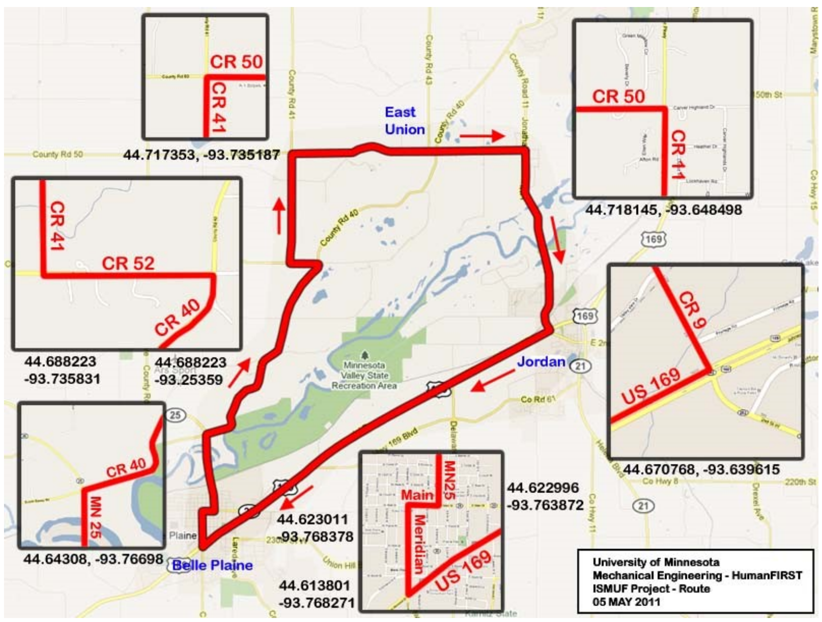
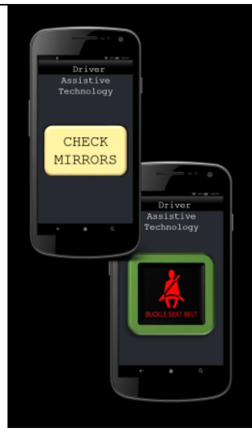
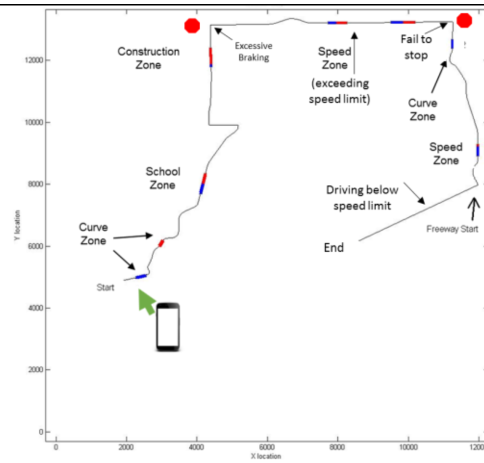
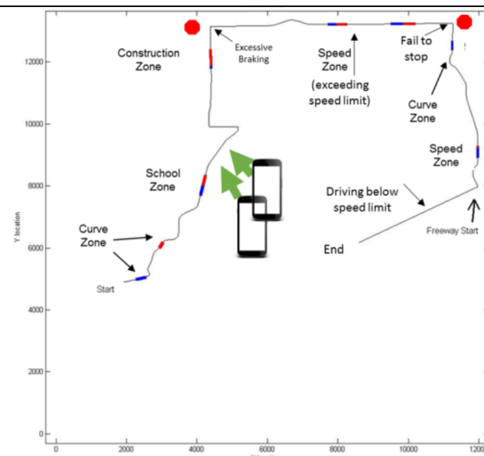


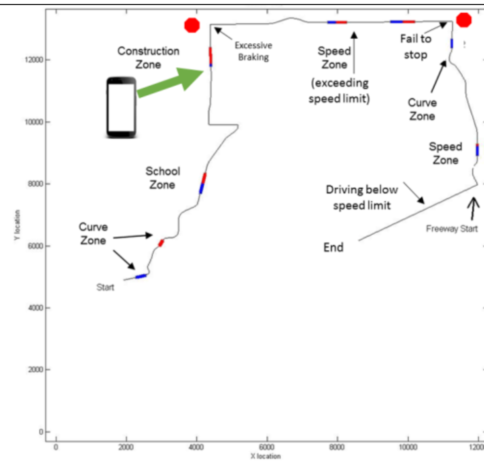
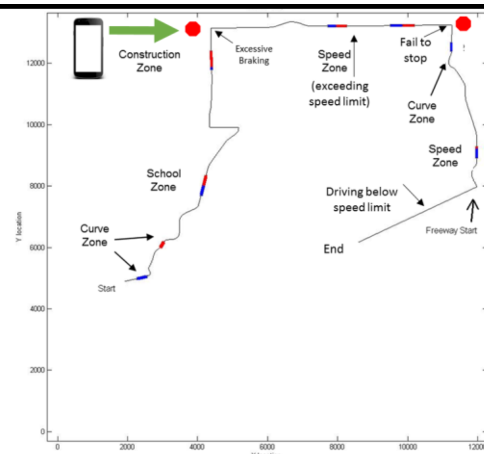
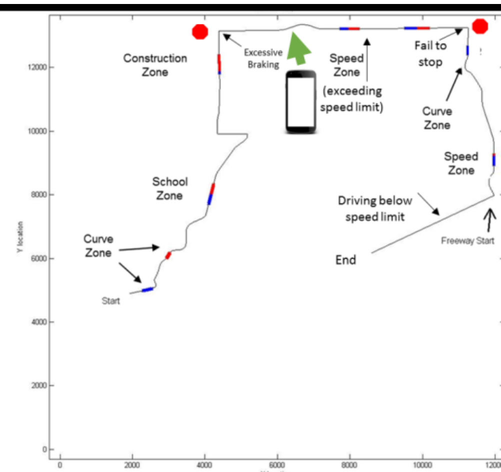
Figure 3.2. Driving route utilized in the automated driving simulated world

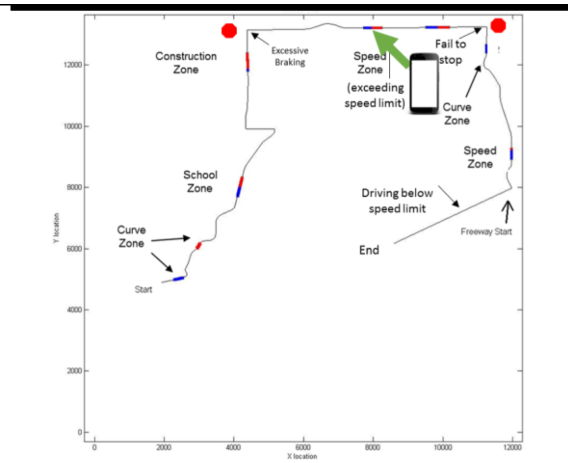
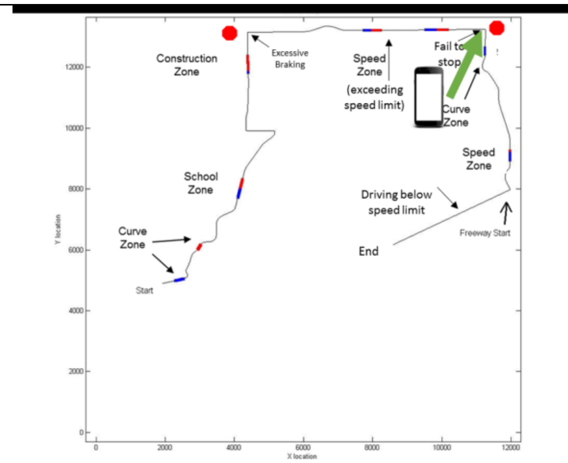
The route incorporated multiple speed changes, two curve warnings, one school zone, and one construction zone throughout the scenario. The ODSS notifications were intended to assist drivers with adopting the appropriate driving behaviors when they experienced a new scenario. The curves, school, and construction zones each had sub-zones that included an advance notification zone and the actual zone of interest (see Table 3.1). In addition to structural scenarios, the system was set up to present various behavior-related warnings to drivers. Excessively high and low speed, aggressive braking, and failure to stop were all built in to the system. ODSS information was presented using visual and auditory cues.

