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Text Driving, Senior Mobility and Automated Sidewalk Assessment

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TEXT DRIVING, SENIOR MOBILITY AND AUTOMATED SIDEWALK ASSESSMENT

BY

SANAZ MOTAMEDI

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN

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OF

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2017
ABSTRACT

In modern society, quality of life is greatly impacted by human mobility. The lifestyles and abilities of each age group creates different risks and challenges associated with mobility. This research investigated the mobility challenges facing different generations and abilities.

The first part of this research focused on the effect of mobility technology on younger generations by exploring the impact of hand-held and hands-free texting on driving safety. A questionnaire and a driving simulator experiment were conducted to investigate the impact of text driving on drivers’ performance. Conclusions regarding the impacts of different forms of texting, text complexity, and response mode on drivers’ driving performance were drawn.

In the second part of this research, challenges faced by older adult drivers were identified and the impact of assistance using advanced technologies was explored. First, a questionnaire was conducted to investigate older adult drivers’ perceptions about a number of possible driving challenges. Then, the in-vehicle technologies which mitigate these challenges were identified. In this study, the acceptance of the identified technologies is explored by conducting a second questionnaire. A four dimensional model which included perceived usefulness, perceived ease of use, perceived safety, and perceived annoyance is considered in the second questionnaire. According to the responses, potential challenges that older adult drivers were facing and particular in-vehicle technologies which could help ease these driving challenges were identified.

The third and final part of this research focused on sidewalk compliance to the Americans with Disabilities Act (ADA) regulations intended to provide safe mobility
across all generations and physical abilities. In this part of the research, an automated system to assist the current sidewalk measurement and evaluation process at Rhode Island Department of Transportation (RIDOT) was identified and gauge repeatability and reproducibility studies were conducted on the system to test the system's accuracy, quality and reliability. The validated data were compared to the data which were collected with the conventional (manual) method. The compatibility of data with the current RIDOT’s Geographic Information System (GIS) database were studied. Additionally, based on ADA requirements, six indices were developed for sidewalk evaluation using the automated system data. In order to validate the indices, a correlation study was conducted between the indices and the pedestrians perception. This study provided recommendations to the RIDOT authorities to prepare a sidewalk transition plan that complies with ADA requirements automatically and objectively.
ACKNOWLEDGMENTS

First, I would like to thank my advisor Professor Jyh-Hone Wang for his encouragement, advice, guidance, and help in developing my skills throughout the years. His motivating and ambitious way of teaching and sharing his experience in this field of research made the dissertation an effective and enjoyable experience.

Second, I would like to thank my committee members, Dr. Maier-Speredelozzi, Dr. Hunter and Professor Clark for reviewing my dissertation and sharing their knowledge.

Last but not the least, I should mention that I could not have accomplished any of this without my parents, Aliosat Motamedi and Ommehleila Aboutalebi, my love, Seyed Hadi Nasrollaholhosseini, and his family, whose encouragements and supports has been vital in achieving my goal. I also would like to thank my friends and my labmates who help me to make this happen.
This dissertation is an original intellectual product of the author, Sanaz Motamedi. It should be mentioned that this dissertation is prepared in Manuscript Format according to the guidelines presented by the University of Rhode Island Graduate School. This dissertation consists of three manuscripts. Chapter 2 covers the first manuscript which is called “The Impact of Text Driving on Driving Safety” and was published in International Journal for Traffic and Transport Engineering. In chapter 3, the second manuscript titled “Older Adult Drivers’ Challenges and In-vehicle Technology Acceptance” mentioned which was published in International Journal for Traffic and Transportation Engineering. Afterwards, in the chapter 4, the Automated Sidewalk Assistant System which is able to evaluate sidewalk based on ADA is explained.
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CHAPTER 1

1.1. INTRODUCTION

Different groups of people face different mobility risks and challenges due to their diverse lifestyles, and physical abilities. In the first part of this research, the risks of using technologies while driving and the impact on driving performance were investigated. The focus of this part of the research was on drivers using their phone while driving, which has been identified as a major threat in driving safety, and has caused serious and fatal crashes. In the modern life, drivers stay connected to their social life, not only by calling but also by sending text messages and emails. To address this concern, 46 states have banned text driving (Insurance Institute for Highway Safety Highway Loss Data Institute, 2016). However, car manufacturers introduced another way of sending text messages and emails with hands-free technology and claimed this technology could improve distracted drivers’ safety. This accessory in modern cars has gone legally unopposed. The questions exist arise are whether hands-free texting is safer than hand-held texting, and whether other factors such as complexity and responding mode of text affect drivers’ performance. To answer these questions, this research designed and conducted an online survey and a virtual-reality driving simulator experiment to examine how safe hands-free text driving could be compared to hand-held text driving, how the context complexity of texts affects drivers’ performance, and how safe reading a text message without responding to it could be compared to both reading and responding to a text message while driving.
The second part of this research explored mobility impacts on older adult drivers. Due to increasing quality-of-life in the developed countries, the population of older adult drivers is growing. According to Casutt et al. (2014) estimation, older adult drivers’ population will be the fastest growing driver segment in ten years. In addition, older adults’ sensory, physical, and cognitive capabilities are noted to be decreased due to the normal process of aging. These decreased capabilities as well as increased tendency to keep driving created a safety issue among older adult drivers. Therefore, in order to reduce the driving risks associated with older adult drivers driving, challenging driving situations and feasible means to assist older adult drivers driving in these challenging situations should be identified. This study explored state-of-the-art driving assistance technologies. Additionally, older adult drivers’ acceptance about the technologies which might improve their driving safety were investigated in this part of the research.

The third and final part of this research focused on sidewalk compliance to the Americans with Disabilities Act (ADA) regulations intended to provide safe mobility across all generations and physical abilities. The ADA set forth specifications for sidewalks to ensure that people of all physical abilities and generations can safely use public sidewalks. In order to ensure that sidewalks conform to the ADA guidelines, many aspects of sidewalks such as running slope, cross slope, evenness, roughness and curb ramp have to be measured, recorded, and assessed. To ensure the compliance to ADA guidelines and the ease of use of sidewalks by all residents of Rhode Island, an automated sidewalk quality assessment system was needed. It was the intention of this study to identify the functionality and specifications of an automated sidewalk
assessment system. A study was conducted to help assess the system based on functionality, specifications, quality, reliability, accuracy of data collected, and compatibility with the current RIDOT’s GIS database. The study intended to identify the option that best fits the needs of the RIDOT. Field studies were carried out at various sidewalks. The system's accuracy, quality, compatibility, and reliability were tested by multiple gauge studies. The automated system data were compared with the current manual assessment method. After validating the automated system, its data was used to develop indices for evaluating sidewalks. These indices were based on ADA requirements and they were validated by a correlation study which was conducted between the indices and the pedestrian perception. This study provided recommendations to the RIDOT authorities regarding validation of the automated system and indices which evaluate sidewalks according to ADA requirements automatically and objectively.
CHAPTER 2

“The Impact of Text Driving on Driving Safety”

by

Sanaz Motamedi¹ and Jyh-Hone Wang²


is presented in Transportation Research Board 95th Annual Meeting

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ABSTRACT

In an increasingly mobile era, the wide availability of technology for texting and the prevalence of hands-free forms have introduced a new safety concern for drivers. To assess this concern, a questionnaire was first deployed online to gain an understanding of drivers’ text driving experiences as well as their demographic information. The results from 232 people revealed that the majority of drivers are aware of the associated risks with texting while driving. However, more than one-fourth of them still frequently send or read text messages while driving.

In addition to the questionnaire, through the use of a virtual-reality driving simulator, this study examined drivers’ driving performance while they were engaged in some forms of text driving under different challenging traffic conditions. Through a blocked factorial experiment, drivers would either read a text message or respond to it with two levels of text complexity while using either hand-held or hands-free texting method. Their driving performance was assessed based on the number of driving violations observed in each scenario. Conclusions regarding the impacts of different forms of texting, text complexity, and response mode on drivers driving performance were drawn.
2.1. INTRODUCTION

Distracted driving due to cell phone use has been identified as a major threat in driving, causing serious and sometimes fatal crashes. According to the National Safety Council (NSC), nearly 25% of all car crashes (1 out of 4) involved cell phone distraction. In 2011, cell phone use in motor vehicle crashes caused $100B in damages (NSC 2015). Due to the danger it poses to the public, cell phone use in driving has been banned in 37 states in the United States (Governors Highways safety Association 2015). Moreover, smartphones give people the opportunity to stay connected at all times, not only by calling someone, but also by texting and sending emails. These secondary tasks that people engaged in while driving could cause serious safety risks. According to the National Safety Council, sixty percent of drivers read (but do not respond to) a text or e-mail while driving, and 25% of drivers read and respond to a text or e-mail while driving (NSC 2015). As a result, 46 states have banned text driving (Insurance Institute for Highway Safety 2015). It is worth noting that hand-held texting is the main focus of these laws (NSC 2012). Hands-free or voice control texting has gone legally unopposed as it is considered to be a safer texting alternative. However, there is some research indicated that hands-free form of texting is not harmless. This difference in perspectives is a testament to how widespread texting is, either hand-held or hands-free, and how it has become one of today’s greatest threats to motorist safety.

To address this modern life concern, text driving, a survey and a driving simulation study were conducted. The survey was given through SurveyMonkey to investigate which age groups text more frequently while driving, what the opinion of drivers’ were about the effect of text driving, and gain a better understanding of drivers’ form of text
driving. After gathering the driver’s demographics regarding their text driving experiences, a driving simulation experiment was conducted. A virtual-reality driving simulator experiment gauged the adverse effects of different forms of text driving under various roadway conditions and circumstances on individuals of different ages and genders. Subjects were asked to drive through various scenarios and read text messages, or read and respond to text messages in both hand-held and hands-free form. In addition to the form of the texting, two context complexity levels were considered. The context complexity levels affect the cognitive load of drivers. Moreover, during the experiment, subjects used their own personal smartphones and speech-to-text system to text in different forms and complexity levels while driving. The findings of this study helped to understand the impacts of text driving, whether it is hand-held or hands-free.

2.2. BACKGROUND

Research shows that using a cell phone while driving and thus taking the eyes off the road could lead to crashes (Stutts et al. 2001; Hedlund et al. 2006). Many legislators and drivers thought this risk was only associated with hand-held cell phone use while hands-free use would be much safer (Mayhew et al. 2013). Automobile manufacturers also claim that hands-free text-messaging systems reduce driver’s distraction. For instance, Ford Motor Company examined driver performance while using the voice interface in Ford Motor Company’s SYNC in a fixed-based driving simulator. They found that the voice interface minimized distraction compared to visual-manual interfaces (Shutko et al. 2009). Moreover, there are various naturalistic studies which indicated that auditory-vocal interfaces have driving performance advantages over
visual-manual interfaces. For example, Dingus (2014) compared the effect of different secondary tasks on drivers’ behavior and associated risk. Based on his research, it was clear that hand-held electronic interfaces were the most serious driving distraction due to their visual and manual interfaces. In addition to Dingus, other researchers have come to similar conclusions. They described the relative risks of specific secondary tasks while driving based on a naturalistic driving study. In contrast to hand-held texting or browsing tasks, listening and talking tasks were found not particularly risky (Dingus et al. 2011). In the crash analysis conducted by the Transportation Research Board, non-visual interfaces such as talking and calling were found safer if only such interfaces are indeed non-visual (Victor et al. 2013). Dozza et al. (2013) in his naturalistic study concluded that there was no difference between cell phone conversation and manipulation. Many researchers come to the conclusion that by keeping hands on the wheels and eyes on the roads, the risk associated with secondary tasks, such as text driving, has been removed.

On the other hand, some researchers found that by freeing the hands of drivers from devices cannot assure drivers’ safety. According to the Governors Highway Safety Association, there are four types of distractions: Visual, Auditory, Manual, and Cognitive (William-Bergen et al. 2011). Hands-free or voice text driving involves all four types of distractions in various degrees. A research was conducted with both an on-road and a driving simulator experiment including cognitive, visual, and manual tasks with a voice prompt and non-voice prompt. It found there are less visual demands upon drivers with voice prompt tasks. Additionally, the difficulty of the tasks increased the intensity of mental workload (Xie et al. 2013). Interacting with a speech-to-text system
was the most cognitively cumbersome activity compared to others such as listening to a radio, conversing with passengers, etc. (Strayer et al. 2015). The National Highway Traffic Safety Administration published guidelines for further investigations of this risky behavior. In details, this study involved a driving simulator and occlusion goggles under different text type, length, and ambient conditions. It examined the total eye-off-road time and total shutter open time in these different conditions. Understandably, the guidelines revealed that when the level of ambient complexity and length of text increased, the ratio of the total eye-off-road time and total shutter open time also increased. It is worth noting that this ratio slightly increased when reading a text message rather than responding to a text message (Peng et al. 2014). Xie et al. (2013) indicated the drivers who were distracted by cell phones, did look at their environment but fail to see up to 50 percent of the information in their driving environment. Although vision is the most important sense for safe driving, drivers using hands-free phones have a tendency to “look at” but not “see” objects. Moreover, not only the way that drivers use cellphone while driving had impact on their behavior but also age and gender of drivers can be effective factors. According to Akaateba and Amoh-Gyimah ‘s study (2013), younger male had significantly more traffic violations regarding to cell phone use while driving due to overestimating their driving skills.

Studies mentioned above measured some hands-free secondary tasks such as listening, calling and texting. The question here is how safe hands-free text driving can be, how the context complexity level of hands-free text driving affects drivers’ behavior, and how much reading of a text message in driving is safer compared with responding to a text. It is the intention of this study to compare drivers' (balanced in age and gender)
performances while they are text driving in two forms: hand-held and hands-free with two different levels of context complexity and two response modes: read-only and response-required. The impacts of these three factors on driver performance were assessed. Eight driving scenarios with multiple challenging road events and environmental conditions were developed to assess driver performance. Each driver was tested in all eight scenarios that varied by the three factors. The experiment results provided valuable information as to how the communication methods individuals employed in text driving could cause safety concerns while driving.

2.3. DESCRIPTION OF STUDY

To gain insight into drivers’ performance associated with the different forms of text driving in various challenging conditions, a survey and a driving simulation experiment were conducted. The survey investigated the texting habits and driving experience of drivers through SuveyMonkey on the Internet. The participants’ demographic information such as age and gender were collected in order to establish experimental parameters such as blocking and sample sizing. Participants were asked to give a personal rating of how they believe texting affects their own driving, as well as whether they have ever used hands-free texting or not. The driving simulation experiment aimed to examine individual’s driving performance with different forms of texting under various scenario elements, including brake events, signs, and traffic rules. The designed experiment allowed a complete analysis of each participant’s driving performance given various types of conditions as well as different forms of texting. A detailed description of both the survey and the driving simulation experiment is given below.
2.3.1. Survey

A survey (via SurveyMonkey) was conducted on smartphone users to inquire about their use of smartphones while driving. The online survey provided the opportunity to recruit people anywhere in the country. It also eliminated the possibility of entering incorrect data from a pencil and paper survey. Using SurveyMonkey, the data downloaded directly to Excel which allowed us for further analysis. Participants completing the survey were asked to provide certain demographic information including age, gender, and detailed driving experience. Following that, five questions were asked about driver’s experience in text driving such as frequency, form, and effect. They were also asked to provide a personal rating on how they felt texting while driving affected their driving. In appendix 1 and appendix 2, you can see a sample survey and the consent form, respectively. A total of 232 subjects, 119 females, 113 males, participated in the survey. Among them, 98 participants were in the 20+ age group, 76 participants were in the 30+ age group, 43 participants were in the 40+ age group, 14 participants were in the 50+ age group and one person in the 60+ age group.