The interface was tested to determine how well the basic posted speed limit interface, particularly when participants are traveling at or under the speed limit, could be integrated with the use of turn-by-turn navigation, such as Google Maps. The white speed limit sign was superimposed over the navigation screen in the bottom right corner of the screen (see Table 3.1). Any alert or warning icon would expand the interface from the bottom corner and take over the entire screen, blocking out the navigation image. Once the alert or notification was completed, it would resume to the smaller, superimposed, white speed limit sign. There were approximately 17 discreet vehicle behaviors or road conditions by which participants were exposed to a change in the interface icon and presented an audio message.

Table 3.1. Examples of sequence of vehicle behavior or road condition events with corresponding warnings/notifications and placement within simulated world.

Vehicle Behavior	Interface Display (or display series)	Audio Message	Map Placement
Initiating Drive		"Reminder: Buckle Seat Belt" "Reminder: Check mirrors"	
Traveling at 55 MPH, then traveling under 55 MPH		n/a	

Approaching Construction Zone with Reduced Speed		“Work Zone Ahead. 1 Mile. Reduce Speed to 45 MPH”	
Aggressive Braking Detected at Stop Sign		“Aggressive Braking Detected”	
Approaching Curves in Roadway		“Sharp Curve Ahead. Use Caution”	

Speeding 3.5 MPH Over 35 MPH Limit then 7.5 MPH Over Limit		"Exceeding Speed Limit"	
Vehicle Did Not Make a Complete Stop at Stop Sign		"Stop Sign Violation Detected"	

3.3 RESULTS, FEEDBACK, AND REDESIGN RECOMMENDATIONS

In general, the feedback about the ODSS was positive. Users thought the system was effective, had appropriate alert timing, and that the alerts had clear meanings. Many reported a surprise at the unobtrusiveness and non-distracting nature of the system compared to their expectations of how it would operate.

Mental workload scores, as measured by the Rating Scale Mental Effort (RSME; see Appendix A), averaged 14.5 (*SD* = 14.2), on a scale from 0 to 150, suggesting very low mental workload experienced during the simulated drive. The usability of the system, measured by the System Usability Scale (SUS; see Appendix D), found an average score of 74.75 (*SD* = 20.83), reflecting an above average usability score.

The final interview and technology questionnaire revealed general commentary from the participants about the ODSS and its design features. The following items summarize user feedback about the usability of the system.

1. Users did not understand the meaning of the turtle symbol used to indicate that the driver was currently slower than the speed limit. Further, the turtle symbol was frequently unnoticed by participants altogether.

   Recommendation: Change the turtle symbol to be more salient/meaningful or remove it. However, the low contrast speed limit sign alone may not be enough information for users to understand that they are going under the speed limit. Adding the driver's current speed or a display to indicate current speed may make the symbol easier to understand, but it should not be too demanding on the driver.

2. Users did not like having to look to the bottom right of the screen to see the speed limit symbol.

   Recommendation: Move the symbol to one of the top corners to minimize eye movement within the driver's field of view or remove superimposed feature with navigation. Only three of the participants reported to using navigation on a regular basis.

3. Users felt that the "Reduce Speed Ahead" warnings presented too much information on screen. Users feel that they already know the current speed and only need the new speed limit.

   Recommendation: Point out the new speed limit and remove the old speed limit (see Figure 3.3). After the auditory alert, give the user feedback if they are exceeding or below the new limit.

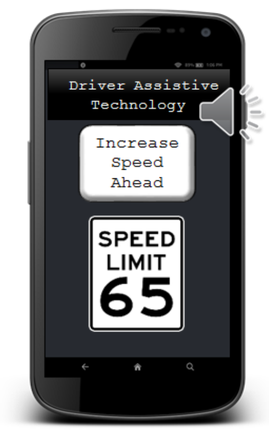


Figure 3.3. Suggested adjustments for speed information

4. Users felt that the timing of some alerts were inappropriate. Specifically, the "Reduce Speed Ahead: Work zone" alert may have been presented too soon. Alternatively, the "Sharp Turn Ahead" alert may have been presented too early.

   Recommendation: Test whether the timing of these alerts need to be changed by asking whether they had enough time to react to a scenario for each warning. One option would be to use a freeze probe technique to ask these questions after each warning during the simulation.

5. "Buckle Your Seatbelt" and "Aggressive Braking" symbols are low contrast (i.e., red text on black background, see Figure 3.4).

   Recommendation: Change the color scheme to be higher contrast.

Figure 3.4. Suggested adjustments for contrast

6. Some users felt that the ODSS might be a distraction rather than a help.

   Recommendation: Test the final system to make sure that it is not a distraction. Distraction may not be an issue once users have learned the system feedback. A diary study would be useful to examine how users feel after using the ODSS for a week or two.

7. Some users wanted more auditory information so that they did not have to look at the screen as frequently.

   Recommendation: Ask users what types of auditory information they would like to be included in this system. Make any non-essential auditory information optional settings.

8. Some users want to be able to customize the application warnings. Users that felt certain warnings were annoying or unnecessary might want to be able to turn off the alerts.

   Recommendation: Ask users which warnings they would like to be able to customize. Make any non-essential warnings optional settings. A Kano Analysis could be used to examine whether the features are necessary.

9. Some users felt that the voice should be less robotic or warmer.

   Recommendation: Record audio notifications using professional human voice actor.

3.3 CONCLUSIONS

Overall, the results of the simulation test of the interface revealed that very few of the original recommendations for modifications of the TDSS from the focus groups, interviews, and surveys held true. Once the participants in the simulation test observed the feedback in a more immersive context of a moving vehicle, they rejected many of changes that added complexity to the warnings, icons, or auditory messages, such as current and new speed postings. Some of the other suggestions were minor issues in terms of usability, but would require more extensive programming and engineering work to accomplish, such as changing the notification point of advanced curve warnings.

Fortunately, many of the remaining preferences or recommendations were already put into place in the commercial version of the TDSS application, which was renamed RoadCoach, which is currently only in use for research purposes and not found in any application marketplace. This commercial platform had already removed any specific information or mention about “parents” and had removed information that was specific to other on-board sensors used in the TDSS field operational test. Many of the recommendations from older drivers were already implemented into RoadCoach, such as:

- Ability to run navigation in the foreground and let RoadCoach run the background while still pushing audio messages through. This helps to solve the issue for those who want to run both systems simultaneously; however, it does not include any “draw on” functions by which the current speed is displayed. This may cease to be an issue for users of some more advanced navigation system that already display the posted speed limit.
- Customization is also partially addressed through RoadCoach system by allowing the system to be “audio-only” through running in the background and determining whether the driver would like notifications to be sent to second parties, such as a trusted friend, physician, or adult children.
- The robotic voice issue is also solved because a voice actor was utilized to record all auditory messages. This adds a warmer element to the audio messages, for which the older drivers had expressed preference. A limitation with this, however, is that it would be costly and difficult to make any changes to the messages—requiring a new voice actor to replicate the sound of the existing suite of messages or to re-record all messages with a new actor.
- Finally, the name RoadCoach, which was selected through focus groups in a separate study with teens and parents, is a great fit for marketing to older adults as well as teens, because it does not single out any age group, younger or older, and suggests that it is a system for all drivers. Based on the strong feedback received from the older driver focus groups, the name RoadCoach, although not specifically presented in the same form, is expected to be well received.

CHAPTER 4: CONTROLLED FIELD TEST/USABILITY TEST

4.1 OVERVIEW AND ROADCOACH ADOPTION

The final on-road experiment of this study was the culmination of the user-centric design of the driving application to support older drivers. Based on earlier feedback regarding the desire by older drivers to not be singled out for special treatment or focus, as well as functional features of the system, the new commercially adapted **RoadCoach** application was seen as a logical system for on-road testing. RoadCoach does not specify that the application is for older drivers and suggests a supportive role for the smartphone application. *From here on, the ODSS will be referred to as RoadCoach*. This evaluation was conducted at the HumanFIRST laboratory in the Department of Mechanical Engineering at the University of Minnesota as well as on nearby city streets and highways as participants drove a university vehicle with the RoadCoach application active. The purpose of the study was to gather user feedback on the features of the interface and its functions while driving.

4.2 METHOD

4.2.1 Participants

Eleven adults (8 males, 3 female) aged 66-80 (*M* = 70.64 years, *SD* = 3.85) were recruited from the Minneapolis area to participate in this evaluation. In general, participants drove frequently, with 10 of the 11 drivers reporting that they drove at least five to six days a week. On average, participants reported they drove 122 miles per week and had been driving for 53.27 years (*SD* = 6.54). All drivers were required to have a valid U.S. driver's license, drive a minimum of 4,000 miles per year, have a visual acuity of 20/40 (either corrected or uncorrected), and have no medical history that might put them at risk while driving.

Prior to beginning the study, drivers completed an informed consent process and a questionnaire about their demographics, driving history, and driving opinions (see Appendix B). Behavioral questions included items related to purposes for driving, risky driving behaviors (e.g. speeding, running lights, etc.), seat belt use, and cell phone use while driving.

Overall, drivers had a very few driving citations with only two drivers reporting that they had been issued any type of citation for their driving in the past five years (i.e., one for a stop sign violation and one for careless driving). Of the eleven drivers, only two reported having been involved in a car crash within the past five years, while zero drivers reported having been at fault in a car crash over the past five years. In general, the drivers considered themselves to be quite good drivers with only one driver reporting their driving skill as average, while the other ten drivers reported their driving as either slightly above average (*n* = 5) or above average (*n* = 5).

4.2.2 Equipment

A Samsung Galaxy S7 with a 5.1-inch screen was used to display the RoadCoach interface for this study. It was mounted to the dash of the vehicle just to the right of the steering wheel, so that it was in nearly the same parallel plane as the vehicles instrument gauges. The RoadCoach mobile application was run on this smartphone throughout the duration of this study. The RoadCoach is a driver support application that provides in-vehicle coaching to reduce risky driving behaviors associated with crashes. The interface provides drivers with both visual and auditory warnings regarding their driving performance, as well information regarding the roadway. The auditory messages are meant to be the primary source of information with the visual warning messages intended to be a redundant source of secondary information. The purpose of these audio/visual priorities is to limit the visual demands of the driver, provided the external ambient noise is low enough for the audio messages to still be heard. The auditory messages were designed to be short and simple as to minimize the distraction and make their intention as clear to the driver as possible. The visual images were also designed to be simple and as large as possible so as to minimize the amount of time necessary for drives to look at them and derive their intended message. This design was especially pertinent for the visual warnings not accompanied by auditory messages.

4.2.2.1 Information, Reminders, & Warnings

The interface of the RoadCoach allows for the presentation of only one visual message or warning at a time. The default message on the screen is the current posted speed limit. The RoadCoach application was designed to utilize GPS information for the location of the phone and show the associated posted speed limit of the roadway on which the driver is currently traveling. The images displayed on the screen change depending on the behaviors of the driver or upcoming changes in the roadway.

4.2.2.1.1 RoadCoach Website

The RoadCoach logs driver violations into a website account that each user can create. Once a user has created an account, any violations they incur can be seen on the website and viewed. Users can sort through several metrics on the website, including number of drives in which the RoadCoach was used, distance driven using the application, and the number of hours driven using the application. This information can be viewed in weekly or monthly form. Users can also view and track the number of violations they have accrued. Violations can be broken down and viewed by time of day as well as weekly and monthly totals (see Figure 4.1).

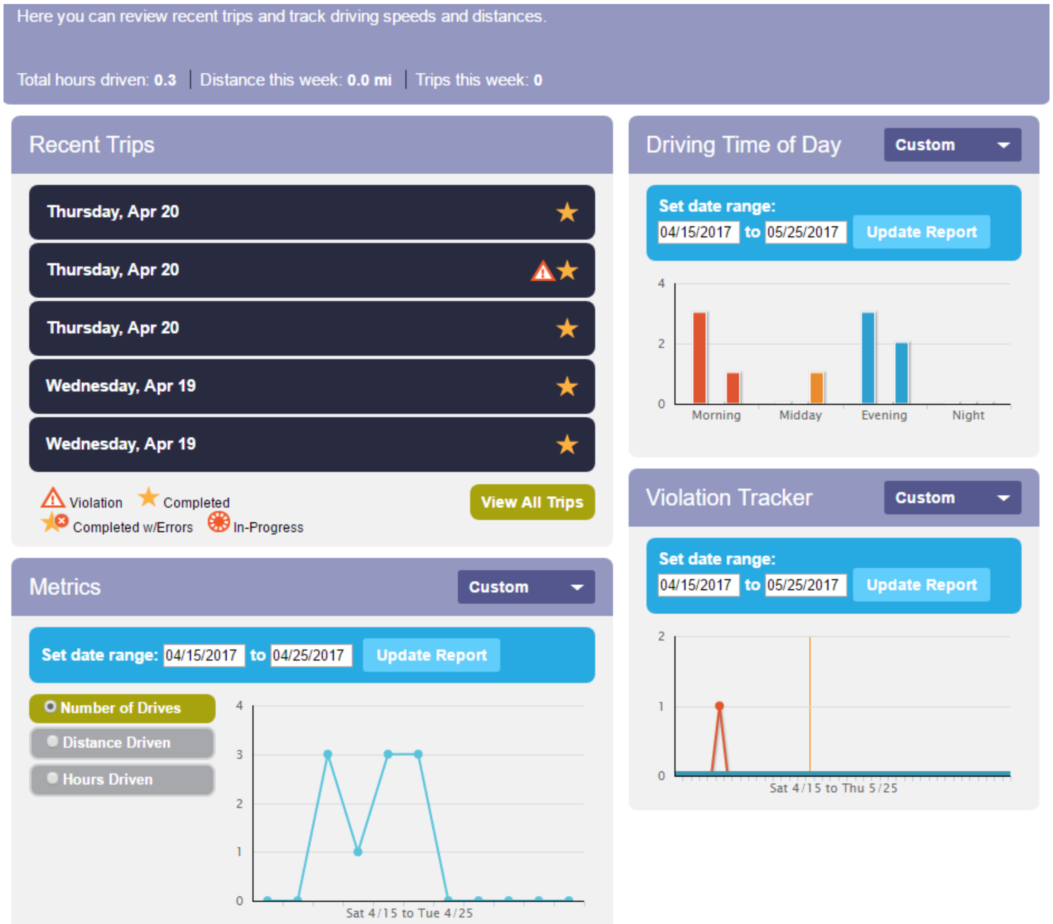


Figure 4.1. RoadCoach website home page

4.2.2.1.2 Speeding

The RoadCoach informs drivers whenever they are speeding through an intelligent speed adaptation system with three levels of speed notification. The default image displayed on the screen is the current posted speed limit, which looks like a standard roadside speed limit sign (see Figure 4.2). Whenever the vehicle begins to travel anywhere from 3.5 mph to 7 mph over the known posted speed limit, the background of the posted speed limit on the screen changes to yellow (see Figure 4.3) to indicate to drivers that they have begun to exceed the speed limit. Because this range of speed falls within some expected range of speed fluctuation and is not perceived to be excessive speeding by drivers previously tested, no auditory warning accompanies this first level of speeding notification. Once drivers begin to speed in excess of 7 mph, the background of the posted speed limit on the screen changes to red (see Figure 4.4). This is also accompanied by an auditory message of "Exceeding speed limit, please slow down." If driver continued to exceed the speed limit by more than 7 mph, they would receive another auditory warning after several seconds of "Exceeding speed limit, please slow down." If the speeding continued, a third auditory warning of "Please slow down. Violation will be recorded if speeding continues" would play after five more seconds of speeding. If the speeding still persisted, a message of

“Violation has been recorded” would play (see Figure 4.5). The alert sequence would then desist for thirty seconds before the cycle of auditory warnings would start over again from the beginning.