2.3.2. Driving Simulation Experiment

2.3.2.1. Design of the Experiment

The driving simulation experiment was designed to assess the effect of various forms of texting behaviors in driving. The factors investigated in the developed driving simulation experiment were categorized into two types: main factors and blocking factors (see Table 1). In particular, hand-held vs. hands-free texting was considered as the first main factor. Secondly, we also investigated whether responding to a text or
simply reading a text had any influence on drivers’ driving performance. Moreover, in order to see whether the context complexity of a text message had any significant impact upon performance, separate text conversations were created to generate a clear distinction between hard and easy texts. Following the survey results, four age groups were considered: 20+, 30+, 40+ and 50+, and two genders as blocking factors in the experiment. In total, three main factors and two blocking factors are measured.

<table>
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<td><strong>Factors</strong></td>
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<td><strong>Main Factors</strong></td>
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<tr>
<td>Texting form</td>
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<td>Response mode</td>
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<tr>
<td>Text Complexity</td>
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<tr>
<td><strong>Blocking Factors</strong></td>
</tr>
<tr>
<td>Age</td>
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<tr>
<td>Gender</td>
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A blocked factorial experiment design (1) with three main factors: the form of texting (F), response mode (R), and text complexity (C) and two blocking factors: age (A) and gender (G) was employed in the study with the following model.

\[ y = \mu + \tau_i + \beta_j + \gamma_k + (\tau \beta)_{ij} + (\tau \gamma)_{jk} + (\tau \beta \gamma)_{ijk} + \delta_l + v_m + (\delta v)_{lm} + e_{ijklm} \]  

(1)

\( \mu, \tau, \beta, \gamma, (\tau \beta)_{ij}, (\tau \gamma)_{jk} \) and \((\tau \beta \gamma)_{ijk}\) represent the effects of the main factors: F, R, C and their two way and three way interactions, respectively. \( \delta, v, \) and \((\delta v)_{lm}\) are the effects of blocking factors: A, G, and their interaction. \( e_{ijklm} \) refers to the analysis error.
2.3.2.2. Participants

A total of 48 drivers balanced in age (four age groups considered) and gender took part in the experiment. The participants were recruited from the University of Rhode Island, the Rhode Island Division of Motor Vehicles (DMV), nearby Wal-Mart and shopping malls. All of the participants had their drivers’ license for at least 2 years and drive approximately 12,000 miles annually. None of the participants had a record of cellphone violation while driving. All experiments were conducted in the Driving Simulation Lab at the University of Rhode Island.

2.3.2.3. Driving Simulator

A virtual-reality driving simulator in the lab was employed in the experiment. The simulator provides a high-fidelity real-world driving environment that can be customized for various applications (Wang & Song 2011; Motamedi, et al. 2015). The TranSim VS IV driving simulator, produced by the L3 Corporation, is a virtual-reality driving simulator which consists of a regular driving module and three channel plasma monitors in an immersive driving environment that combines the look and feel of a real vehicle. Participants interact with the simulator using a sedan’s steering wheel and pedals that provide real-time feedback. A separate program called “Scenario Builder” was used to create the desired conditions for scenarios. In this study, due to the consideration of two forms of texting, levels of the context complexity, and response modes, eight scenarios were developed and randomly assigned to each condition in order to avoid learning effects. The number of traffic violations that occurred during
each scenario was assessed. Figure 1 gives a snapshot of the driving simulator employed in the experiment.

![Driving Simulator](image)

Figure 1 TranSim VS IV, The Driving Simulator Employed in the Experiment

2.3.2.4. Simulated Scenarios

The participants engaged in eight scenarios including all combinations of the three main factors. In each scenario, the participants drove approximately one mile on the urban two-lane road. The participants were asked to keep their speed in the 25-35 mph range or they would be penalized in the speed maintenance or driving over speed limit categories. The challenging situations could include crash or near crash events, for instance, where other drivers or pedestrians could emerge suddenly thus provoking collisions if not avoided. By demanding active action from the driver, we were able to obtain an assessment about each driver’s performance. Moreover, these eight scenarios were not exactly similar in order to avoid the learning effect. These eight scenarios are
similar in many ways, such as road environment, number of traffic lights, stop signs, left and right turns; however, they are different in objects such as people and cars used in the scenarios. Furthermore, the participants received a maximum of five texts while they were facing challenging traffic situations in each of the eight scenarios.

In the hand-held part of the experiment, participants held their own smartphones in their hand; and they received, read, and responded to text messages with varying levels of context complexity while driving. The participants were asked to use their personal smartphones to eliminate any variation caused by using an unfamiliar smartphone.

In the hands-free part, participants did not touch either their smartphones or any button. The texts were read aloud to them by a computerized voice which was created to mimic the interaction that would occur with an integrated Bluetooth hands-free audio system which is common in modern automobiles. Using simple voice commands, participants received and sent text messages vocally. The sequence of prompts simulates the hands-free audio systems in the modern automobiles. A computerized voice notified the driver: “You have received a new message. Do you want me to read it, yes or no?” The driver simply would say, “Yes” in order to vocally receive the text message. After listening to the text, the drivers were asked, “Do you want to respond?” Then the driver based on forms of the text message, read-only or respond-required, would answer.

The other factor investigated was reading or responding which added degrees of cognitive load which could adversely affect an individual’s ability to drive. Two sets of text messages were developed regarding this factor (see table 2). It is worth noting that at the beginning of the experiment, participants were informed about whether they would be required to read/listen to the text messages or respond to them.
Table 2 Example of Text Messages

<table>
<thead>
<tr>
<th>Factor</th>
<th>Hard Level</th>
<th>Easy Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read-only</td>
<td>The budget for the curiosity rover that was sent to Mars is less than the worldwide military expenditures made in only 13 hours.</td>
<td>Hey, this is your assistant Steven. I have a new phone number. I just wanted to make sure that you could put me in your contacts”</td>
</tr>
<tr>
<td>Response-required</td>
<td>In March, Malaysia flight 370 disappeared. What is the most surprising part of the Malaysian flight 370 mystery?</td>
<td>Hey, how was your day? I was wondering what time you are free.</td>
</tr>
</tbody>
</table>

Additionally, the effect of the cognitive load of the text messages with different levels of the context complexity and forms was measured in this study. Two distinct sets of text messages were developed with cognitively “easy” and “hard” texts (see Table 2). The rationale behind the text development and selection lies in the idea of passive versus creative thought. By either presenting to or requesting information from a participant that incites or demands a thoughtful response as opposed to a simple regurgitation of fact, a higher level of cognitive demand is placed upon the subjects (Beede & Kass 2006). For example, prompting the participant with a choice, perhaps siding on a controversial current event, they are forced to take a stance. In taking this stance, they put themselves through a rigor where they search their minds and decide on their values.

2.3.2.5. Conducting the Experiment

An orientation video was administered to explain the experiment to the participants and they were given a 10 minute warm-up run, followed by the experiment. In total,
participant went through eight scenarios in random sequence. In addition to the random sequence of eight scenarios, all combinations of the three main factors were randomly chosen. It is worth noting that at the beginning of each scenario, the participants were informed of the form of texting, hand-held or hands-free, and how they would need to respond to the text messages which they receive during the scenario. Then participants drove the 8 scenarios and did the different forms of text driving. They were allowed to take a break after each scenario.

2.3.2.6. Measurement

The participants’ driving performance was recorded and monitored by two researchers and one video camera. The two researchers documented the driver’s driving violations based on Table 3. The measured number of traffic violations that occurred within the eight scenarios was the response. Moreover, a video captured the entire test showing a direct shot of the driver and the screens in front of the driver. In the case of any disagreement between the two researchers during the assessment, a video check process enabled the researchers to resolve the disagreement.

As mentioned above, the response was determined based on 10 categories as shown in Table 3. The numbers of violations were recorded for each of these categories with the exception of speed maintenance and visual focus which were measured with a Likert scale between 0 and 5 (the smaller, the better). The weights shown in Table 3 were obtained based on consultation with the Division of Motor Vehicles driver examiners and traffic safety officials. After multiplying the number of recorded violation \( V_i \) by its weight \( W_i \) and subtracting the sum of all multiplied numbers from 100, an
individual's score/response (the higher, the better) for each scenario was obtained (Equation 2). Therefore, there would be eight scores/responses for each subject corresponding to eight scenarios (all combinations of the three main factors). Table 4 is one example of the recorded violation and the performance score/response.

\[ S_{\text{for each Scenario}} = 100 - \Sigma V_i \times W_i \]  

(2)

<table>
<thead>
<tr>
<th>Violation</th>
<th>Driving Over Speed Limit</th>
<th>Following Distance</th>
<th>Improper Lane Position</th>
<th>Hard Braking</th>
<th>Collision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>2</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Violation</td>
<td>Hands off Wheel</td>
<td>Failure to Signal</td>
<td>Speed Maintenance</td>
<td>Violating Sign/Light</td>
<td>Visual Focus</td>
</tr>
<tr>
<td>Weight</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

2.4. RESULTS AND DISCUSSION

2.4.1. Survey Results

Two hundred and thirty-two people participated in the survey. Based on the answers obtained, 80% of the participants reported text driving for more than 3 years, 13% with 1 to 3 years of texting experience, and the rest with less than 1 year. Moreover, 20.3% of the participant’s vehicles have an integrated hands-free feature for smartphones. Approximately 70% of them admitted using hand-held texting while driving, 17.2% have used both forms of texting, and the rest have used hands-free texting while driving. It is worth noting that 88.4% of the participants agreed that any form of texting while
driving has negative or very adverse effects on their performance. However, 25.4% of them reported that they still often, frequently or very frequently do text driving. Figure 2 and 3 illustrated the text driving frequency. Additionally, the frequency and effect of text driving was demonstrated in Figure 4.

2.4.2. Experiment Results

Table 5 gives the mean driving performance at each level and condition. The results were analyzed using the ANOVA (with 95% confidence level) procedure and the results are explained below (Table 6). Among all three main factors, the form of texting, hand-held and hands-free, was significant with a p-value < 0.0001. Moreover, as figure 5 shows, hands-free text driving caused significantly less distraction compared to hand-held text driving. The other main factor that was significantly affecting drivers’ performance was response mode (p-value = 0.024). Drivers had better performance in read-only than response-required response mode (Figure 5). It is worth noting that the text complexity factor appears to be marginally significant (p-value = 0.059). In addition, there was only one two-way significant interaction between the response mode and texting form factors as shown in Figure 7.
Table 4 Example of Recorded Violation

<table>
<thead>
<tr>
<th>Violation Score</th>
<th>Over Speed Limit</th>
<th>Following Distance</th>
<th>Improper Lane Position</th>
<th>Hard Braking</th>
<th>Collision</th>
<th>Hands off Wheel</th>
<th>Failure to Signal</th>
<th>Speed Maintenance</th>
<th>Violating Sign/Light</th>
<th>Visual Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>81</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>75</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>81</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>91</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>83</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>69</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>83</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>82</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>
Figure 2 The Text Driving Effect on Driving Performance by Age Group

Figure 3 The Text Driving Frequency by Age Groups
Figure 4 Frequency and Effect of Text Driving

Table 5 Mean Responses at Various Levels and Conditions

<table>
<thead>
<tr>
<th>Factor</th>
<th>Hand-held</th>
<th>HANDS-FREE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Read-only</td>
<td>Response-required</td>
</tr>
<tr>
<td></td>
<td>Easy</td>
<td>Complex</td>
</tr>
<tr>
<td>Female</td>
<td>20°</td>
<td>82.00</td>
</tr>
<tr>
<td></td>
<td>30°</td>
<td>87.83</td>
</tr>
<tr>
<td></td>
<td>40°</td>
<td>82.33</td>
</tr>
<tr>
<td></td>
<td>50°</td>
<td>76.33</td>
</tr>
<tr>
<td>Male</td>
<td>20°</td>
<td>85.67</td>
</tr>
<tr>
<td></td>
<td>30°</td>
<td>88.43</td>
</tr>
<tr>
<td></td>
<td>40°</td>
<td>79.17</td>
</tr>
<tr>
<td></td>
<td>50°</td>
<td>69.67</td>
</tr>
</tbody>
</table>
According to the ANOVA results, among the blocking factors, age was significant with a p-value <0.0001. The second age group (30+) drivers had better performance than other age groups (Figure 5). Moreover, as you can see in Table 6, there is a significant interaction between age and gender (with a p-value <0.0001). Figure 6 clearly illustrated that performance of drivers in the age group of 30+ is better than other age groups regardless of the gender. It can also be seen that men had better performance than women in younger age groups (20+ and 30+). However, men's performance was found worse than women's in older age groups such as 40+ and 50+.

Table 6 ANOVA for the Full Model

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>1</td>
<td>6056.09</td>
<td>6056.09</td>
<td>67.76</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>R</td>
<td>1</td>
<td>462.00</td>
<td>462.00</td>
<td>5.17</td>
<td>0.024*</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>320.92</td>
<td>320.92</td>
<td>3.59</td>
<td>0.059</td>
</tr>
<tr>
<td>F*R</td>
<td>1</td>
<td>358.68</td>
<td>358.68</td>
<td>4.01</td>
<td>0.046*</td>
</tr>
<tr>
<td>F*C</td>
<td>1</td>
<td>80.05</td>
<td>80.05</td>
<td>0.90</td>
<td>0.345</td>
</tr>
<tr>
<td>R*C</td>
<td>1</td>
<td>44.22</td>
<td>44.22</td>
<td>0.49</td>
<td>0.482</td>
</tr>
<tr>
<td>F<em>R</em>C</td>
<td>1</td>
<td>297.90</td>
<td>297.90</td>
<td>3.33</td>
<td>0.069</td>
</tr>
<tr>
<td>A</td>
<td>3</td>
<td>5796.78</td>
<td>1932.62</td>
<td>21.62</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>G</td>
<td>1</td>
<td>119.58</td>
<td>119.58</td>
<td>1.34</td>
<td>0.248</td>
</tr>
<tr>
<td>A*G</td>
<td>3</td>
<td>3699.30</td>
<td>1233.08</td>
<td>13.80</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>Error</td>
<td>369</td>
<td>32980</td>
<td>89.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack-of-fit</td>
<td>49</td>
<td>4666.2</td>
<td>95.23</td>
<td>1.08</td>
<td>0.347</td>
</tr>
<tr>
<td>Pure Error</td>
<td>320</td>
<td>28314.6</td>
<td>88.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>383</td>
<td>49906.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at α = 0.05
According to the driver simulation experiment results, hands-free texting favorably impacted drivers’ performance. In order to further investigate hands-free texting and its effect, we used ANOVA separately in all violation categories to identify those which resulted in noticeably less distraction. The ANOVA results reported that hands-free texting could significantly help drivers maintain better visual focus on the road ($p$-value < 0.001), speed maintenance ($p$-value < 0.001), less hands off the wheel ($p$-value < 0.001), better lane position ($p$-value < 0.001) and collusion ($p$-value = 0.018). With respect to other violations, driver’s driving performance hands-free texting did not improve driver’s performance.