Figure 4.2. Default image of current posted speed when not speeding

Figure 4.3. Display when speeding by 2-7 mph

Figure 4.4. Display when speeding by more than 7mph

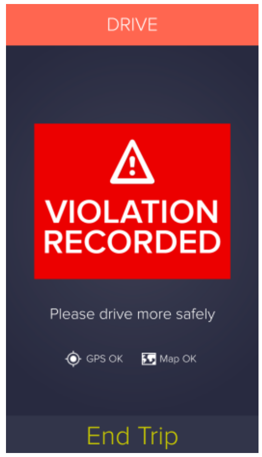


Figure 4.5. Display when a speeding violation has been recorded

Drivers are also provided with notifications of any upcoming changes in the posted speed limit in the roadway. Drivers would be given an auditory message as they approached the new speed zone of “Speed limit changes to 50 mph ahead.” As the vehicle entered the new speed zone the image on the screen of the posted speed limit would change and be accompanied with an auditory message of “Speed limit 50 mph” (see Figure 4.6)

Figure 4.6. Advanced speed notification

4.2.2.1.3 Advance Curve Notification

The RoadCoach provides drivers with advance curve warnings by looking ahead at the current road of travel (up to 55m). When a driver approaches a sharp curve in the road, they will receive an auditory warning of “Left/Right curve ahead” as well as a visual image of the appropriate type of curve warning sign (see Figure 4.7). When the precise direction of the curve is unknown or it is a more complex curve, such as an S-curve, the audio feedback will simply say “curve ahead.” This is to provide drivers ample time to slow the vehicle in anticipation of the approaching curvature in the roadway.

Figure 4.7. Advanced curve notification

4.2.2.1.4 Aggressive Maneuvering

Using the smartphone's accelerometers and GPS, the RoadCoach's algorithm identifies excessive maneuvers during acceleration, deceleration, and turning to give feedback to the driver. The RoadCoach will also record violations for these maneuvers. If a driver has an excessive acceleration (3.5 m/s^2) they will receive a visual warning (see Figure 4.8) as well as an auditory warning of "Excessive acceleration, use caution) while recording a violation to the drivers account. If drivers decelerate too quickly (-3 m/s^2), they will receive a visual warning (see Figure 4.8), as well as an auditory warning of "Hard braking detected, violation has been recorded." The RoadCoach will record the violation to the driver's website account. Aggressive turning is also recorded when drivers take a turn too quickly, (4.5 m/s^2) which will trigger a visual warning (see Figure 4.9) along with an auditory warning of "Excessive turning, use caution." This violation will also be recorded and uploaded to the driver's website account.

Figure 4.8. Aggressive acceleration & braking warning

Figure 4.9. Aggressive turning warning

4.2.2.1.5 Stop Sign Violation

The RoadCoach software contains a database for stop signs at major roads and queries this database to determine if drivers come to complete stops at these stop signs. If a driver goes through an intersection with a stop sign and does not reduce their speed to at least 5 mph, they will receive a violation. The interface will display a visual warning (see Figure 4.10) as well as an auditory message of "Failed to stop at stop sign, violation has been recorded." The 5 mph threshold was implemented to reduce false alarms of stop sign violations due to the sampling rate collected through GPS signals where the driver may have come to a complete stop but it was not detected fully.

Figure 4.10. Stop sign violation warning

4.2.2.1.6 Optional Text Messaging

The RoadCoach also offers an optional feature that some users may choose to utilize in which a secondary party may be included in sharing their driving performance. This could be a trusted friend, family member, or medical professional. When a user sets up an account they can designate such a person by entering their cell phone number. In the event of a violation, the application will automatically send a text message to the designated person about what kind of violation was recorded, the location, and a timestamp of the violation (see Figure 4.11). This information could also be viewed on the user's website account by whomever they may choose as their designated secondary party. This feature was presented and described to participants in the tutorial, but was not enabled during the controlled field test.

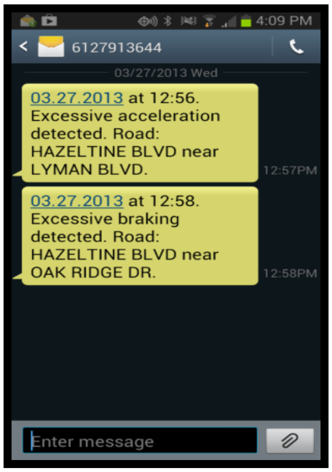


Figure 4.11. Screenshot of text notification function

4.2.2.2 Vehicle

The vehicle used for this study was a 4-door 2009 Chevrolet Impala. The vehicle had electric seats and side mirrors so each driver could easily adjust their positioning within the vehicle as well as the mirrors to their own comfort and liking. The vehicle was equipped with cruise control, although none of the participants elected to use it while driving. All occupants were required to wear their seat belts for the entirety of the experiment.

4.2.2.3 Video Recording

Visual distraction is a particular concern with any in-vehicle system which provides visual feedback or icons to drivers. In order to determine the frequency and duration at which drivers chose to look at the smartphone while they drove, software was installed onto the smartphone to capture forward facing video of the driver to capture gross head and eye movements toward the phone's screen in a non-obtrusive way. This software placed a circular display of the video it was recording in the lower right corner of the screen which could not be removed, but did not occlude any of the icons or critical visual information of the system (see Figure 4.12). To reduce any potential distraction by this video indicator, a black square was place over the screen to prohibit the driver from seeing it.

Figure 4.12. Screenshot of forward facing video capture image (*participant's identity has been occluded*)

4.2.3 Procedure

Upon completion of the consent form and driving questionnaire, participants received an introductory presentation to the RoadCoach. The presentation included a description of the purpose of the RoadCoach application and how the application would function while they were driving. They were also given an explanation with maps outlining the route they would be driving while the RoadCoach application was active. After this, they were taken on a demonstration route, which consisted of a 12-minute drive on a busy urban street (see Figure 4.13) before the vehicle reached the location of what would be the starting point of the practice route (see Figure 4.14). Two researchers were present in the vehicle. One researcher drove the vehicle and gave instructions on where the participant would be turning for portion of the experimental route while the participants sat in the passenger seat and another researcher sat in the back seat. The purpose of this was to familiarize the participants with the route to minimize any confusion on direction when they were driving. It also served to give them on-road exposure to the application's interface and allowed them to discuss any questions or immediate feedback they had regarding the application and its functions with the researcher in the back seat. The demonstration route also provided the participants experience with any sign changes or notifications from the RoadCoach before they began driving on the experimental route. The demonstration route began at a parking lot located on the University of Minnesota's campus. The entire duration of the demonstration route and discussion was roughly 27 minutes.

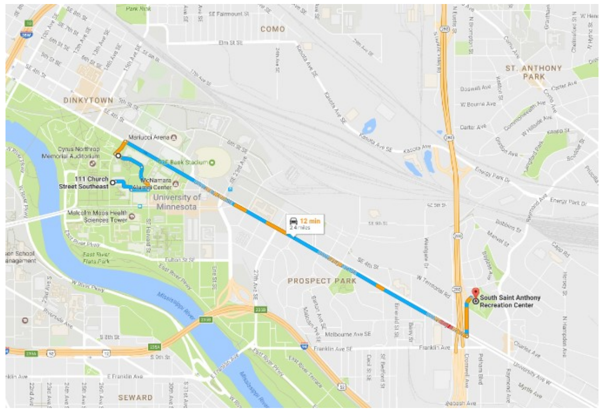


Figure 4.13. Demonstration route to experiment starting point

Once the demonstration route was finished, the vehicle was parked in the parking lot of a local recreation center which served as the starting point for the practice and experimental route. Participants then switched seats with the researcher in the driver seat. Once they had adjusted the seat, mirrors, and steering wheel to their liking, the participant went on a short practice route (see Figure 4.14) with the researcher in the passenger seat giving them turn by turn directions. This route consisted of driving through a neighborhood at low speeds (20-30 mph) and a short distance on a city street with low traffic. This drive included multiple stop signs and one stop light. The purpose of the practice route was to familiarize drivers with the functions and feel of the vehicle, so the RoadCoach application was not active during this route. The practice route lasted approximately 5 minutes. Upon completion of the practice route, drivers returned to the same parking lot and were asked if they felt comfortable enough with the vehicle to continue to the experimental route.

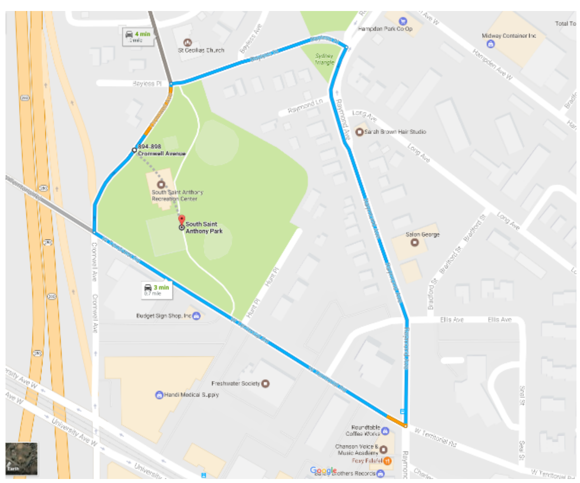


Figure 4.14. Practice route

Participants then began the experimental route which took an average of 13:33 minutes to complete the course, which was 6.5 miles long (see Figure 4.15). Upon exiting the parking lot onto a city street, drivers quickly merged onto a nearby four-lane divided highway. The posted speed limits for this highway were 55 mph initially, and halfway through the posted speed was reduced to 50 mph. Drivers then exited from the highway using left-hand exit where they then merged back onto a city street with a posted speed of 40 mph. Shortly after they made a turn onto another city street with a posted speed of 30 mph. Drivers then merged onto a six-lane divided interstate which had a posted speed of 60 mph that was reduced to 55 mph after approximately 1.5 miles. Drivers then exited the highway using a right-hand exit to merge onto a city street with a posted speed limit of 30 mph. After nearly one mile of driving on this street the drivers pulled into a small parking lot on the campus of the university. This drive included a total of ten stoplights and one stop sign. Drivers were instructed to drive as they normally did in their own vehicle and to interact with the RoadCoach at their own leisure.

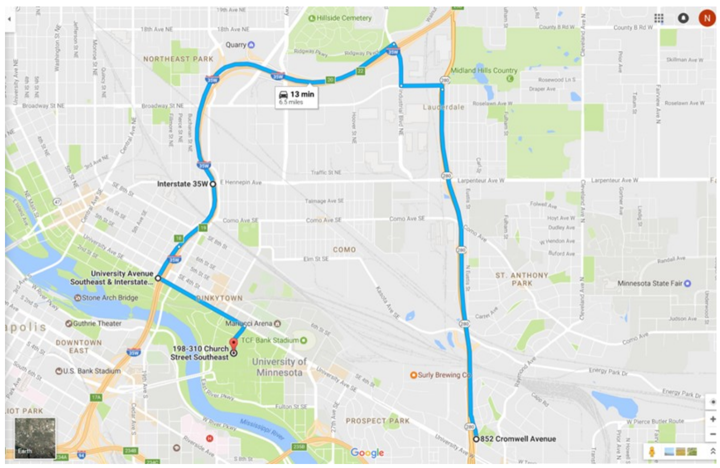


Figure 4.15. Experimental route

After finishing the experimental route, participants filled out the Systems Usability Scale (SUS) as well as Rating Scale Mental Effort (RSME), the latter rating how much mental effort they felt the task they had just completed required. The SUS and RSME are shown in Appendix D and A, respectively. Participants then returned to the laboratory, where a researcher gave them a tutorial on each of the different functions and warnings of the RoadCoach. An open-ended interview session followed the tutorial to ascertain what the participants liked and disliked about the application, as well as the overall perceived user-friendliness of the RoadCoach. The interview also tried to determine how likely these potential users might be to use the RoadCoach application if it were available to them and what cost they would be willing to pay for the application, to see if the participants saw any value in the system.

4.3 RESULTS

4.3.1 Warnings and Messages

All information displayed on the phone from the RoadCoach application during the experimental drive was recorded and analyzed for each participant. The front-facing camera of the phone was used to record driver eye movements and gazes towards the phone's screen were analyzed. The purpose of this was to determine how frequently participants looked at the phone in general as well as how often they looked at each individual message or warning they received. The RoadCoach application displayed the known speed limit as the default image throughout the drive. Table 4.1 shows the types of messages or notifications that were provided to drivers throughout the experimental drive as well as what percent of the time drivers looked at the phone upon receiving each message or warning. On average, drivers looked at the phone about two-thirds of the time when a new image was displayed or an auditory notification was given. The duration of these gazes ranged from less 200 milliseconds to up to two seconds. Drivers reported that they did not need to look at the interface for very long each time because the majority of the images were quite intuitive and had large text which reduced the amount of time necessary to interpret whatever message was being displayed.

Table 4.1. Gazes at messages and voice notifications

Type of message provided by RoadCoach	Percent of time drivers looked when the message was provided
Yellow speeding warning sign	62.65% (*52/83*)
Red speeding violation sign	80% (*8/10*)
New posted speed limit	43.33% (*26/60*)
All voice notifications	62.79% (*27/43*)

Table 4.2 shows the average number of gaze's drivers made for each type of message or warning from the RoadCoach while driving along the experimental route. On average, each driver made 22.7 (*SD* = 6.46) gazes at the RoadCoach interface during their thirteen-and-a-half-minute drive. The average number of gazes per driver also includes times when drivers were simply looking at the posted speed limit and not necessarily a new message or warning. This amounted to only looking at the phone 1.68 times per minute, with the average duration of each gaze lasting less than 500 milliseconds. This means that the application does demands little visual attention from drivers, who should maintain their gaze on the roadway.

Table 4.2. Average number of gazes per message displayed

Type of warning/message displayed	Average number of gazes per warning/message (*SD*)	Average number of unique displays per driver (*SD*)
All warnings & messages combined	22.7 (*6.46*)	25.12 (*3.35*)
New posted speed limit	2.6 (*0.97*)	6.0 (*0*)
Yellow speed warning sign	3.4 (*1.26*)	8.3 (*2.75*)
Red speed warning sign	0.8 (*0.92*)	1.0 (*1.33*)
All auditory messages	2.7 (*1.06*)	7.82 (*1.57*)

4.3.2 Satisfaction and System Usability

Upon completion of the experimental route, drivers were given the System Usability Scale (SUS) satisfaction survey to measure their overall acceptance of the RoadCoach. The SUS satisfaction measure scores range from 0 to 100, with a larger number indicating a higher level of perceived satisfaction. Satisfying systems tend to produce SUS scores in the 70 – 100 range. A typical system SUS score is 68.

The RoadCoach interface received an average SUS score of 93.86 (*SD* = 8.01) from participants. An average score of 93.86 indicates that drivers were highly satisfied with the design and user-friendliness of the interface and found it to be very usable. This was reflected in the post-experiment interviews with participants.

4.3.3 Subjective Workload (RSME)

After completing the experimental drive with the RoadCoach application active, drivers completed a standard mental workload rating scale (Rating Scale of Mental Effort or RSME). The workload scale ranges from 0 (Absolutely No Effort) to 150 (Extreme Effort). The average RSME score was 26 (*SD* = 11.53), which correlates to the scale's descriptive term of "a little effort." This rating suggests that participants did not believe that using the RoadCoach during their drive required a substantial amount of mental effort. This rating only reflects the participants first time use with the interface, the amount of mental resources in using the interface would presumably decrease as drivers habituate to it.

4.3.4 Subjective Comments

After participants completed the experimental route using the RoadCoach, they completed an open-ended interview about what they LIKED, DISLIKED, and would CHANGE. All subjective comments by users are given in Appendix C, Tables 1 and 2. General likes and dislikes are shown in Table 4.3, while Table 4.4 shows what users indicated they would like to possibly change about the application.