Figure 5 Main Effect Plots on Main Factors and Blocking Factors
Figure 6 Interaction Plots between Texting Form and Response Mode

Figure 7 Interaction Plots between Age and Gender
2.4.3. Discussions

According to the survey results, although almost all of the participants agreed that any form of text driving has negative or very negative effects on their performance, nearly 25% of them reported that they still frequently or very frequently do text driving. This finding is supported by the National Safety Council report about distracted drivers (NSC 2010). Despite participants’ stated belief in the dangers, they reported using cell phones while driving.

There are four types of distractions considered in text driving: visual, auditory, manual, and cognitive. Hands-free or voice texting while driving involves all four of these types of distractions in various degrees (William-Berken et al. 2011). But the question is whether these distractions are unsafe? According to the driving simulation experiment results, hands-free text driving, compared to hand-held text driving, could lessen drivers’ distraction especially in terms of visual and manual ability. The results obtained from this study clearly demonstrated that an auditory- vocal interface had advantages over visual-manual interfaces. This finding is consistently supported by many naturalistic studies (Dingus 2014; Dingus et al. 2011; Victor, et al. 2013; Dozza et al. 2013; William-Berken et al. 2011). Another promising finding is that the response mode of text driving mostly had a significant effect on performances could be blamed more on visual and manual distraction. This is also supported by previous studies (Strayer et al. 2013; Peng et al. 2014). Regarding the cognitive load effect of texting, the experiment results did show marginal significant differences between hard and easy levels of complexity. This finding agrees with the naturalistic studies which stated that drivers should be very deep in thought to increase the risk of crashes (Dingus 2014;
Dingus et al. 2011; Victor et al. 2013; Dozza et al. 2013; William-Bergen et al. 2011). It can be concluded that visual and manual distractions are key causes of crash or near crash situations while heavy cognitive load can worsen these distractions.

### 2.5. CONCLUSION

This study identified the impact of text driving in different forms, response modes, and complexity levels on driving performance. The online survey was conducted to gain a better understanding of the daily texting experiences and participants' text driving behaviors. The majority of drivers reported that they are aware of the many risks associated with text driving; however, approximately one-fourth of them reported that they still often do text driving. The driving simulation experiment examined the effect of two forms of text driving (hand-held and hands-free), two response mode (read-only and response-required), and two levels of text complexity (hard and easy) on drivers’ performance. As a result, hands-free texting and not responding to texts significantly improved drivers’ performance in different challenging situations. The results gained from the study support the notion that reducing visual and manual distractions could improve driving safety. It also showed that the age of drivers affected the performance of their driving. Male drivers in the 30+ age group had the best performance while male drivers in the 50+ age group had the worst performance. Gender does not appear to impact the driving performance.

Although this research utilized a high fidelity simulator with a high level of experimental control, replications of the study in real-life driving settings, such as naturalistic studies, are needed in order to ensure the validity of the findings. In future
studies, other factors such as weather conditions, traffic density, and visual conditions (day/night) will be addressed. Other forms of hands-free devices will be considered.
ACKNOWLEDGMENTS

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REFERENCE


CHAPTER 3

“Older Adult Drivers’ Challenges and Technology Acceptance”

by

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ABSTRACT

Driving is an essential activity in living a fulfilling lifestyle. Older adults, like the rest of the population, require a means of transportation to participate in important lifestyle choices; however, declines in their sensory, motor, perceptual, and cognitive abilities limit their driving capabilities. These limitations motivated this study to investigate older adult drivers’ driving challenges and solutions by conducting two questionnaires. The in-vehicle technologies which mitigate driving challenges were identified in the first questionnaire. In this study, the acceptance of the identified technologies is explored by conducting a second questionnaire. A four dimensional model which included perceived usefulness, perceived ease of use, perceived safety, and perceived annoyance is considered in the second questionnaire.

In total, 250 older adult drivers participated in these questionnaires. The responses obtained from both questionnaires identified potential driving challenges that they were facing and whether they intend to use the identified in-vehicle technologies. Having more information about the acceptance of these technologies can help engineers better understand the factors that make technologies useful to older adult drivers, and thus improve their driving safety.
3.1. INTRODUCTION

In developed countries, the population of older adult drivers is predicted to be the fastest growing driver segment in the next ten years (Casutt et al. 2014). As quality of life in these countries increases, older adult drivers are more likely to continue driving regardless of their age (Bélanger et al. 2010). Their tendency to continue driving is increasing while complicating factors such as age-related sensory, physical, and cognitive changes, as well as complex modern traffic environments, pose increasing risks to the older adult populations. In addition to these risks, if older adult drivers are involved in crashes, they are more fragile and more likely to incur fatal injury while as Schulz et al (2014) stated today’s health care costs are unendurable to them. The trends are working unfavorably in both directions, with the older adult driver population and their tendency to continue driving increasing, and their driving capabilities are decreasing due to the normal aging process (Musselwhite et al. 2015). This negative trends and other mentioned risks have created increasing safety issues for older adult drivers. A variety of in-vehicle technologies has been developed and implemented in modern vehicles to mitigate driving challenges. In order to develop and employ technologies which address the needs of older adults, it is important to understand older adult driver acceptance of these technologies. The important questions are:

- What driving situations pose challenges to older adult drivers?
- What kind of assistance do they need in those situations?
- Which in-vehicle technologies can provide the needed assistance?
- What are the highlighting dimensions of older adult drivers’ in-vehicle technology acceptance?
To answer these questions, a survey was conducted to identify those challenging driving situations that older adult drivers tend to avoid or feel reluctant to engage. Older adult drivers were also surveyed on their demographic, driving experiences, health concerns, and crash experiences. After identifying the driving challenges and type of required assistance, this study explored feasible in-vehicle technologies that could provide assistance to older adult drivers. The study focuses on currently available, lower-level in-vehicle technology that could enhance older adult drivers' driving and their driving safety. Through the questionnaires, we explored older adult drivers’ acceptance of identified in-vehicle technologies such as Automatic Windshield Wipers (AWW) system, Night Vision Camera (NVC), Adaptive Cruise Control (ACC), Lane Departure Warning (LDW) system, Side View Assist (SVA) system, and Automated Pedestrian Detecting system (APD).

3.2. BACKGROUND

3.2.1. Older Adults and Driving Risks

The population of older adult drivers is increasing in the United States. With the aging of the Baby Boom generation, census data estimates that the population over 65 years old will double by 2050 (Ortman et al. 2014). To live a fulfilling independent lifestyle, older adults need to have access to goods and services as well as to social and leisure activities. Driving is the easiest, but also the riskiest, way to access these activities (Hojjati-Emami et al. 2014). The American Association of Retired Persons reported drivers over 65 make 90% of their trips in private vehicles as a primary means...
of transportation (Houser 2005). Although age cannot be a reliable indicator of an individual’s driving performance (Siren & Meng 2012), older adult drivers are noted for their decline in sensory and motor capabilities, and increase in perceptual and cognitive impairment (Horswill et al. 2008; Motamedi 2016; Pavlou et al. 2016). Dawson et al. (2009) mentioned that by 2030 older adult drivers will account for one fourth of driver fatalities. These findings cause concerns about the potential driving risks, which older adult drivers pose to themselves and to other road users. While driving is an essential activity in the older adult lifestyle (Rosenbloom et al. 2012), an important question needs to be addressed: “How can driving risks associated with older adult drivers be reduced?”

In order to answer this question, challenging driving situations identified by older adult drivers were in need of investigation. A review study of older adult drivers and their crash involvement, which included articles published in North America since 1990, found that these drivers are more likely to have been at fault in intersection crashes than younger drivers (Cicchino & McCartt, 2015). They also experienced a high rate of crashes when they were turning, particularly when making left turns (Cicchino & McCartt, 2015; Mayhew et al., 2006). However, subjective studies have shown that older adult drivers report decreased driving abilities in certain conditions, including complex intersections, highways, difficult weather conditions, and driving at night (Levin et al. 2012). Moreover, previous subjective research has identified that older adult drivers avoid driving in challenging situations, such as at night, in bad weather, on slippery roads, and in heavy traffic (Charlton et al. 2006). According to a survey conducted in 2012, with participation of 1,962 older adult drivers, night driving, bad
weather, unfamiliar areas, heavy traffic, and long distances were found to be more challenging for older adult drivers compared to drivers in their 40s (Henriksson et al. 2014). These challenges possibility speed up older adults’ driving cessation. MacLeod et al. (2014) mentioned that health concerns such as vision, cognitive and some functional limitation of older adults were other predictor of the driving cessation. Key questions remained unanswered in mentioned studies are how could older adults' driving safety be enhanced and what driving assistance technology could be provided? This study identified possible difficulties and challenges facing older adult drivers and explored some modern in-vehicle technologies to address these questions.

3.2.2. In-vehicle Technologies

In-vehicle technologies have been categorized according to a scale ranging from 0 to 5 (Mehler et al. 2014) associated with their level of automation. At Level-0 are technologies with a degree of functionality that may provide information assistance but no automated control of the vehicle. In-vehicle technologies in the higher levels have more automated control of the vehicle. Although Level-4 systems such as self-driving cars seem to be a final solution for challenges facing older adult drivers, we are not quite ready for it yet (Reimer 2014). Therefore, in this study, the focus was on lower level automation systems which could improve driver safety in identified driving situations based on an initial questionnaire. An apparent and important reason to choose low-level systems is the limited cognitive capacity of older adult drivers, as mentioned before (Siren & Meng 2012). The recent research revealed that age had a negative impact on the safety effectiveness of in-vehicle systems with high level of automation (Son et al.
The systems may distract older adult drivers instead of increasing their safety while driving (Lam 2002). Thus, it is imperative to investigate older adult drivers’ acceptance regarding the available lower-level technologies and the effective adoption of these technologies which have an essential role in transitioning older adult drivers toward fully automated vehicles (Reimer 2014).

3.2.3. Technology Acceptance

Many new driving assistance technologies are developed to help resolve some specific driving challenges. However, these new technologies can not benefit the users, especially older adult users, unless they are accepted. One of the early frameworks which explained technologies acceptance is the Technology Acceptance Model (TAM) (Davis 1989). This model found perceived usefulness and perceived ease of use to be main effective factors on users’ decision. This model was extended to TAM2 (Venkatesh & Davis 2000), TAM3 (Venkatesh & Bala 2008) and the Unified Theories of Technology Acceptance Model (UTAUT) (Venkatesh et al. 2003) which integrated different models with the base of TAM.

TAM and its extended models were used and applied in different contexts with the original context of this model being the desktop computer. For a driving environment, there has been limited research considering factors such as motion and environmental conditions. Osswald et al. (2012) introduced the Car Technology Acceptance Model (CTAM) for fuel consumption and traffic emission in-vehicle technology application. This model basically added perceived anxiety and perceived safety as relevant and additional dimensions for the UTAUT model. Madigan et al. (2016) stated that the
reliability of the CTAM’s scales were well demonstrated but the impact of these factors on behavioral intentions of driving information technology systems was not investigated. Moreover, all of the above mentioned models might be age, gender, and experience sensitive. Therefore, in this study the TAM model was employed with the recently introduced dimension of CTAM, perceived safety, and perceived of annoyance to assess the acceptance of in-vehicle technologies in a driving environment.

3.3. METHODOLOGY

To gain insights into the mobility challenges facing older adults and their acceptance of in-vehicle technologies, two questionnaires were developed and administered to a number of older adult drivers in Rhode Island. According to United States Census Bureau (2015), 16.1% of the population in this state are 65 and older which ranks Rhode Island the 9th oldest state in the nation. The study conducted in Rhode Island could be easily modified to suit the needs of other states to assess their aging drivers.

The first questionnaire was designed to study the situations that older adult drivers identified as challenging. A total of 135 subjects participated. After finding challenging driving situations and the assistance that older adult drivers need in these situations, a number of in-vehicle driving assistance technologies were identified and selected. Then in the second questionnaire, older adult drivers were asked about acceptance of these in-vehicle technologies. This questionnaire was developed based on a new adapted conceptual model for older adult drivers’ technology acceptance. In this study, the TAM model is adapted for the driving environment by adding perceived safety and perceived
anxiety dimensions. A total of 115 subjects participated in the second questionnaire. A detailed description of each questionnaire is provided below.

3.3.1. Questionnaire 1

Questionnaire 1 collected participants’ driving profile including demographics, driving experiences, health concerns, and crash experiences. Additionally, each participant was asked to identify the challenge level of 20 specific driving situations on a scale from 1 to 5 with 1 being not challenging and 5 being extremely challenging. These 20 situations are deducted from crash data analysis literature (Mayhew et al. 2006; Cicchino & McCartt 2015; Levin et al. 2012; Charlton et al. 2006; Henriksson et al. 2014) and are summarized in Table 7.

The 135 participants were recruited from the University of Rhode Island, the Osher Lifelong Learning Institute (OLLI), and other local communities such as older adult centers and churches. All participants were living in Rhode Island, holding a valid driver's license, and still driving. It is worth noting that the administration method of this questionnaire was paper-and-pencil. The researchers met all participants in person, explained the purpose of the questionnaire, and gave instructions to the participants. They were asked to sign the consent form (see Appendix 5). The questionnaire included a total of 28 questions (see Appendix 3). These questions could be classified into 5 groups:

1. Demographics such as age (including five groups: <60, 60-70, 70-80, 80-90, >90) and gender (including two groups: female and male);
2. Driving experiences such as car usage, frequency of driving, and average trip length in time;
3. Health concerns such as memory, vision, hearing, muscle weakness, speaking, balance, pain, heart condition, bones or joints, and breathing;

4. Driving situations where they were at fault in a crash experience in the past 10 years;

5. Challenge rating of each of the 20 specific driving situations in a 1 to 5 Likert scale.

Most of the questions asked the participant to check boxes with some questions requiring written answers. Lastly, participants were asked if they were interested in taking part in a follow-up questionnaire regarding in-vehicle technology in the future. Through the results of this questionnaire, it was expected that sufficient information could be gathered regarding older drivers driving experiences and their capability of driving in those challenging situations.

3.3.2. Questionnaire 2

After identifying older adult drivers’ challenging driving situations, some in-vehicle technologies that could mitigate older adults' driving difficulties were investigated. Six in-vehicle systems that assist drivers in various driving situations were identified (Mitchell, CGB and Suen, 1997; Davidse, 2006). In the second column of Table 7, the challenging driving situations were categorized based on their similarities. Moreover, the type of support that could prevent such driving-related difficulties, and the in-vehicle technology which could provide such a support were provided in other columns.
### Table 7 The Challenging Driving Situation Classifications, the Needed Assistance and Proposed In-vehicle Technologies

<table>
<thead>
<tr>
<th>Challenging Driving Situation</th>
<th>Grouped Situation</th>
<th>Possible Weakness</th>
<th>Proposed In-vehicle Technology</th>
<th>Provided Assistance</th>
<th>Improvement Made</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Driving in light rain</td>
<td>Weather Condition</td>
<td>Vision Divided attention</td>
<td>Automatic Windshield Wipers (AWW) system</td>
<td>Adapts the speed of wipers according to the precipitation</td>
<td>Reduce drivers’ need to multi-tasking</td>
</tr>
<tr>
<td>• Driving in light snow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Improve speed of processing information and making decisions</td>
</tr>
<tr>
<td>• Driving in light fog</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Driving in heavy rain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Driving in heavy snow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Driving in heavy fog</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Driving at night on lighted urban roads</td>
<td>Night Driving</td>
<td>Night vision</td>
<td>Night Vision Camera</td>
<td>Detect objects on road</td>
<td>Improve Low-light vision</td>
</tr>
<tr>
<td>• Driving at night on unlighted urban roads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Driving at night on lighted rural roads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Driving at night on unlighted rural roads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Driving on highways or high-speed roads that familiar with.</td>
<td>High Speed Roads</td>
<td>Motion perception Contracts sensitivity Peripheral vision</td>
<td>Adaptive Cruise Control (ACC) Lane Departure Warning (LDW) system</td>
<td>Control the vehicle speed according to other vehicles on the road Keep the vehicle in the lane</td>
<td>Draw attention to approaching traffic Assist the driver in directing his/her attention to relevant information</td>
</tr>
<tr>
<td>• Driving on highways or high-speed roads that unfamiliar with.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Changing lanes on a three- or four-lane divided highway.</td>
<td>Changing Lane</td>
<td>Flexibility of head and neck Peripheral vision</td>
<td>Side View Assist (SVA) system</td>
<td>Assist driver to check blind spots and signal if there are objects located in the blind spot</td>
<td>Increase the frequency of checking blind spots Draw attention to approaching traffic Provide early warning on the approaching traffic</td>
</tr>
<tr>
<td>Challenging Driving Situation</td>
<td>Grouped Situation</td>
<td>Possible Weakness</td>
<td>Proposed In-vehicle Technology</td>
<td>Provided Assistance</td>
<td>Improvement Made</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-------------------</td>
<td>-------------------</td>
<td>-------------------------------</td>
<td>----------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>• Driving in heavy traffic</td>
<td>Heavy Traffic</td>
<td>Motion perception Contracts sensitivity</td>
<td>Adaptive Cruise Control (ACC)</td>
<td>Assist driver to control the vehicle speed according to other vehicles on the road</td>
<td>Draw attention to approaching traffic Assist the driver in directing his attention to relevant information</td>
</tr>
<tr>
<td>• Approaching an intersection with traffic lights</td>
<td>Intersection</td>
<td>Selective attention</td>
<td>Automated Pedestrian Detecting (APD) system</td>
<td>Detects and alerts drivers when there is a danger of collision with a pedestrian or other objects</td>
<td>Assist the driver in directing his attention to relevant information Provide early warning on the approaching pedestrian Improve speed of processing information and making decisions</td>
</tr>
</tbody>
</table>
The first selected system was the Automatic Windshield Wipers (AWW) system which adapts the speed of wipers according to the precipitation through infrared sensor detection. It could improve driving safety by allowing drivers to continue focusing on the road without being distracted by the windshield wiper speed as the precipitation increases or decreases (Young 2014). This system could improve the speed of processing information and making decisions. The second system considered is the Night Vision Camera (NVC). This technology provides roadway information that is either difficult or impossible for the driver to obtain through direct vision, using infrared cameras to detect objects on a road. There are many studies confirming benefits of this system in enhancing safety although not many older adult drivers used this system (Eby et al. 2015). The third system considered in this study is the Lane Departure Warning (LDW) system designed to keep cars in the lane. It was estimated that this system could decrease 3 percent of all crashes that happen in the US (Blower 2014). Eby et al. (2015) recommend this technology to older drivers especially those who took medication that can cause drowsiness and those who took long trips. The fourth was the Adaptive Cruise Control (ACC) system that could help older adult drivers by adapting their driving speed to traffic on high speed roads. This system cuts some of the driving tasks and can have a positive impact on traffic operation by directing their attention to traffic (Li et al. 2016). The fifth system considered was the Side View Assist (SVA) system or Blind Spots Warning system. Lavalliere et al. (2011) in their simulator study compared blind spot checking among younger and older adult drivers and concluded that older drivers checked blind spots significantly less frequently. The authors mentioned that the system not only decreases older adult drivers' crashes, but also increases mirror checking.
frequency and provides prior knowledge on the next traffic situation which could promote more situational awareness. Last but not least, the Automated Pedestrian Detecting system (APD) was considered in the study. It appeared as the first in the Seven New Technologies to Help Older Drivers by Mulholland (2009). This system detects and alerts drivers when there is danger of collision with a pedestrian or other objects.

The identified in-vehicle technologies could potentially improve older adult drivers’ driving safety only when they are accepted and used by older adult drivers. This study was motivated to investigate older adult drivers’ acceptance of these technologies by considering a conceptual model called the Usefulness, Ease of use, Safety, and Annoyance model (UESAM). This model is based on two main effective factors on user decision such as perceived usefulness and perceived ease of use (TAM) as well as perceived safety (CTAM) and perceived annoyance. Since this study did not measure the variables after an actual driving experience, the model could study only perceived use behavior. The definition of the dimensions is stated in Table 8.

Table 8 Definition of the Conceptual Research Model Dimensions

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perceived Usefulness</td>
<td>The degree to which a driver believes that using a particular in-vehicle</td>
</tr>
<tr>
<td></td>
<td>technology could be helpful for his/her driving performance.</td>
</tr>
<tr>
<td>Perceived Ease of Use</td>
<td>The degree to which a driver believes that using a particular in-vehicle</td>
</tr>
<tr>
<td></td>
<td>technology could be used with little effort.</td>
</tr>
<tr>
<td>Perceived Safety</td>
<td>The degree to which a driver believes that using a particular in-vehicle</td>
</tr>
<tr>
<td></td>
<td>technology could ensure his or her well-being while driving.</td>
</tr>
<tr>
<td>Perceived Annoyance</td>
<td>The degree to which a driver believes that using a particular in-vehicle</td>
</tr>
<tr>
<td></td>
<td>technology could annoy him/her.</td>
</tr>
<tr>
<td>Perceived Use Behavior</td>
<td>The degree to which a driver believes that he/she would use a particular in-</td>
</tr>
<tr>
<td></td>
<td>vehicle technology.</td>
</tr>
</tbody>
</table>

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Questionnaire 2 was developed to rate the acceptance of the selected in-vehicle technology systems based on the UESAM model. After contacting the older adults who participated in the first questionnaire, questionnaire 2 was conducted in the same locations mentioned in section 3.1. The questions were categorized into 5 parts (see Appendix 2). The first 4 parts are the same as the first questionnaire. In the last part, participants were asked to rate six in-vehicle technology systems. Before being rated, each system was presented to the participants through slides, photos, and short videos. Following each presentation, based on the proposed model, participants’ opinions were collected. The perceived use behavior of each system was also rated. Participants rated each system using a 5 point Likert scale ranging from 1 (not likely) to 5 (extremely likely). All of the questions were multiple choice.

3.4. RESULTS

The results were divided into two parts corresponding to the two questionnaires. Questionnaire 1 identified the driving situations that were considered challenging by older adult drivers. As the results, the assistance which older adult drivers need in those driving situations as well as the in-vehicle technologies developed to provide the assistance were determined. In order to investigate older adult drivers’ acceptance regarding these in-vehicle technologies, questionnaire 2 was developed and conducted. Both questionnaires collected driving profile of participants.

3.4.1 Questionnaire 1

The majority of participants were recruited from three age groups, 61-70, 71-80, and 81-90 years old. Approximately 50% of them were in their 70s and 30% of them were
in their 60s. 16% of participants were between 81 and 90 years old, and one participant was in his/her 90s. Five of the participants were less than 60 years old. It is noted that two-thirds of participants were female. All of the participants were active drivers, and the majority of the older adult drivers (42%) have held their driver's license for 51-60 years. 30% of participants have had their license for 41-50 years, 24% received their driver's license for more than 60 years, and 4% have had their license for 31-40 years. Figure 8 shows results obtained from both questionnaires on how often and how long older adult drivers typically drive. According to the left-hand side of the figure, approximately 64% of the participants reported that they drove more than once a day. The right hand side of the figure showed that more than half of the participants responded that their drives took approximately 15-30 minutes.

One aim of the questionnaire was to map the self-reported health status of participants with their driving profiles. Health concerns included 10 categories (see section 3.1). Participants could choose multiple health concerns if applicable. The results are represented on the left-hand side of Figure 9. More than half of the participants (54%) reported having some health concerns. As shown, vision, bones and joints (flexibility), and memory were the top-rated health concerns by older adult drivers. In the questionnaire, participants were asked to report crash experiences that they had in the previous 10 years (allowed multiple choices). Overall, 94% of the participants had at least one crash experience. According to Figure 9, most of the crash experiences occurred at snow, fog, intersections, changing lanes, night, merging into traffic and highways.
Figure 8 The Length and Frequency of Older Adults Driving Obtained from Both Questionnaires

Figure 9 Health Concerns and Crash Experience of Older Adult Drivers Obtained from Both Questionnaires
In order to understand the driving situations which older adult drivers consider challenging or dangerous, the last part of the questionnaire asked them to rate the listed 20 specific driving situations. A 1 to 5 Likert scale allowed participants to provide a rating on these challenging and dangerous driving situations where 1 means not challenging and 5 means extremely challenging.

Figure 10 shows the average rating of challenging driving situations according to participants’ ratings. Weather conditions such as snow, fog, and rain, night driving in urban and rural, unfamiliar high-speed roads, passing vehicles, heavy traffic, and changing lanes were considered more challenging driving situations (rated more than 2 in average which means somewhat challenging) than others by older adult drivers.

Figure 10 The Average Rating of Challenging Driving Situations
One aim of the first questionnaire was to gain a better understanding of the relationship between driving profiles and their ratings. According to the older adult drivers’ ratings, the first 13 driving situations from the left on Figure 10 were considered challenging (rated more than 2). These challenging situations were categorized into six groups based on their similarities: weather conditions, night driving, high-speed roads, changing lanes (or passing vehicle), heavy traffic and intersection. The majority of older adult drivers who rated weather conditions, night driving, and changing lanes (the three top challenging situations) as challenging driving situations (more than 2) were in their 70s, and most of them were females. Most of the female older adult drivers in the 61-70 age group rated unfamiliar highways and heavy traffic as challenging. Moreover, more than half of the older adult drivers who considered these five driving situations challenging drove not more than once a week. It is worth noting that the majority of the participants’ trips took less than 30 minutes. Older adult drivers who drove less frequently and for shorter lengths were more likely to consider these five driving situations challenging. In terms of health concerns, the participants who rated these five driving situations challenging typically had at least 2 health concerns.

3.4.2 Questionnaire 2

As was the case for questionnaire 1, in questionnaire 2, 95% (majority) of participants were between 61 and 90 years old. 3% and 2% of the participants were older than 90 years old and younger than 60 years old, respectively. 61% of participants were female. 35% of older adult drivers have held their driver's license for 51-60 years, 27% of participants have had their license for more than 60 years and 23% of participants
have received their drivers’ license between 41 and 50 years ago. There were 7 older adult drivers who had acquired their driver license less than 20 years. There were other 7 drivers who have their license for 21-30 years. Only three older adult drivers have held their license for 31-40 years.

Similar to questionnaire 1, two survey questions asked about how often and how long older adult respondents usually drove (see Figure 8). Similar to the first questionnaire’s results, more than half of them reported that they drove more than once a day and they usually drive 15-30 minutes.

Figure 9 illustrates the percentages of reported health concerns from questionnaire 2’s participants. More than half of them reported some health issues. Clearly, vision, bones, and joints (flexibility), pain, and balance were the most reported and prominent concerns of older adult drivers. These results were almost similar to the health concerns results of questionnaire 1 except for vision, memory and speaking which may be more popular in questionnaire 1 and pain which is more popular in questionnaire 2. Figure 9 represents the crash experiences on its right hand side. More than half of the responders (59%) did not have any crash experiences. But the most popular response was that crash experiences occurred due to weather conditions such as snow and fog, intersections, changing lanes, driving at night, merging into traffic and driving on highways. These results are similar to those obtained from questionnaire 1.

As mentioned, the aim of questionnaire 2 was to explore older adults’ acceptance regarding the six in-vehicle technologies which aim to enhance the driving safety in the identified driving situations. Participants’ acceptance was measured based on the UESAM model. In addition, they were asked to rate how likely they would be to use
the system. The Likert scale in this questionnaire ranges from 1 (not likely) to 5 (extremely likely). In this section, firstly, the descriptive statistics of older adults’ opinions about each of the in-vehicle technologies was reported. Secondly, the study compared the six systems based on the UESAM model’s dimensions. Then perceived use behavior was discussed. Data were classified according to popular health concerns to see if there is any difference between perceptions of older adults with different health concerns. Subsequently, the scope was changed to look at each system individually to determine the underlying structure in the UESAM model results.

Table 9 illustrates the average ratings of each system based on UESAM model’s dimensions and perceived use behavior. According to the Analysis of Variance (ANOVA) results on multiple mean comparisons, there were significant differences between the six technologies in each dimension. In the last two columns of Table 9, F-values and P-values was reported. The SVA had the highest mean rates for perceived usefulness, perceived ease of use, and perceived safety dimensions while the AWW had the lowest mean for perceived annoyance. As mentioned above, the participants were asked if they would use (perceived use behavior) the system. According to the ANOVA results, there were significant differences between the perceived use behavior (considering all four model dimensions) of the six systems with a P-value <0.001. Drivers again rated the SVA highest among all of the systems for perceived use behavior.

In order to investigate the relationship between health concerns and perceived use behaviour of different in-vehicle technologies, perceived use behavior ratings were categorized into four different groups according to older adult drivers' health concerns
To investigate whether older adult drivers with different health concerns had different preferences about using the six systems, the first group consisted of drivers with only vision concerns (26 responders). According to ANOVA results, perceived use behavior ratings for the six systems were not equal (P-value <0.001) and SVA had the highest mean (4.34). It is worth noting that the mean ratings for SVA perceived use behavior among drivers with vision impairments were higher than all other drivers. The second group was drivers with only memory concerns (25 responders). This second group’s perceived use behavior ratings for the six systems were not equal, and SVA was rated higher than other systems with means equal to 4.08 (P-value <0.001). According to mean comparison, responders with memory concerns rated the six systems lower than all other drivers. The third group was respondents including those with multiple health concerns: bones, pain, balance, hearing, and vision concerns (27 responders). This group did not rate the systems differently. However, the means of perceived use behavior ratings of this group were higher than all other
responders. Lastly, there was a group of 35 responders who do not have any health concerns. Their perceived use behavior ratings were not significantly different. However, this group’s ratings for all systems was lower than those of all other drivers. It is worth noting that SVA was rated highest by healthy older adult drivers and by those with multiple health concerns.