Table 4.3. What users LIKED and DISLIKED about the RoadCoach

What did you LIKE about the RoadCoach	What did you DISLIKE about the RoadCoach
• It will help keep their focus on driving • 7 MPH speed warning threshold • Speeding warnings • The name RoadCoach • Having the posted speed limit as the default image • Advance speed warnings • Advance curve warnings • Stop sign violations • Simplicity of the interface design	• The voice used for the auditory warnings • The posted speed of the application being occasionally inaccurate • The aggressive driving maneuver warnings seemed unnecessary for adults • The optional text message feature seemed unnecessary for adults

Table 4.4. What users would change about the RoadCoach

What, if anything would you change about the RoadCoach application?
• Make it so you can set your own speeding violation threshold • Change the aggressive violation signs to be a little more intuitive • Make the voice on the application louder • Get rid of the text “maps ok” & “GPS ok” on the default page, they seemed unnecessary • Update the posted speed limits to be more accurate and not mismarked • Would like to be able to have the RoadCoach application integrated into their GPS system

4.4 CONCLUSIONS

Results from this study showed that participants had a very high level of satisfaction with the RoadCoach interface. Users especially liked that the notifications for upcoming changes in the posted speed limit as well as warnings when they began to excessively speed captured their attention and helped to reestablish their situational awareness when their minds began to wander. While the warnings associated with speeding and the advanced speed warnings were the features that users most often said they liked best, they also reported a preference for the advance curve warning feature, even though drivers did not experience this during the on-road portion of the study. They felt that the advanced curve warning would be very useful in letting them know that they needed to adjust their speeds if they were approaching unexpected sharp curves. Aside from specific features of the interface, users were also very vocal of their preference for the simplicity of the design of the application overall. Users indicated that they did not think the application was too cluttered and was simple to interact with, as well as very user-friendly.

The perceived user-friendliness and simple design of the RoadCoach application may explain in part why users also rated the interface as having a very low mental workload demand. The overall RSME score for mental workload for the RoadCoach was equivalent to “little effort” on the workload scale. This low level of workload may also be reflected in the eye movement data collected during the experimental drive. On average, users only looked at the interface displayed on the phone for approximately 400 milliseconds. While this does still require brief visual distractions from the roadway, these durations are still quite short in duration and are unlikely to differ in duration from glances to other objects within the vehicle such as the dash cluster or radio display.

Participants also indicated that they liked the auditory notifications because it did not require them to take their eyes off of the roadway. Users thought this would be a nice feature to have when driving in heavy traffic or in unfamiliar driving environments. Participants were divided, though, on always having the voice notifications on. Some users did not like the voice used on the application, while others thought it might not be loud enough. Users did like that they could turn off the voice feature if they so desired.

4.4.1 Limitations

The overall reviews from participants in this study were very positive, but there were some limitations to the study that may affect the generalizability of the results. Participants only used the interface for a limited amount of time and thus were not able to truly experience all facets of the system. This short duration may have also affected participant attitudes toward the interface in that there may have been some novelty effects in their responses. It is also unclear how often drivers would attend to the RoadCoach application if they were to use it on their normal, daily route instead of the unfamiliar route used for the study.

CHAPTER 5: FINAL RECOMMENDATIONS

This study originally sought to adapt the design and functionality of a Teen Driver Support System (TDSS) smartphone application (Creaser et al., 2015) into an Older Driver Support System by carefully considering the needs and limitations of an aging driving population. Advanced in-vehicle sensing and warning systems, like the TDSS, are well-positioned to offer tailored support for older drivers to help them safely maintain their driving independence. The design of such systems should be paired with iterative and in-depth user testing to ensure that the unique needs and requirements of older drivers are met (Newell, Arnott, Carmichael, & Morgan, 2007). The practice of this assumption, however, reveals that the premise that older drivers require and accept a targeted design based on unique user requirements is perhaps flawed. The results of the study revealed an unexpected conclusion: Older drivers can best be supported with a universally designed system that is created to address the needs and risks of all drivers in need of support, not specifically targeted for older drivers.

5.1 ODSS / ROADCOACH SUMMARY

The Older Driver Support System study took a multi-method iterative approach to the design of the smartphone interface and functions, involving older adults as the user population of interest. The initial methods included surveys, focus groups, and interviews (the latter included one subject matter expert in gerontology). The ideal features of the application from these qualitative methods appeared to be navigation, real-time speed information, and context-aware alerts. The preferred iconography was simple and recognizable, with straightforward meanings. Finally, the older adults did not want the application to be specified directly for them, preferring an application that was for general consumption that they could use.

The second phase of the study included a simulation test in which older drivers sat in a driving simulator and watched a video of a car following a route, while the smartphone interface provided alerts and other functions in time with the driving video. The integrated and more complex information features in the display that were suggested in the previous phase of the study (navigation with speed limit signs, turtle iconography) were disliked by the older adults, as they spent time visually interpreting the interface and taking their eyes off the road. The older adults suggested using more auditory cues to reinforce visual information to allow them to keep their visual attention on the driving task. In response, researchers removed navigation information and made the speed information the predominant visual feature of the display, with other audio-visual elements occasionally appearing as alerts.

The third and final phase of the study was a field usability test with the ODSS smartphone interface, now titled RoadCoach, to meet the request of older drivers to not market the application directly to them. Older adults drove a vehicle around a pre-determined course with the smartphone application active. The user rating of the workload and usability of the ODSS/RoadCoach system was very positive. As for suggested design changes from the drivers, the trend continued for further simplification and increased perceptual salience of the elements of the interface, such as removal of certain system status cues that were irrelevant to the driving task, and altering the audio components for better comprehension.

One of the primary takeaways from this iterative design process was that the general design principles at play were consistent: 1. Reduce extraneous mental workload in the driving task, 2. Simplify and reduce visual clutter, 3. Integrate information in a reasonable manner and provide redundant coding. These principles are well known and apply to most human populations (Wickens, Liu, Lee, & Gordon-Becker, 2004). Therefore, the universality of the applied principles, along with the desire for older drivers to be treated in a similar fashion as their younger counterparts, suggest that universal design may be the best approach for user-centered design in transportation.

5.1.1 Universal Design

This study seeks to adapt the functions and design of a Teen Driver Support System (TDSS) smartphone application (Creaser et al., 2015) into an Older Driver Support System via consideration of the needs and limitations of the aging driver population. Advanced in-vehicle warning and sensing devices, like the TDSS or RoadCoach, are well-positioned to offer tailored support for older drivers to help them safely maintain their driving independence. Achieving these goals is critical since reducing fatal crash rates among older drivers is paramount in working toward our goals of zero deaths on our nation's roadways; however, reaching older drivers through tailored design and focused marketing is a challenge, as found in our focus groups that labels such as "senior", "aging", or "older" are not always well received. Other work has similarly noted these challenges and has highlighted that designing with older users in mind (e.g., larger controls or displays), while not explicitly targeting them through marketing, benefits not only older drivers, but also drivers of other age groups through its universally designed features (Steinfeld & Steinfeld E, 2001; Eby & Molnar, 2012).

Mace (1997) describes universal design as "the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design." Examining the design process through this lens allows us to consider that addressing the driving safety risks of older drivers is not quite so unique when considering the behaviors of other at-risk populations. Like older drivers, novice drivers have been shown to have poorer information processing abilities (Patten, Kircher, Ostlund, Nilsson, & Svenson, 2006) and decreased visual search strategies (Crundall & Underwood, 1998) compared to middle-aged experienced drivers. What's more, both populations have a poor ability to accurately judge their driving abilities in terms of hazard perception (Horswill, Sullivan, Lurie-Beck, Smith, 2013). Both young drivers and rural drivers, just like older drivers, have been associated with increased likelihood to abstain from seatbelt use (Goetzke & Islam, 2015). These groups represent the most at-risk extremes of those who stand to gain the greatest safety benefit through design and technological support. Despite the differing factors relating to unsafe intersection navigation for teens and older drivers, Caird, Chisholm, and Lockhart (2008) found that both age groups benefited from in-vehicle signing. Creating proper in-vehicle support that can address the complex challenges of high-risk road users will further support all drivers with fewer demands.