Figure 11 Classifying Perceived Use Behavior Ratings with Respect to Drivers’ Health Concern

The scope was changed to look at each system at a time. Due to correlations (>0.7) shown between the model dimensions and each in-vehicle technologies, Principal Component Analysis (PCA) was applied in this study. This technique derived uncorrelated linear components from the original data. The first principal component accounts for the maximum possible proportion of the variance of the original data set, and subsequent components account for the maximum proportion of the unexplained residual variance, and so forth. In fact, each of principal components are a linear combination of original variables and set of eigenvectors weights. Equation (3) illustrates the linear models.

\[ V_j = \beta_{1j} x_1 + \beta_{2j} x_2 + \cdots + \beta_{Nj} x_N = \mathbf{\beta}_j^T \mathbf{x} \]  

\[ (3) \]
$V_j$ are the underlying linear components as a function of the original $X$ variables such as the four model dimensions. $\beta$ represents a set of eigenvector weights. The variance covariance matrix of the components would be a diagonal matrix with eigenvalues of the linear combinations along the diagonals which could be describe as:

$$S_V = \beta^T S_x \beta$$  \hspace{1cm} (4)

Where $S_V$ is a variance covariance matrix, $B$ is matrix of eigenvalues and $B^T$ is transpose of it. $S_x$ is the matrix of variances and covariances among the four original variables which was calculated from the following equation.

$$S_x = \frac{1}{N} \sum_{i=1}^{N} (X_i - \bar{X})(X_i - \bar{X})^T$$  \hspace{1cm} (5)

To distinct between the model dimensions, the principal component analysis (PCA) was conducted. Based on Harlow (2014) recommendation, the scree plot could be considered as one way of assessing the number of components. This plot, which is introduced by Cattell (1966), has the number of eigenvalues on Y-axis and maximum number of dimensions on the X-axis. The point at which eigenvalues drop off to insignificant size is estimation for the number of underlying components. Figure 12 provides the scree plot for the all six in-vehicle technologies. As you can see, after two components, the eigenvalues size drop. AWW is an exception in which the drop happened after first one component.
Another way of look at PCA is by examining the eigenvalues and the percentage of variance explained. Table 10 reports the explained variance percentage and cumulative percentage of the components for each in-vehicle technology. As noted, the first component explained more than half of the variance. According to Harlow's (2014) recommendation, it would be reasonable to consider the number of component which explain 50 percent or more of variance. To follow the recommendation, the second component should not be added.

Table 10 shows the orthogonally rotated loadings from PCA of the the UESAM model for each of the in-vehicle technology. Perceived usefulness, perceived ease of use, and perceived safety show loadings greater than 0.52, indicating a clear component structure for this construct. The loading for perceived annoyance is higher (>0.990) in the second component. In this study, an oblique Promax rotation is also conducted. The results revealed similar pattern of PCA loadings.

Using the PCA uncorrelated linear components derived from the original data. The first principal component accounts for the maximum possible proportion (more than half) of the variance of the original data set. Perceived usefulness, perceived ease of use and perceived safety were the UESAM model dimensions which have high loadings for this component.
Figure 12  Scree Plot for the six In-vehicle Technology

Table 10 Percentage Variance and Cumulative

<table>
<thead>
<tr>
<th>Component</th>
<th>ACC</th>
<th>SVA</th>
<th>LDW</th>
<th>APD</th>
<th>NVC</th>
<th>AWW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Var%</td>
<td>Cum%</td>
<td>Var%</td>
<td>Cum%</td>
<td>Var%</td>
<td>Cum%</td>
</tr>
<tr>
<td>1</td>
<td>0.591</td>
<td>0.591</td>
<td>0.564</td>
<td>0.564</td>
<td>0.560</td>
<td>0.560</td>
</tr>
<tr>
<td>2</td>
<td>0.253</td>
<td>0.844</td>
<td>0.304</td>
<td>0.868</td>
<td>0.248</td>
<td>0.808</td>
</tr>
<tr>
<td>3</td>
<td>0.116</td>
<td>0.960</td>
<td>0.100</td>
<td>0.968</td>
<td>0.119</td>
<td>0.927</td>
</tr>
<tr>
<td>4</td>
<td>0.040</td>
<td>1.000</td>
<td>0.032</td>
<td>1.000</td>
<td>0.073</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Table 11  Varimax Rotated PCA Loading Matrix for the UESAM Model of Six In-vehicle Technology

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>ACC</th>
<th>SVA</th>
<th>LDW</th>
<th>APD</th>
<th>NVC</th>
<th>AWW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C.1</td>
<td>C.2</td>
<td>C.1</td>
<td>C.2</td>
<td>C.1</td>
<td>C.2</td>
</tr>
<tr>
<td>Usefulness</td>
<td>0.60</td>
<td>&lt;0.1</td>
<td>0.58</td>
<td>&lt;0.1</td>
<td>0.56</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>0.56</td>
<td>&lt;0.1</td>
<td>0.56</td>
<td>&lt;0.1</td>
<td>0.53</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Safety</td>
<td>0.58</td>
<td>&lt;0.1</td>
<td>0.60</td>
<td>&lt;0.1</td>
<td>0.63</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Annoyance</td>
<td>&lt;0.1</td>
<td>0.99</td>
<td>&lt;0.1</td>
<td>1.00</td>
<td>&lt;0.1</td>
<td>0.99</td>
</tr>
</tbody>
</table>
3.5. DISCUSSION AND CONCLUSION

As the population of older adults in developed countries continues to grow, particularly due to the “baby boom” generation, concerns about the safety of older adult drivers and those who share the road with them have increased. Through the two employed questionnaires, possible situations that lead crashes to occur and technology solutions that could improve older adult driving safety were identified.

According to the results obtained from the first questionnaire, like other self-reported and subjective studies (Charlton et al. 2006; Levin et al. 2012; Henriksson et al. 2014), this study found that older adult drivers identified weather condition, night and high-speed roads as challenging driving situations. Although participated Rhode Island older adult drivers have seasonal weather conditions experience, they mentioned that weather conditions as the most challenging driving situation. The other key finding was that drivers who drove less frequently rated the top three mentioned challenging driving situations higher.

After identifying challenging driving situations for older adult drivers, six in-vehicle technologies which could mitigated challenges were identified. In regards to investigating older adult technology acceptance, a four dimensional model was considered in this study. According to the principle component analysis, perceived usefulness, perceived ease to use, and perceived safety were constructed underlying dimensions which explains most of the variability in rating of all six in-vehicle technologies.

The other finding from the second questionnaire is that the Side View Assist (SVA) system was found as the best acceptable in-vehicle technology for older adult drivers.
This system was rated significantly higher than others. This system could help increase the frequency of checking blind spots, draw attention to approaching traffic and provide early warning on approaching traffic. As a result, it could decrease older adult drivers' crash risk (Traffic Safety Facts 2013). In addition, due to vision and attention supports provided by this system, the older drivers who are vision and memory impaired significantly rated this technology higher than others. It’s worth mentioning that older adult drivers with multiple health concerns reported being more likely to use the in-vehicle technologies than other older adult drivers.

The result of this study could help us gain a better understanding of older adults’ driving challenges and their acceptance and potential usage of in-vehicle technological solutions. The authors plan to conduct a nationwide questionnaire in a future study to assess older adults across the nation regarding their driving challenge concerns and means to ease these concerns. Moreover, future research needed to conduct empirical study in actual car environment and include other dimensions to the conceptual research model.
ACKNOWLEDGMENTS

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CHAPTER 4

“Automated Sidewalk Quality and ADA Compliance Assessment in Rhode Island”

by

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ABSTRACT

The recent push to improve safety and accessibility for sidewalk users has led to enforcement of ADA compliance for sidewalks in cities and urban areas. To ensure that sidewalks conform to ADA regulations, many attributes of sidewalks such as running slope, cross-slope, surface condition, curb ramp, etc. have to be measured, recorded, and assessed. Currently, most of the Rhode Island sidewalk measurement and assessment is done manually by the Rhode Island Department of Transportation (RIDOT). This costly and time consuming work has put the state behind the national schedule for ADA compliance. To expedite and to improve the walkability of the sidewalks in Rhode Island, an automated sidewalk quality assessment system is needed. It was the intention of this study to identify an automated system to improve the current sidewalk measurement and evaluation process for RIDOT. Field studies were carried out on various sidewalks at the University of Rhode Island to test the automated system's accuracy, quality, and the reliability. The results were then compared to the sidewalk data collected using the manual method. The automated system integrated the sidewalk attribute data into ArcGIS and the current RIDOT Geographical Information Systems (GIS) database. This study ultimately could help Rhode Island to comply with ADA sidewalk requirements.
4.1. INTRODUCTION

Sidewalk systems are an important part of the urban traffic system. With increasingly severe traffic congestion in recent years, sidewalks have become more and more attractive as a low-carbon transportation mode (Zhao et al. 2012). According to the Census Bureau, about 19 percent of the United States population (about 56.7 million people) are permanently disabled. This means nearly 1 in 5 people in the U.S have some sort of disability (Bernstein 2016). 3.6 million individuals of this population actively use a wheelchair on a daily basis, therefore requiring the use of wheelchair-friendly sidewalks. In Rhode Island, 13.4 percent of the state population have disabilities, and more than half of this population has an ambulatory disability (Yang et al. 2016). Moreover, 18.2 percent of the Rhode Island population is above the age of 60, an age that typically marks the beginning of ambulatory challenges (U.S. Census Bureau 2015). For these individuals, accessible and safe sidewalks enable them to reach their destinations in the community and enjoy the benefits of city services, programs, and activities. Keeping them active and engaged is important to the nation’s overall public health (O’Hanlon & Scott 2010). Therefore, constructing and maintaining accessible sidewalks plays an essential role in ensuring public health of the United States.

To mark the beginning of an end to mobility barriers, the Americans with Disabilities Act (ADA) established a series of standards and guidelines for enabling the accessibility of “the public street to people with disabilities with a continuous, unobstructed pedestrian circulation network to the maximum extent feasible” (Kockelman et al. 2000). The ADA’s aim is to combat the lack of accommodations presently available to people with disabilities in the United States. This monumental
legislation is the most recent stride for civil rights in the U.S. for the disabled population, ensuring that all people can take full advantage of public facilities. The Americans with Disabilities Act Application Guideline (ADAAG) states a set of crucial descriptions for designing and constructing sidewalks that allow wheelchair users to have a safe trip (Ai 2016). Since the mid-90s, significant efforts and resources have been expended to measure and evaluate sidewalks for ADA compliance in Rhode Island. Due to the recent mandate posted by the Federal Highway Administration (FHWA) and the Department of Justice (DOJ), ensuring that all state sidewalks comply with the Americans with Disabilities Act (ADA) is critical to the Rhode Island Department of Transportation (RIDOT).

The FHWA published a report on a Sidewalk Assessment Process in 1999 (Kirschbaum et al. 2001). The Sidewalk Assessment Process was implemented in several cities and involved the manual evaluation of sidewalk features including widths and slope measurements, among other qualities (Kockelman et al. 2000). This method of data collection requires hand measurement and visual estimation which can result in inaccurate data. More recently, local governments have utilized Geographic Positioning Systems (GPS), Geographic Information Systems (GIS), and Personal Digital Assistant (PDA) for pedestrian data collection in the City of Tucson, Arizona (ADA Sidewalk Inventory Study Report 2012) and the City of Bellevue in Washington (Loewenherz 2010). However, the implementation of ADA compliance in this way is still extremely time consuming and costly. Furthermore, this method of data collection requires hand measurement and visual estimation which makes this method extremely inaccurate. The high cost and time required for these manual assessment methods highlight the
significant need for an effective automated sidewalk assessment system to help ensure ADA compliance in a timely and cost-effective manner.

It was the intention of this study to identify an automated system to expedite the current sidewalk measurement process. The automated system’s measurements were validated by comparing them to the results from manual measurements. Based on the validated automated measurement, this study developed indices for evaluating sidewalk attributes automatically and objectively.

4.2. BACKGROUND

4.2.1. Automated Sidewalk Assessment System

A number of systems were developed to collect more accurate and comprehensive sidewalk data. One type of developed system is the inertial profiler-based system that measures slope-related attributes (running slope and cross-slope) and dimension-related attributes. For instance, in a study conducted by the Georgia Institute of Technology, sidewalk data was gathered using an Inertial profiler-based system. In that system, there was an Android tablet attached to a basic wheelchair (Frackelton et al. 2013). The Android App, SideWalk Sentry™, records video, GPS, accelerometer, and gyroscope data on a secure digital (SD) memory card. The field data was then transferred to the Georgia Tech server for automated post-processing. Based on sidewalk recorded image, sidewalk width is estimated. The localized presence of walkway obstructions was recorded, and major sidewalk cracks that may need repair or reconstruction were identified. Using this technology, researchers worked with local volunteers to collect
data from 40 sidewalk segments across Atlanta, Georgia. One problem with this strategy is that the results put a large emphasis on variables such as cracks, gaps, and level changes and cause the specific ADA compliance requirements, including grade and cross-slope, to seem insignificant.

Some companies have developed their own automated systems for measuring sidewalk attributes. For example, Beneficial Designs developed a push-cart manually rolled by a worker to be used for Public Right of Way Assessment (PROWAP). The cart equipped with integrated sensors, a GPS, and a PDA, which can collect in 10 to 20 percent of the usual manual collection time. The system was tested in the city of Gardnerville, Nevada and obtained accurate results (Cline & Lynskey 2010).

In another example, Starodub, Inc. gathered data on sidewalks in the Bellevue, Washington area while under contract with the FHWA. They used a Segway HT based system that collected information using Ultra-Light Inertial Profiler for American Disability Act (ULIP-ADA) acquisition software, and esri ArcPad for end coordinates. The system used by Starodub, Inc. had the ability to identify detailed attributes of sidewalks including cross slope, running slope, and bumps that did not comply with ADA standards. This study put a strong emphasis on the accuracy of collected data, and Starodub, Inc. conducted multiple controlled experiments to ensure the accuracy and precision of the machine’s collected data. The researchers concluded that there was a high level of consistency between the ULIP-ADA and smart level data. The system also permitted the user to review the raw sensor data, providing another opportunity for quality inspection. The data gathered using this system integrated seamlessly with the city’s GIS database and was made available to analysts, decision makers and the public.
(Gagarin & Mekemson 2015). However, contracting outside companies can be costly.

In addition to inertial profiler-based systems, there are also vision-based systems that innovatively collect the sidewalk’s attributes. A study published in 2013 states the lack of sidewalk accessibility data currently available and aims to find a simpler, more efficient alternative to “labor intensive and costly” street audits. The study used untrained workers to manually label a variety of sidewalk irregularities, including permanent obstacles, missing curb ramps, and uneven surfaces. Google Street View (GSV) imagery was used to make note of the sidewalk information (Hara et al. 2013). The initial feasibility study was performed using data from Los Angeles, Baltimore, Washington, D.C., and New York City. The GSV approach, however, involved a few significant shortcomings. The use of untrained volunteers led to a certain level of inaccuracy that can be difficult to account for. According to the study, overall data accuracy was 78.3% for multiclass classification and 80.6% for binary classification when compared to ground truth data. Other means of data collection, such as the use of a walking profiler, can provide a more accurate data set to work with. Another limitation is that information can only be gathered in areas where GSV images are available. The researchers recognized that while this collection method can provide information on major accessibility issues like pathway obstacles and missing curb ramps, ramps, specific accessibility data like width and cross-slope cannot be obtained using the GSV image approach.

Another approach for collecting sidewalk attribute measurements is using Light Detection and Ranging (LiDAR). Researchers at Georgia Institute of Technology have put significant time and effort into finding efficient and cost-effective ways of gathering
sidewalk data relating to ADA standards (Ai 2016). In one study conducted by Georgia Tech’s School of Civil and Environmental Engineering, researchers used 3-D Mobile LiDAR and image processing to gather sidewalk measurements. The system contains four video cameras, two mobile LiDAR, and a global navigation satellite system. To document numerous attributes at the same location, the system’s cameras were synchronized, and the technology used specific algorithms to connect different sidewalk segments that were interrupted by obstacles like parked cars or trees. In addition to sidewalk segments, the video log also collects curb ramp images using a deformable part model. A 3-D representation in the LiDar point cloud was then used to measure the necessary ADA attributes of the sidewalk or curb ramp, and the collected data is subsequently incorporated into a GIS platform. Based on the data gathered in a small-scale experimental test on Ferst Drive in Atlanta, Georgia, the LiDAR approach produced accurate and precise results when compared with the manual ground assessment from field surveys. This system takes significantly less time than inertial profiler-based systems, which travel at a relatively slow speed and can only cover selected measuring locations in a given time period. Additionally, LiDAR technology is becoming more affordable and accessible as technology advances. However, this method has never been tested in larger-scale city settings, and still has minor issues with curb ramp data extraction.

To encourage individuals to use active means of transportation, sidewalks must meet ADA compliance standards. As demonstrated, researchers have developed numerous automated systems including the inertial profiler-based system, vision-based system, and LiDAR-based system to automatically generate spatial sidewalk inventories and
evaluate sidewalk quality. However, these approaches all involve a variety of hindrances to collecting city-wide sidewalk data. In some cases, the data procured was not accurate enough or didn’t provide the detailed information needed for the assessment of ADA compliance. In other cases, the implementation of the process was too costly or hadn’t been applied to large-scale data collections. This study aimed to identify a system that was available for procurement and had an acceptable level of quality, reliability, and accuracy according to RIDOT standards.

4.2.2. Index for Sidewalk Assessment

Infrastructure condition assessments play an important role in the decision making process for infrastructure maintenance actions. Although sidewalks are counted as part of the primary infrastructure, a method for evaluating their status is missing in the literature (Sousa et al. 2017). Several assessment surveys have been developed to obtain indices for evaluating sidewalks. In these studies, different factors and attribute of sidewalks were considered. For example, a survey produced by researchers at the University of South Carolina focused on gathering sidewalk maintenance input from pedestrians in order to promote health and create a community environment that supports physical activity (Hansen et al. 2009). Each question in the survey aimed to provide maintenance information on specific sidewalk attributes including obstructions, levelness, cleanliness, and surface conditions. Participants were asked to rate each attribute’s level of maintenance on a simple and understandable 3-point Likert scale. The researchers used the data from this survey to develop an overall index score for every sidewalk block. The block’s index score was determined by combining the ratings of each of the attributes to create an overall index score ranging from 1 (not at all
maintained) to 3 (well maintained). While this survey provides an example of using surveys to validate and determine a sidewalk index, the broad nature of this study’s overall index does not meet the specific needs of ADA standards. In order to evaluate ADA compliance, a sidewalk needs index ratings for each sidewalk attribute.

Another study which proposed an index regarding sidewalk quality was conducted at Universidade Federal da Paraíba in São Carlos, Brazil (Ferreira & Sanches 2007). They used data from wheelchair users to develop a sidewalk quality and accessibility index. The Accessibility Index (AI) considers current conditions and design characteristics of sidewalks and street crossings. After answering multiple demographic questions, wheelchair participants were asked to classify by order of importance the attributes they felt most contributed to comfort and safety on sidewalks. The attributes included longitudinal profile, surface roughness, sidewalk material, width, and intersections of urban streets. The successive intervals method was then used to identify each variable’s level of importance, and a quality and accessibility index was subsequently created. While this survey provides important material regarding on-site surveying, the study only targets wheelchair users and lacks involvement with ADA compliance.

Sprinkle Consulting, Inc. and the Florida Department of Transportation worked together to develop a way to quantify pedestrian’s perception of roadway safety and comfort (Landis et al. 2000). The quantification of pedestrian perception was developed through the Pedestrian Level of Service Model (LOS). Before conducting the survey, the researchers determined the factors most influential to pedestrians. These factors included the presence of a sidewalk, buffers to provide space between pedestrians and
roadway traffic, the frequency of driveways, and the speed of traffic. After the data was collected, a step-wise regression analysis was performed to find the best LOS model form. The calculated model be used to provide transportation officials across the country with a way of quantifying the level of service that a given road provides to pedestrians. However, this study is focused on quantifying a level of satisfaction with roadways rather than sidewalks. The LOS model emphasizes factors related to motor vehicle presence on roadways rather than specific sidewalk attributes.

Another study was performed in Rome, Italy and used a survey to quantify the conditions of sidewalks using a Sidewalk Condition Index (SCI) (Corazza et al. 2016). The SCI is designed to be a numerical indicator that rates the condition of each sidewalk section based on the survey responses. The survey consisted of distresses including block cracking, diffused cracking, linear cracking, patching, potholes, corrugation bleeding, raveling, weathering, deformation, depressions, and edge disruption. Participants rated each attribute’s level of severity on a 3-point scale ranging from low to high. The survey found that pedestrians put more emphasis on cracking, patching, potholes, and deformation due to roots. The SCI was calculated by subtracting the various severities of the sidewalk attributes from 100. The subtracted value was determined by dividing the total area of a given distress by the sample unit area, and then multiplying that value by the weight of the distress determined in the survey. SCI scores range from 0 to 100, with 100 being the best possible sidewalk section. The index developed in this study provided constructive information on key urban areas that needed sidewalk improvements. However, like other indexes, the study is limited to only one, comprehensive index rather than individual indexes relating to specific ADA
requirements.

As mentioned above, there were a few studies that developed indices for evaluating sidewalk status; however, ADA regulations and guidelines were not considered as a foundation in their indices. In this study, sidewalk indices were developed to evaluate sidewalks using automated measurements based on ADA regulations.

4.3. METHODOLOGY

Extensive research on existing standards and regulations was conducted to help understand the functionalities and specifications required of an automated system. Based on the federal standards for sidewalk design attributes and consultation with the RIDOT, a list of requirements and specifications was developed (Table 12).

After an extensive online search and attendance to a variety of exhibitions including 2016 and 2017 Transportation Research Board (TRB) meeting exhibitions, four vendors were identified. The Surface System & Instrument’s (SSI) CS 8900 (see Figure 13) was the only machine able to measure the sidewalk attributes according to ADA regulation (except vertical clearance and width). This system automatically identifies and notes ADA sidewalk code violations. The ADA association of this profiler makes it invaluable to RIDOT’s enforcement of ADA standards. After identifying these advantages and consulting with RIDOT officials, the SSI system was identified as the best automated system suited for RIDOT’s need.
Table 12 Functionalities Lists of the System

<table>
<thead>
<tr>
<th>Sidewalk Attributes</th>
<th>Functionalities of the system</th>
<th>Precision</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width and Distance</td>
<td>Ability to measure the width and distance of the sidewalk section</td>
<td>1/16 in (1mm)</td>
<td>±0.33mm</td>
</tr>
<tr>
<td>Surface and Changes in Level</td>
<td>Ability to measure the quality of the surface</td>
<td>1/8 in (3mm)</td>
<td>±1mm</td>
</tr>
<tr>
<td>Grade or Running Slope</td>
<td>Ability to measure the running slope</td>
<td>0.8% or (0.3 degrees)</td>
<td>±0.16 degree</td>
</tr>
<tr>
<td>Cross-slope</td>
<td>Ability to measure the cross-slope</td>
<td>0.5% or (0.3 degrees)</td>
<td>±0.1 degree</td>
</tr>
<tr>
<td>Vertical Clearance</td>
<td>Ability to measure the vertical clearance</td>
<td>1/16 in (1mm)</td>
<td>±0.33mm</td>
</tr>
</tbody>
</table>

The CS8900 Walking Profiler is an automated data collector that gathers and seamlessly integrates ADA-specific sidewalk data with GIS software. SSI also offers software and hardware assessment tools for the Walking Profiler that include a dual axis inclinometer and data collection and reporting of ADA-specific sidewalk attributes. Multiple sensors and a user-friendly interface with real-time profile viewing enable the profiler to gather over 200,000 miles of accurate and optimal data. The profiler’s ability to instantaneously collect and analyze data has the potential to significantly save time and manual labor. Data collection on the SSI profiler is also customizable. Users can add notes, pause data, and edit, crop, delete or reverse sections of runs. Once all the necessary field data had been gathered, the data can be exported to a wide variety of file formats including ERD, PPF, PRO, SURVEY, Excel, and shapefile. A shapefile is a non-topological format for storing the geometric location and attribute information of
geographic objects such as a sidewalk. Shapefiles are used to automatically integrate data into GIS software and identify the sidewalk locations that need improvement.

Figure 13 SSI Profiler, The Selected Automated System

In order to verify repeatability, reproducibility, and quality of the automated system’s measurements, this study used a five-step approach. In step one, the repeatability and reproducibility of manual sidewalk assessments were examined. In step two, the manual assessment method was used to collect data on various sidewalks to be compared with the automated assessments. In step three, the repeatability and reproducibility of the automated sidewalk assessment system was evaluated. In step four, the automated system was used to collect sidewalk data. In the final step, the automated sidewalk assessment measurement and the manual assessment measurement were compared to validate the quality and reliability of the automated measurement.
All the above-mentioned field studies were conducted at the University of Rhode Island. The measured sidewalks were divided into different stations and segments. A segment is regarded as a concrete block which was approximately 5 feet long, and a station was approximately 250 feet long, therefore including about 50 segments. In some cases, the stations were smaller due to existing driveway, curbs, etc. Figure 14 illustrates a schematic of a 5-feet sidewalk segment and the measurements taken.

After verifying the repeatability and the reproducibility of the automated system, a cost-effectiveness study was used to evaluate the cost of automated and manual measurements. Additionally, ADA Sidewalk Indices (ADA-SI) were created. These indices quantified the accessibility and safety of the sidewalks according to ADA compliance. Then a survey was conducted to validate the indices with sidewalk users’ perceptions. The ADA-SI enable RIDOT to merge pedestrian safety and ADA compliance into the mainstream of transportation planning, design, and construction.

Figure 14 Sidewalk Measurement Schematic
4.3.1. Step One: Gauge R&R Study for Manual Sidewalk Assessment

Gauge R&R studies were performed to investigate the variability of the manual measurement. A digital inclinometer was used to measure cross slope, and running slope which are the most fundamental attributes of sidewalks. The tall handle of the digital inclinometer is attached to save the back and knees of inspectors (see Figure 15).

Figure 15 Digital Inclinometer

This Gauge R&R study explored the overall variation that is caused by sidewalk segments and the measurement system, as indicated in equations 6, 7 and 8. The measurement system variation consisted of repeatability and reproducibility. Reproducibility included the variation due to workers and the variation due to their interaction with various sidewalk segments. Repeatability contained variation due to the
gauge itself. This study estimated how much of the total variation was caused by the measurement system. This Gauge R&R study also investigated how much of this variability was caused by differences between workers and gauges and whether such a measurement system capable of discriminating among different sidewalk segments. In this study, a two-way analysis of variance (ANOVA) was employed to calculate variance components, and then those components were used to estimate the percent variation due to the measuring system. According to the Automotive Industry Action Group (AIAG) guidelines, if the variation of the system measurement is less than 10% of the total variation, then the measurement system is acceptable (Down, Michael; Czubak, Frederick; Gruska, Gregory; Stahley 2010).

\[
\sigma_{\text{Total variation}}^2 = \sigma_{\text{Sidewalk Segment}}^2 + \sigma_{\text{Measurement System}}^2
\]

(6)

\[
\sigma_{\text{Measurement System}}^2 = \sigma_{\text{Repeatability}}^2 + \sigma_{\text{Reproducibility}}^2
\]

(7)

\[
\sigma_{\text{Reproducibility}}^2 = \sigma_{\text{Worker}}^2 + \sigma_{\text{Worker} \times \text{Sidewalk Segment}}^2
\]

(8)

To conduct a Gauge R&R study, three workers who were trained for using the mentioned instruments measured the sidewalk on Upper College Road at the University of Rhode Island as shown in Figure 16. Each worker measured the sidewalk attribute three times. Fifteen segments were randomly chosen. Once the random segments were identified, workers were randomly assigned to measure the sidewalk attributes. Before starting measurement, the center of each selected sidewalk segment (concrete block) was marked. The specific positions on which the gauges needed to be placed were also marked (see Figure 17). Table 13 shows the data sheet that was used to record the data.
Figure 16 The Data Collection Location of Gauge R&R Study for Manual Measurements

Figure 17 The Marked Points on Sidewalk Concrete Blocks for Manual Measurements

Table 13 Data Sheet for Collecting Data

<table>
<thead>
<tr>
<th>Worker ID</th>
<th>Segment # (Block #)</th>
<th>Running Slope %</th>
<th>Cross Slope %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1       2  3</td>
<td>1   2   3</td>
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<td>1       2  3</td>
<td>1   2   3</td>
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<tr>
<td></td>
<td></td>
<td>1       2  3</td>
<td>1   2   3</td>
</tr>
</tbody>
</table>
4.3.2. Step Two: Manual Sidewalk Assessment

After validating the repeatability and reproducibility of the manual sidewalk assessment method, data on various sidewalks at the University of Rhode Island were collected using the same manual measurement method. Along the sidewalk path, the center of each segment was marked by paint. A digital inclinometer was used to measure running slope and cross-slope. Based on RIDOT officials’ recommendation, each slope was measured three times and the highest number was recorded. Regarding change in surface level, if the depth of the sidewalk gap was more than 0.25 inches, that gap’s depth and width would be recorded with a profile gauge. The profile gauge data was accurately measured by placing the profile gauge on grid paper and taking a photo while in the field. Later, the sidewalk gap depth and width were measured and recorded in the database. The location information was gathered with a Global Navigation Satellite System (GNSS) Surveyor with 2 feet accuracy. The GNSS Surveyor has the capacity to connect to the iPhone using Bluetooth technology. In this study, an iPhone 7 was used to insert data into a surveying app which was developed by the University of Rhode Island.

Workers followed the RIDOT Intersection Inspection Form (see appendix 6) to measure curb ramps. The slopes of the curb ramp’s various elements including approach, landing, ramp, flare, and gutter were measured in the direction shown in Figure 18.
4.3.3. Step Three: Gauge R&R Study for Automated Sidewalk Assessment

A similar gauge R&R study to section 4.3.1 was used for automated measurement in this step. Two trained observers used the SSI profiler three times to collect data from the first station. They taped the center marked points and pushed the profiler along the path with its left wheels on the taped center of path. Figure 19 illustrates the location and the procedure of this field study. The reproducibility and repeatability of the automated sidewalk measurement system were assessed.