The result of the study indicate that designing a system that is accommodating of older drivers' most pronounced needs and presenting the features in a way that invites use from drivers of all age groups provides the right combination of tailored *and* universal design that the older population would respond to best. Ultimately, this study suggests the best way to reach our goals in reducing fatal crashes among older drivers is to continue our pursuit in inclusive countermeasures that reach all drivers.

5.2 FINAL RECOMMENDATIONS

Recommendations for this interface were derived from the users' comments in the post evaluation interview. Table 5.1 contains a list of recommendations, which are based on the features that proved to be the most influential in user preference.

Table 5.1. Recommended interface changes

Make the posted speed more reliable. Forty percent of the yellow speed warning signs and 70% of red warning speed signs were displayed in the errant speed zone, which only comprised roughly 15% of the entire drive.
Consider changing the braking violation sign to a side view of a vehicle with the nose tilted downward and tire marks behind the vehicle.
Consider changing the acceleration violation sign to a side view of a vehicle with the nose pointed upward .
Consider removing the "GPS ok" & "Maps ok" indicators on the main screen. Participants were uncertain of what these meant and there is nothing users could do to change this information.
Consider giving users the ability to change the speeding warning threshold.
Include a tutorial explaining how Passenger Mode works.

In summary, users rated the RoadCoach very highly in overall satisfaction, while rating it lower in perceived mental demand. Participants also noted that they enjoyed the simplicity of the design of the application and thought that it would be quite useful in helping them with their driving. The two most common reasons for this were that users thought it would help to keep them from speeding as often as well as help them retain more situational awareness of the driving environment. There were no specific warnings that they thought would accomplish this more than others, but all participants believed the interaction from the RoadCoach would be a good reminder for them to focus on their driving.

Future research is needed to further determine the potential long-term effectiveness of the RoadCoach on driving behavior. It is still unclear if the use of the application would have any actual effects on driver behavior or performance. Also, as drivers in this study were only exposed to the application for a relatively brief duration, it is unclear if their preferences and desire to use the application in the real world would continue once they have habituated to the novelty of such an interface. Additional research will be needed to attempt to answer these questions to better understand the potential impact in-vehicle coaching applications, like the RoadCoach could have on adult drivers.

The next steps for this work will aim to examine the efficacy of RoadCoach during a prolonged field operational test in which older drivers will use the system in their everyday driving without the presence of a researcher. This next phase will better identify if the features of the system (e.g., intelligent speed adaptation and aggressive maneuver warnings) reduce risky driving from individual baseline driving measures as intended. Further, the prolonged exposure of the system (e.g., over many weeks or months) will better convey the user acceptance and willingness to use the system by the older population once the system is no longer novel and used under the direct supervision of a researcher. The results of the next phases of this work will be instrumental in better determining the potential of the RoadCoach tool, or other in-vehicle technologies like it, to be successful in supporting extended safe and independent driving among our nation's aging population.

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APPENDIX A

RATING SCALE MENTAL EFFORT

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

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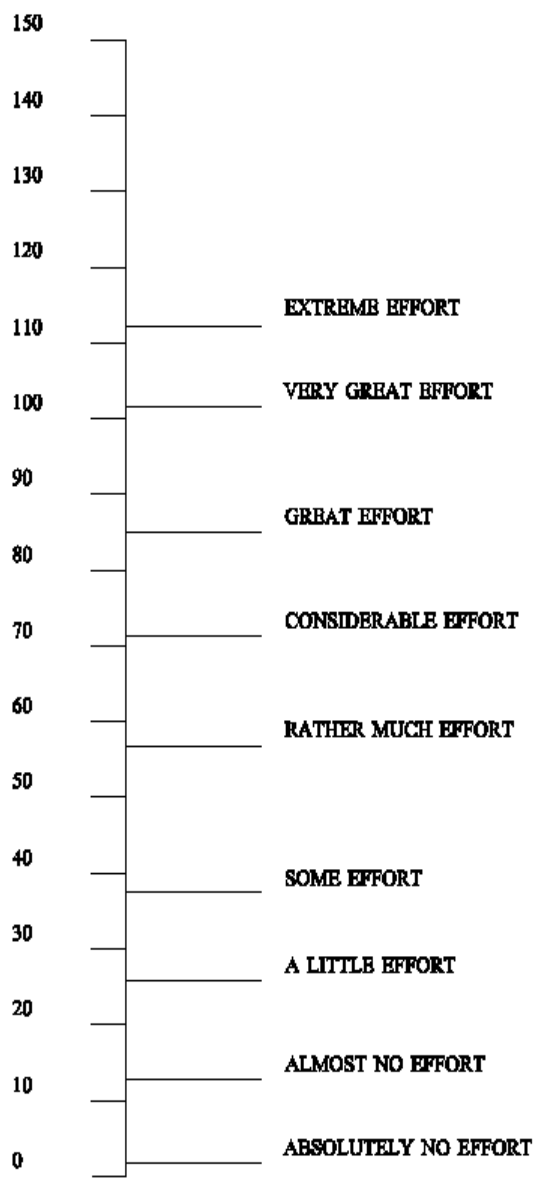

APPENDIX B

DRIVING HISTORY & OPINIONS QUESTIONNAIRE

DRIVING HISTORY & OPINIONS

This questionnaire will collect information regarding your driving history, your current driving behaviors, and driving records such as tickets and crashes. Your answers will be completely confidential. If you feel uncomfortable answering a particular question, you may leave it blank. Please tick one box for each question.

1. Your date of birth: MM: ________ / DD: ________ / YYYY ________

2. Your sex:
   - ☐ Male
   - ☐ Female

3. Please state the month and year when you obtained your driving license:

   MM: ________ / YYYY ________

4. How would you rate yourself as a driver?
   - ☐ Above average
   - ☐ Slightly above average
   - ☐ Average
   - ☐ Slightly below average
   - ☐ Below average

5. How often (days per week) do you typically drive?
   - ☐ Every Day
   - ☐ 5 or 6 days per week
   - ☐ 3 to 5 days per week
   - ☐ 1 or 2 days per week
   - ☐ Less than 1 day per week

6. On average, how many miles do you currently drive every week? ______________________

7. Per week, how often do you currently drive:

	Less than once	Once or twice	Three to five times	Six to seven times	More than seven times
To and from work.	①	②	③	④	⑤
To personal hobbies/ activities (e.g., fitness center, volunteer)	①	②	③	④	⑤
To run errands.	①	②	③	④	⑤
To visit a friend	①	②	③	④	⑤
To visit family	①	②	③	④	⑤
To go places for entertainment (e.g., dinner, movie theater)	①	②	③	④	⑤
To drive around with no particular place to go.	①	②	③	④	⑤

8. In general, tell us how often:

	Never	Seldom	Often	Very Often	Always
You wear your seat belt as a driver.	①	②	③	④	⑤
Your passengers wear their seatbelts.	①	②	③	④	⑤
You talk on your cell phone while driving.	①	②	③	④	⑤
You send text messages while driving.	①	②	③	④	⑤
You drive with 3 passengers or more.	①	②	③	④	⑤

9. In general, how often do you:

	Never	Seldom	Often	Very Often	Always
Exceed the speed limit in residential or school zones	①	②	③	④	⑤
Drive through a stop sign without stopping completely (e.g., rolling stop).	①	②	③	④	⑤
Switch lanes to weave through slower traffic.	①	②	③	④	⑤
Drive 10 to 19 miles per hour over the speed limit.	①	②	③	④	⑤
Pull out into traffic without waiting for a large enough space between cars.	①	②	③	④	⑤
Play the radio so loud that you would not be able to hear car horns/sirens.	①	②	③	④	⑤
Change lanes without signaling.	①	②	③	④	⑤
Drive through an intersection when the light was red or just turning red.	①	②	③	④	⑤
Tailgate or follow someone too closely.	①	②	③	④	⑤
Change lanes without enough room between cars.	①	②	③	④	⑤
Cut in front of a car to turn.	①	②	③	④	⑤
Drive in a way to show off to other people	①	②	③	④	⑤
Drive 20 or more miles per hour over the speed limit.	①	②	③	④	⑤
Race another car for a short distance.	①	②	③	④	⑤
Make an illegal U-turn.	①	②	③	④	⑤

Pass 2 or 3 vehicles at a time on a road with two-way traffic.	①	②	③	④	⑤
Pass a car in a no-passing zone.	①	②	③	④	⑤
Go 5 or more miles over the speed limit on a gravel road.	①	②	③	④	⑤
Lose traction while on a gravel road	①	②	③	④	⑤
Take a turn on a roadway so quickly that you feel the car tilt.	①	②	③	④	⑤
Drive through an uncontrolled intersection (i.e., no light or stop sign) without slowing or stopping.	①	②	③	④	⑤

10. In the last 5 years, how many times have you been given a TICKET for:

	Tickets (if none, write 0)
Speeding	
Stop sign/light violation	
Not wearing a seat belt	
Operating while intoxicated	
Careless/dangerous driving	
Other	

11. In the last 5 years, how many at fault crashes (ones that you caused) have you had?

Number of at fault crashes ____ (if none, write 0)

12. In the last 5 years, how many <u>minor</u> road crashes have you been involved in where either you or the other driver were at fault?