4.3.4. Step Four: Automated Sidewalk Assessment

After the repeatability and reproducibility of the automated sidewalk assessment system were validated, the system was used to collect sidewalk data from the same locations that were measured manually in step 2.
4.3.5. Step Five: Comparison Between Manual and Automated Sidewalk Assessment

Sidewalk attributes can be recorded manually and automatically, as demonstrated by the previous steps. The focus of this step is to compare the manual and automated cross-slope and running slope measurements of sidewalk path and curb ramps. Paired t-test was used to compare the data gathered using the two methods. Paired t-test was used to determine whether the manual and automated assessments, collected at different sidewalk locations, were different or not. The null hypothesis is that there is no difference between these two assessments while the alternative hypothesis is that there is a significant difference between them.

For the comparison study of sidewalk path, a sidewalk station located at the front of Green Hall, University of Rhode Island, was measured both manually and automatically at the same day. In total, there were 31 segments (about 160 feet) marked for measurement. Two points for each segment were measured (Figure 20).
For the comparison study of curb ramps, three curb ramps located at Upper College Road, University of Rhode Island (as shown in left-hand side of Figure 19) were selected. All elements of curb ramps which are shown in Figure 18 were measured manually and automatically on the same day.

Figure 20 Data Collection for Comparison Study

4.3.6. Cost Effectiveness

During the field studies required in steps 2 and 4, cost and time associated with data collection using both the automated and the manual sidewalk assessment systems were collected (see Table 14). The total labor cost per mile was calculated (see Equation 9) based on the number of workers \( W_i \), a standard stipend rate \( SR_i \), the number of hours which the worker spent on the field \( T_i \), and the assessed sidewalk length \( L_i \).

\[
Total\ on - field\ labor\ cost\ per\ mile = \sum_{i=1}^{n} \frac{w_i \times SR_i \times T_i}{L_i}
\]  

(9)
### Table 14 In-field Labor Cost

<table>
<thead>
<tr>
<th>The measurement method</th>
<th>Number of workers</th>
<th>Observer stipend rate (per hour) (SR_i)</th>
<th>Number of hours spend on Field Study (hour) (T_i)</th>
<th>Assessed sidewalk length (mile) (L_i)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

### 4.3.7. ADA Sidewalk Indices (ADA-SI)

In this section, the ADA Sidewalk Indices (ADA-SI) were discussed. In this study, sidewalk attributes listed in the ADA regulation were considered in developing ADA-SI. These indices not only address most of the ADA regulation’s sidewalk concerns but also took a step further and evaluate the sidewalks quantitatively. Using the ADA-SI, a sidewalk’s status can be reported quantitatively. The considered sidewalk attributes regarding and the corresponding ADA regulation are summarized in Table 15.

The ADA-SI include 6 indices. In this study, two different methods to calculate the indices were proposed. The first method was focused on the violations which occurred on sidewalks. The second method was focused on the maximum length that the sidewalk is free of violation. Both methods were validated by a survey which is based on pedestrian’s perception. It is worth noting that the SSI profiler generates the 6 indices’ elements present in both methods. In the following sections, the indices and the survey are explained.
Table 15 Federal Standards (ADA) Associated with this study

<table>
<thead>
<tr>
<th>Sidewalk Attributes</th>
<th>Federal Standards (ADA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Running Slope (R)</td>
<td>5% maximum slope or equal to roadway slope</td>
</tr>
<tr>
<td>Cross-slope (C)</td>
<td>2% maximum cross-slope</td>
</tr>
<tr>
<td>Obstruction free length (O)</td>
<td>No obstructions may be present within the pedestrian access route</td>
</tr>
<tr>
<td>Surface level/Evenness (E)</td>
<td>Vertical displacements up to ¼” are allowed</td>
</tr>
<tr>
<td></td>
<td>Vertical displacements from ¼” to ½” inch must be beveled to a slope no greater than 1:2</td>
</tr>
<tr>
<td></td>
<td>Vertical changes greater than ½” inch must be smoothed so as not to exceed a ramp slope of 8.33%</td>
</tr>
<tr>
<td>Surface Roughness (S)</td>
<td>Surface must be “firm,” “stable,” and “slip-resistant”</td>
</tr>
</tbody>
</table>

4.3.7.1. ADA-SI Elements

**Running Slope Index (RSI).** Running slope is one of the fundamental attributes of sidewalks (Ferreira & Sanches 2007) considered in the ADA-SI. It is defined as the slope parallel to the direction of pedestrian’s path. The federal standard allows a maximum 5% slope.

In the first quantification method, the number of running slope violation is considered in the ADA-SI calculation. Additionally, the length of the sidewalk that maintains an unacceptable running slope is considered as the weight in this index. This index can be easily calculated (see Equation 10). $NR$ and $LR_i$ refer to the number of running slope violation and the length of violation at the sidewalk path. $L$ is the total length of the sidewalk station.
In the second method, the maximum length of sidewalk that is free of any running slope violation, $Max(NLR_i)$ is considered and calculated as follows:

$$RSL_2 = \frac{Max(NLR_i)}{L}$$  \hspace{1cm} (11)

**Cross-slope Index (CI).** Cross-slope is defined as the slope measured perpendicular to the direction of the pedestrian’s path. This attribute is considered in ADA-SI because high cross-slopes tend to pull wheelchairs away from their linear path. The federal standard allows a maximum of 2% cross-slope for a sidewalk. Therefore, in the ADA-SI, any cross-slope greater than 2% is taken into account for the ADA-SI calculation.

In the first method, the number of cross-slope violation ($N_C$) and the distance this violation was maintained ($L_C_i$) is considered (see Equation 12).

$$Cl_1 = \frac{NC \sum L_C_i}{L}$$  \hspace{1cm} (12)

In the second method, the maximum length of a sidewalk path free of any cross-slope violation $Max(NLC_i)$ is used. The $Cl_2$ is calculated in Equation 13.

$$Cl_2 = \frac{Max(NLC_i)}{L}$$  \hspace{1cm} (13)
**Obstruction Index (OI).** Any objects which limit the passage space and reduce the clearance width of the sidewalk are defined as obstructions. According to the federal standard, at least 3 feet of cross width a sidewalk path must be free of any obstructions. Some studies highlighted it as one of the most important factors for sidewalk evaluation (Ferreira & Sanches 2007; Williams et al. 2005). In the ADA-SI, obstruction is considered.

In the first method, the \( OI_1 \) is equal to the number of obstructions which exist in sidewalk and their length (see equation 14). \( O_k \) and \( L_{O_k} \) refer to number of obstruction and the length of the obstruction in the sidewalk station.

\[
OI_1 = \frac{NO \sum L_{O_k}}{L} \tag{14}
\]

In the second method, the maximum length of sidewalk free of any obstructions \( \text{Max}(NOL_k) \) is used. Equation 15 shows how the \( OI_2 \) is calculated.

\[
OI_2 = \frac{\text{Max}(NOL_k)}{L} \tag{15}
\]

**Changes in Surface Level Index (CSLI).** Changes in surface level create problems for wheelchair users and the visually impaired. Even for able-bodied pedestrians, bumpy surfaces can be cumbersome and hazardous to walk through. ADA regulations and various research studies state the importance of this sidewalk attribute (Williams et al. 2005; Corazza et al. 2016). In the ADA-SI, a surface change of more than \( \frac{1}{4}'' \) is defined as an evenness issue.
In the first method, the number of evenness issue is considered in the ADA-SI. In Equation 16, $m$ refers to number of the surface changes.

\[ CSLI_1 = \frac{m}{L} \]  \hspace{1cm} (16)

In the second method, the max length of sidewalk free of any evenness violation $\text{Max}(LNVC_m)$. $CSLI_2$ is calculated in Equation 17:

\[ CSLI_2 = \frac{\text{Max}(LNVC_m)}{L} \]  \hspace{1cm} (17)

**Surface Condition Index (SCI).** According to the federal standard, a sidewalk’s surface must be “firm”, “stable”, and “slip-resistant”. Any crack or gap that creates a space with a width more than $\frac{1}{2}$ inch is a violation of federal standards and is included in sidewalk evaluation (Williams et al. 2005; Ferreira & Sanches 2007; Corazza et al. 2016).

For the first method, the $SCI_1$ was calculated using Equation 18. $g$ refers to the number of the violated gap.

\[ SCI_1 = \frac{g}{L} \]  \hspace{1cm} (18)

The second method uses Equation 19 to calculate the $SCI_2$. The maximum length of the sidewalk free from any surface condition violation $\text{Max}(NLSCI_g)$ is divided by the total length of the sidewalk ($L$).
\[ SCI_2 = \frac{\text{Max}(NLSCl_g)}{L} \]

**Roughness Index (RI).** Since the variation in the sidewalk surface causes discomfort for pedestrians, especially for wheelchair users, the roughness index is included in the ADA-SI and some research studies (Ferreira & Sanches 2007; Corazza et al. 2016). According to the federal standard, the sidewalk surface must be “firm”, “stable”, and “slip-resistant”. The absence of an objective guideline for sidewalk roughness is one of the limitations of this standard. Since the International Roughness Index (IRI) is the gold standard for objectively measuring roughness (Arhin et al. 2015), this index was adapted for use in ADA-SI.

IRI is based on the “quarter car simulation” which replicates the ride quality of the road felt by the user. The index measures pavement roughness in terms of the number of inches per mile that a laser, mounted on the profiler, jumps as the profiler is pushed along the sidewalk. The SSI profiler reports the IRI of each sidewalk station automatically. In the United States, the national standard for IRI thresholds for all road classifications range from 96 in/mi to 170 in/mi indicating “acceptable” road segments; however, Arhin et al. (2015) empirically found that an IRI range for the different type of roads. For example, for collector roads, he suggested a range from 188 in/mi to 318 in/mi.

It should be mentioned that higher IRI is the worse the sidewalk is. This means that IRI is a negative index. Since the first method is a negative index too, the IRI was considered as Roughness Index (RI) for this method. However, the second method is positive index. Therefore, the inverse of the IRI was considered in the second method.
4.3.7.2. The Survey: Validating the ADA-SI

To validate the established indices, pedestrians’ perception of sidewalk attributes was gathered through an on-site survey. Forty randomly recruited individuals of ages ranging from 18-70 participated in this questionnaire. Since the participants did not have any disabilities, they were asked to use a wheelchair for half of the study in order to simulate individuals with disabilities. The recruited participants were members of the University of Rhode Island community and the Osher Lifelong Learning Institute, a senior center of at the University of Rhode Island. Participants were offered a $20 gift card as compensation for their time. The two locations used in the previous measurement studies were selected to be used for the survey. These sidewalks were located on Upper College Road, University of Rhode Island and Green Hall, University of Rhode Island (see Figure 21). At both of these locations, 5 sidewalk sections of 160 feet in length were used for evaluation. The first half of participants walked and used a wheelchair on two of these sidewalk sections. The other half of participants did the same for the other three sidewalk sections.

This questionnaire was designed in Google Forms to increase the accuracy and efficiency of data collection. Fifteen questions in total are included in the questionnaire, and the entire survey procedure had four steps. First, the researches explained the purpose of the survey and the procedure, and participants signed a consent form(see Appendix 7). Second, the participants filled out their demographic information including gender, age group, medical concerns, mobility concerns, physical shape, sidewalk travel frequency, and length of their average sidewalk. They also familiarized themselves with the survey questions and how to use the wheelchair.
Next, the individuals were invited to traverse the sidewalk. They were asked to randomly travel (by foot and wheelchair) for about 160 feet on each sidewalk. After each trip, the individuals rated six ADA-related sidewalk attributes on a three-point Likert scale ranging from “needs immediate attention” to “acceptable”. Respondents also rated their overall experience on the sidewalks. After collecting the data from 40 individuals for all 5 sidewalk sections, the average ratings of their perception on each feature the for each sidewalk were correlated with their corresponding index values from the ADA-SI.

4.4. RESULTS

In this section, first, the repeatability and reproducibility of the manual assessments and the automated assessment made by the SSI profiler are reported
and compared. This section includes the results from each of the five steps mentioned in 4.3. The cost-effectiveness results are next provided. The ADA-SI indices were calculated on selected sidewalk sections at the University of Rhode Island. The results were correlated with the survey results at the end.

4.4.1. Gauge R&R Study Results of the Manual Measurements

Gauge R&R studies were conducted to verify the repeatability and reproducibility of the manual measurements. The digital inclinometer was used to measure the cross-slope and the running slope which are the most fundamental attributes of the sidewalk. It should be mentioned that 15 randomly choose sidewalk segment used in this study. The results for each attribute are described in detail in the following sections.

**Running slope Results.** Table 16 reports the F-value and P-value for the two-way ANOVA. Since the P-value of the sidewalk segments was less than 0.05, the sidewalk segments were significantly different. The p-value for workers and their interaction were not significant (p-value > 0.05). The variance components were calculated in Table 17 and used to calculate contribution percentage. As shown in Table 17, differences between sidewalk segments accounted for the most of variability in the measurement (96%). The repeatability and reproducibility contributed to a very small part of the total variation.
Table 16 Two-way ANOVA Results, Manual Running Slope Measurement

<table>
<thead>
<tr>
<th>Source</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sidewalk Segment</td>
<td>150.82</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Worker</td>
<td>3.256</td>
<td>0.053</td>
</tr>
<tr>
<td>Worker*Sidewalk Segment</td>
<td>1.601</td>
<td>0.051</td>
</tr>
</tbody>
</table>

Table 17 Variance of Component, Manual Running Slope Measurement

<table>
<thead>
<tr>
<th>Source</th>
<th>Variance Component</th>
<th>% Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Measurement System Variation</td>
<td>0.013884</td>
<td>4.41</td>
</tr>
<tr>
<td>Repeatability</td>
<td>0.01286</td>
<td>4.09</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>0.001019</td>
<td>0.32</td>
</tr>
<tr>
<td>Worker</td>
<td>0.001019</td>
<td>0.32</td>
</tr>
<tr>
<td>Sidewalk Segments</td>
<td>0.300660</td>
<td>95.59</td>
</tr>
<tr>
<td><strong>Total Variations</strong></td>
<td>0.314544</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Figure 22 illustrates component variation bar chart, R chart, $\bar{X}$ chart, measurement by sidewalk segment plot, worker and sidewalk segment interaction plot, and measurement by worker box plot. In the components of variation bar chart, each cluster of bars represents a source of variation. As shown in the top left side of the figure, each cluster has two bars that correspond to the %Contribution and the %Study Variance. In this manual measurement system, the largest component of variation was due to the variations among different sidewalk segments.

The R chart is essentially a control chart of ranges and graphically displays worker consistency. The plotted points, which represent, for each worker, the difference
between the largest and the smallest measurements of each segment’s running slope. The center line ($\bar{R} = 0.116$) is the average of all the subgroup ranges and is very close to 0. The control limits for the subgroup ranges are UCL = 0.297 and LCL=0. Since the ranges are relatively small and almost all points fall within the control limits, it could be concluded that workers measured the running slope consistently.