(A minor crash is one in which no-one required medical treatment, AND costs of damage to vehicles and property were less than $1000).

Number of minor crashes____ (if none, write 0)

13. In the last 5 years, how many <u>major</u> road crashes have you been involved in where you where either you or the other driver were at fault?

(A major crash is one in which EITHER someone required medical treatment, OR costs of damage to vehicles and property were greater than $1000, or both).

Number of major crashes ____ (if none, write 0)

14. What type of vehicle do you drive most often?
- ☐ Motorcycle
- ☐ Passenger Car
- ☐ Pick-Up Truck
- ☐ Sport utility vehicle
- ☐ Van or Minivan
- ☐ Other, briefly describe: ______________________________________

15. The following questions ask you opinion about crashes. For each statement, please tell us how much you agree or disagree:

	Strongly Disagree	Mostly Disagree	Slightly Disagree	Slightly Agree	Mostly Agree	Strongly Agree
Crashes are most likely to result from difficult driving conditions.	①	②	③	④	⑤	⑥
Crashes are most likely to result from bad luck.	①	②	③	④	⑤	⑥
Crashes are most likely to result from poor driving skills.	①	②	③	④	⑤	⑥
Crashes are most likely to result from a driver's failure to pay attention.	①	②	③	④	⑤	⑥

APPENDIX C

SUBJECTIVE RESPONSES TO OPEN-ENDED INTERVIEW QUESTIONS

Table 1 Subjective participant responses to post-study interview questions

Participant	Do you think 7 MPH is adequate for the speeding violation?	Do you think RoadCoach would help you with your driving?	Do you like that RoadCoach lets you know when you're speeding?	What do you think of the name RoadCoach?	What did you think of the volume level & voice?
1	Yes; I thought that was a good cutoff	Yes	Yes	I thought the name made sense	Volume was ok, but I thought she had an awful voice. I think the higher pitched voice will create unnecessary anxiety
2	Yes; I thought that was adequate	Yes	Yes	I thought it was a good name that was straightforward and intuitive	Thought the voice was ok, but the volume might be too quiet for older drivers
3	It seems adequate; except on long duration highway drives	Yes, I like being warned of the speed limit changing or upcoming curves which is useful when you are in an unfamiliar environment	Yes	I'm ambivalent; gives me a sense of what it's about, but don't have a feeling that it's a clever name or brand	The volume seemed fine, but would want it through the radio; I liked the voice
4	It depends on the flow of traffic; I may have to ignore it to keep up. I like having the warning though	Yes, because it could help you keep focus by continually bringing you back to what's important	I liked the color change but don't always want the warning because I have to keep up with traffic, but it would be nice especially with no traffic around	It does identify what it does and what it's solution is	I would like to be able to turn it on and off. Would be nice to have on long distance boring drives
5	I think it's reasonable, it's different at rush hour and at night. You can just wiz around at night, no cars around. Day time is different with congestion.	It would be very helpful to know about the speed change. Really huge safety feature because it doesn't make you take your eyes off the road.	I think it's a good thing that I don't have to be constantly looking down at the speedometer. I	It's not misleading, tells you exactly what it's doing	I think it's good, I found it really irritating at first with, but I found this good. Not as intrusive as most I've heard. Need the option to turn off or lower volume.

6	It's just right; it's kind of the way I drive. I want to know if I'm going more than 7mph over	Yes	I like the speed limit violation. I want to know if I'm exceeding the speed limit; I think speed is the best element of the application	I like it; "It's just that" the name tells it like it is. It's a coach	It was a little hard to hear; was ok, but might get annoyed with her voice
7	I think it should be 10mph because of how often you're going over to keep up with the flow of traffic	It would be ok. Focuses on driving so not sure that it would be that useful to me	I suppose so. I think it would wake people up	It sounds appropriate	It was ok, not too loud. The voice was fine
8	7 is about right; Most of the time you will only get a ticket if you're going about 8 over. I can still keep up with traffic	Yes; gives you that extra feedback if you're not paying attention and will slow you down from speeding because it's alerting you	Yes	Good name that describes what it does	I could hear it, but wouldn't mind if it was louder; indifferent
9	5 MPH over the speed limit. Rarely drives over 65	Yes; likes the speed display. Would be good for the excessive brake	Yes	Sounds appropriate	Had a hard time hearing it. Would like a higher volume. Voice was ok
10	Maybe 5mph; who cares if you're 2mph over but 5 seems like a little better idea	Uncertain. I would need more feedback and use of it	Yes	It seems ok. I'm neutral	Louder; a little too high pitched aesthetically but was still ok
11	Lower; it's all a value judgement there. Thinks 5MPH and go straight to red and forget the yellow	Would help with certain things. Only has to help with 1 function to be useful so curve warnings at night or speed zone advisory would be useful	Yes	It's alright	Little low; voice was fine

Participant	Would you ever use the website function?	Do you think you would use the optional text message feature?	Would you use this application if it were available?	Would you be willing to pay for it? How much?	Would you use this application if your insurance company gave you a discount for using it, but they got to see you data?
1	Yes; I know I make violations and would like to know what and when they occur	No	Yes	No	Unsure
2	Yes; it would be nice to be made aware of	No	Yes	Yes, $5	Yes
3	I would think initially but the novelty may wear off	Not now but I might later. I don't see the need for me at the moment	Yes	No; used to things like this being for free	Absolutely; might even pay if it could save him money
4	Yes, as long as it wasn't cumbersome and didn't take up much space or time	No; possibly for grandkids	I probably would because it would be good if the grandkids were with me so they could learn to be aware of the safety of driving	Possibly; but not much but $5	Sure
5	Perhaps	I wouldn't use it because I don't have anyone to send it to	Yeah, the speed limit part is so handy to know it easily	$5,10,$100	Maybe
6	No	No	Thinks he would especially as he gets older. It's nice for when you're distracted or absent minded	Yes; $5 would be nothing	No not if they got to see my data unless it's a huge discount
7	No	No	If I a had a phone I might	No	Yes
8	Absolutely; just to see how I'm doing. Everyone always thinks they're the best driver out there but it's good to actually get good feedback. If you're getting several violations each drive that ought to tell you to change your habits	No	Yes	Most applications are free but would be willing to pay $5	Absolutely; not so sure but wouldn't bother me as much; could always turn it off if need be

9	Sure	No	Depends on the cost but yes	I think $150 would be acceptable to pay for it	Yes; yes
10	No; thinks the real time feedback would be adequate	No	If it were free would try it for a period at least	No	No
11	Periodically to see the aggregate. It would be interesting to see the aggregate of other drivers too	No	Sure; would push it on his kids too.	No; it has to be free	Definitely

APPENDIX D

SYSTEM USABILITY SCALE

System Usability Survey SUS

For each of the following questions, place an "X" through the one number to indicate your response.
"1" for strongly disagree, "3" for neutral- neither agree nor disagree, "5" for strongly agree.

1. I think that I would like to use this system frequently.

Strongly Disagree		Neutral		Strongly Agree
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