The $\bar{X}$ chart compares the sidewalk segment variation to the repeatability. The plotted points represent the average measurement of sidewalk segment for each worker. There is the center line ($\bar{X} = 0.897$) which is the overall average, and the control limits (UCL = 1.015 and LCL=0.779) which are calculated based on the number of measurements in each average and the repeatability estimate. There is a greater variation between segment averages than measurement device variation which causes the graph to show a lack-of-control.

The measurement (running slope) by sidewalk segment plot shows all the measurements in the study arranged by sidewalk segments (n=15). The measurements are represented by empty circles and the means represented by solid circles. The line connects the average measurements for each sidewalk segment. Since the empty circles for each sidewalk segment are close together, multiple running slope measurements for each sidewalk segment show little variation.

The measurement by worker box plot determines whether worker measured running slope consistently. The black circle in each box refers to the respective means and a line connects them. Since the line is almost parallel to the x-axis, the workers measured the running slope consistently.
The interaction plot illustrates the average measurement by each worker for each sidewalk segment. As the Figure 22 shows, the lines are overlaid and almost identical. As a result, the workers measured the running slope consistently.

**Cross-slope Results.** The same analysis was done for the cross-slope attribute of the sidewalk segments. The results of the two-way ANOVA are reported in Table 18. The sidewalk segments were significantly different (P-value<0.05) while the workers and their interaction with sidewalk segment were not significantly different (P-value>0.05). After calculating the variance components (see Table 19), it became clear that sidewalk segment had the greatest contribution to total variance by 97%. The variance contribution of the manual measurement system for cross-slope is equal to 3%. The
number of distinct categories value estimated as 6. Therefore, the manual measurement system was acceptable and could distinguish different sidewalk segments.

Table 18 Two-way ANOVA, Manual Cross-slope Measurement

<table>
<thead>
<tr>
<th>Source</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sidewalk Segment</td>
<td>248.593</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Worker</td>
<td>2.522</td>
<td>0.098</td>
</tr>
<tr>
<td>Worker*Sidewalk Segment</td>
<td>1.074</td>
<td>0.387</td>
</tr>
</tbody>
</table>

Table 19 Variance of Component, Manual Cross-slope Measurement

<table>
<thead>
<tr>
<th>Source</th>
<th>Variance Component</th>
<th>% Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Measurement System</td>
<td>0.027355</td>
<td>3.45</td>
</tr>
<tr>
<td>Variation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repeatability</td>
<td>0.026380</td>
<td>3.33</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>0.000974</td>
<td>0.12</td>
</tr>
<tr>
<td>Worker</td>
<td>0.000974</td>
<td>0.12</td>
</tr>
<tr>
<td>Sidewalk Segments</td>
<td>0.766985</td>
<td>96.55</td>
</tr>
<tr>
<td>Total Variations</td>
<td>0.793439</td>
<td>100.00</td>
</tr>
</tbody>
</table>

As was the case for running slope, Figure 23 demonstrates the gauge R&R plots. As shown in the components of variation bar chart, the largest component of variation was caused by sidewalk segments’ variation. The R chart shows consistency in cross-slope measurement since all points fall within the control limits (UCL= 0.1201, and LCL=0). The $\bar{X}$ chart depicts that sidewalk segment averages have a higher variation than measurement, because the chart shows a lack-of-control. The cross-slope by worker box
plot visualizes a comparison between different workers and their measurements. The plot shows that the workers measured this attribute of segments consistently. Additionally, the interaction plot illustrates no interaction between the workers and sidewalk segments.

Figure 23 Gauge R&R Plots, Cross-slope Results

4.4.2. Manual Measurement

After evaluating the manual measurement system, running slope, cross-slope, and level changes between segments were measured. The location information of a segment, segment number (block number), and sidewalk length were also collected and inserted into the University of Rhode Island’s (URI) GIS database. A total of 1,056 feet of
sidewalk was measured manually and stored in the database. Figure 24 depicts the manual data in the URI’s GIS database which was compatible with ArcGIS software (see the shapefile format of the manual data on the right side of the figure).

Figure 24 The Manual Assessment Data, The Data in URI’s GIS Database (on the left) and The Data with shapefile format in ArcGIS (on the right)

4.4.3. Gauge R&R Results of the Automated Measurement System

A Gauge R&R study was conducted to verify the selected automated measurement system, the SSI CS8900. As described in section 4.3, the automated system can measure the sidewalk attributes and tie the information with geographic coordinates. The SSI profiler software can report the collected data in different formats. The most valuable export types are Excel, ArcGIS and PDF. In addition to exporting data in different formats, the software can filter the recorded data based on maximum and minimum values. For example, once the user has established the maximum cross-slope, any output exceeding this value will be automatically listed as a non-conforming sidewalk section in the report. The software is also capable of filtering the data based on the average, range or exact value of recorded data for given distance. In this study, each 0.1 feet of
recorded data in excel format was used for the repeatability and reproducibility validation. The cross-slope and running slope were examined in this gauge R&R study. Each attribute’s results are described in detail in following section.

**Running Slope Results.** The same analysis that was done for manual measurement was performed with automated measurement. Table 20 indicates ANOVA results for the automated running slope measurement. Since the P-value for sidewalk segments is less than 0.001, it can be concluded that there were significant differences among them. However, the worker and the interaction with the sidewalk segments were not significantly different (P-value>0.05). The variance components are reported in Table 21. Apparently, the component that had the most contribution to total variance (91%) was the sidewalk segments. The variance contribution of the automated measurement system for running slope is 9%. The number of distinct categories value estimated as 4. Therefore, the automated measurement system was acceptable and could distinguish between sidewalk segments.

**Table 20** Two-way ANOVA Results, Automated Running Slope Measurement

<table>
<thead>
<tr>
<th>Source</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sidewalk Segment</td>
<td>55.5616</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Worker</td>
<td>0.8786</td>
<td>0.354</td>
</tr>
<tr>
<td>Worker*Sidewalk Segment</td>
<td>1.1153</td>
<td>0.297</td>
</tr>
</tbody>
</table>
Table 21 Variance of Component, Automated Running Slope Measurement

<table>
<thead>
<tr>
<th>Source</th>
<th>Variance Component</th>
<th>% Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Measurement System Variation</td>
<td>0.010313</td>
<td>9.15</td>
</tr>
<tr>
<td>Repeatability</td>
<td>0.010313</td>
<td>9.15</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>0.000000</td>
<td>0.00</td>
</tr>
<tr>
<td>Worker</td>
<td>0.000000</td>
<td>0.00</td>
</tr>
<tr>
<td>Sidewalk Segments</td>
<td>0.102432</td>
<td>90.85</td>
</tr>
<tr>
<td>Total Variations</td>
<td>0.112745</td>
<td>100.00</td>
</tr>
</tbody>
</table>

As was a case for the manual measurement, Figure 25 illustrates six gauge R&R plots. As shown in the components of variation plot, the most of variation was caused by the sidewalk segments’ variation. The next plot is the R chart which demonstrates that all points which refer to measurement ranges fall within the mentioned control limits. In the $\bar{X}$ chart, the majority of the points are out of the limits because of sidewalk segment averages have a higher variation than measurement variation. In the box plot, since the line is parallel to the x-axis, the workers measured this attribute of sidewalk consistently. The interaction plot shows no interaction between the workers and sidewalk segments. These results indicated that the most of variation is due to sidewalk segments and the automated measurement system could discriminate sidewalk segments with different running slopes.
Cross-slope Results. Table 22 reports results of ANOVA for automated cross-slope measurement. There were significant differences among sidewalk segments because P-value is less than 0.001. The worker and their interaction with sidewalk segment were not significantly different (P-values >0.05). Table 23 shows the components of variance and their contributions. As shown, the sidewalk segments had the most contribution to total variance (96%). The variance contribution of automated cross-slope measurement system is 4%. Six was an estimation for the number of distinct categories. Based on these results, the automated measurement system was acceptable and could distinguish among sidewalk segments with different cross slopes.
Table 22 Two-way ANOVA Results, Automated Cross-slope Measurement

<table>
<thead>
<tr>
<th>Source</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sidewalk Segment</td>
<td>134.606</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Worker</td>
<td>1.178</td>
<td>0.283</td>
</tr>
<tr>
<td>Worker*Sidewalk Segment</td>
<td>0.983</td>
<td>0.511</td>
</tr>
</tbody>
</table>

Table 23 Variance of Component, Automated Cross-slope Measurement

<table>
<thead>
<tr>
<th>Source</th>
<th>Variance Component</th>
<th>% Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Measurement System Variation</td>
<td>0.024472</td>
<td>4.36</td>
</tr>
<tr>
<td>Repeatability</td>
<td>0.024445</td>
<td>4.35</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>0.000027</td>
<td>0.01</td>
</tr>
<tr>
<td>Worker</td>
<td>0.000027</td>
<td>0.01</td>
</tr>
<tr>
<td>Sidewalk Segments</td>
<td>0.537012</td>
<td>95.64</td>
</tr>
<tr>
<td>Total Variations</td>
<td>0.561484</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Figure 26 depicts the six gauge R&R plots for the automated cross-slope measurement. As shown in the components of variation plot, the majority of variation was caused by sidewalk segments’ variation. Since most of the points (measurement ranges) fall within the mentioned control limits in the R chart, the workers measured the segments consistently. The $\bar{X}$ chart shows lack-of- control which means variation among sidewalk segments were greater than measurement variation. The box plot shows the workers measured this attribute of sidewalk consistently. There was almost no interaction between the workers and sidewalk segments in the interaction plot. As a
result, the most of variation is due to sidewalk segments and the automated measurement system could discriminate the sidewalk segments.

Figure 26 Gauge R&R Plots, Automated Cross-slope Results

4.4.4. Automated Measurement

After verifying the automated measurement system with the gauge R&R study, the automated sidewalk data was collected. This field study was conducted at the same locations where the manual data was collected, Upper College Road in Kingston, Rhode Island (Figure 27).
After collecting various sidewalk attributes manually and automatically, paired-t-test was employed to compare these two data collection methods. Paired t-test was conducted as explained in section 4.3.5. First, 62 data points on the sidewalk path were measured manually and automatically on the same day. Table 24 and Table 25 display the paired t-test results. The P-value is greater than 0.05 for both running slope and cross-slope attributes. It should be recalled that the null hypothesis was that the means of two assessment methods are equal while the alternative hypothesis was that they are different. Therefore, the study failed to reject null hypothesis. The study proved that
there is no significant difference between the manual and automated measurement results.

Table 24 Results of Paired t-test for Running Slope

<table>
<thead>
<tr>
<th>Assessment Methods</th>
<th>N</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>T-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual Assessment</td>
<td>62</td>
<td>0.9129</td>
<td>0.7587</td>
<td>0.37</td>
<td>0.714</td>
</tr>
<tr>
<td>Automated Assessment</td>
<td>62</td>
<td>0.8924</td>
<td>0.6363</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 25 Results of Paired t-test for Cross-slope

<table>
<thead>
<tr>
<th>Assessment Methods</th>
<th>N</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>T-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual Assessment</td>
<td>62</td>
<td>0.6419</td>
<td>0.3569</td>
<td>0.24</td>
<td>0.813</td>
</tr>
<tr>
<td>Automated Assessment</td>
<td>62</td>
<td>0.6595</td>
<td>0.4428</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As mentioned in section 4.3.5, in the second comparison study, three curb ramps were measured and recorded manually and automatically on same day. Table 26 displays the paired t-test results. The P-value is greater than 0.05. It could be concluded that the study failed to reject null hypothesis and the study proved that there is no significant difference between the manual and automated measurement.

Table 26 Results of paired t-test for Curb Ramp

<table>
<thead>
<tr>
<th>Assessment Methods</th>
<th>N</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>T-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual Assessment</td>
<td>30</td>
<td>4.740</td>
<td>3.291</td>
<td>0.12</td>
<td>0.905</td>
</tr>
<tr>
<td>Automated Assessment</td>
<td>30</td>
<td>4.606</td>
<td>3.244</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.4.6. Cost Effectiveness

In this section, the total in-field labor cost of each method was calculated given a five-year life span for the profiler. The number of workers and other details about their stipends and hours and miles that they worked in the field for comparison study are reported in Table 27. Using equation 4, the in-field labor cost for both methods were calculated. It should be noted that the cost comparison study only considered the running slope, and the cross-slope for the sidewalk path.

If one assumes 20 working days per month and 8 working months per year and 5 miles of sidewalk assessment per day, the SSI profiler could save approximately $534,000 in the in-field labor cost after 5 years (see equation 21, 22, and 23). It is worth noting that this cost did not include the ADA tool kit cost, worker training cost, data manipulation (data entry and GIS integration) labor cost and other related labor cost. According to results shown in Table 27, this profiler decreased the survey time by 60%.

<table>
<thead>
<tr>
<th>The measurement method</th>
<th>Number of workers</th>
<th>Observer stipend rate (per hour) (SR_i)</th>
<th>Number of hours spend on Field Study (hour) (T_j)</th>
<th>Assessed sidewalk length (mile) (L_j)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual</td>
<td>2</td>
<td>30</td>
<td>1.67</td>
<td>0.030</td>
</tr>
<tr>
<td>Automated</td>
<td>1</td>
<td>30</td>
<td>0.67</td>
<td>0.030</td>
</tr>
</tbody>
</table>

\[
\frac{2 \times 30 \times 5 \times 8 \times 5 \times 1.67}{0.030} = \$668,000 \quad (20) \\
\frac{1 \times 30 \times 5 \times 8 \times 5 \times 0.67}{0.030} = \$134,000 \quad (21) \\
\$668,000 - \$134,000 = \$534,000 \quad (22)
\]
4.4.7. ADA Sidewalk Index (ADA-SI)

In this section, the results of the ADA Sidewalk Indices calculations and the survey were reported based on data collected on various sidewalk sections at Upper College Road and Green Hall, at the University of Rhode Island.

4.4.7.1. ADA-SI Calculations

As mentioned in section 4.3.7.1., this study proposed two methods for calculating ADA- Sidewalk Indices. Five sidewalk sections with 160 feet in length were used in this study. Two of these sidewalk sections are located in front of the Green Hall and three of them are located at the Upper College Road. Using the equations mentioned in section 4.3.7., the six indices of both methods for the sidewalks are calculated and reported in. Table 28, Table 29, Table 30, Table 31 and Table 32

Table 28 ADA-SI Calculation fort Upper College Road Part 1, Sidewalk 1

<table>
<thead>
<tr>
<th>Index</th>
<th>Method 1</th>
<th>Method 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSI</td>
<td>0.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>CI</td>
<td>26.2400</td>
<td>0.0819</td>
</tr>
<tr>
<td>OI</td>
<td>0.0050</td>
<td>0.4994</td>
</tr>
<tr>
<td>CSLI</td>
<td>0.0688</td>
<td>0.1275</td>
</tr>
<tr>
<td>SCI</td>
<td>0.0063</td>
<td>0.6563</td>
</tr>
<tr>
<td>RI</td>
<td>488.0200</td>
<td>0.0020</td>
</tr>
</tbody>
</table>
### Table 29 ADA-SI Calculation for Upper College Road Part 2, Sidewalk 2

<table>
<thead>
<tr>
<th>Index</th>
<th>Method 1</th>
<th>Method 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSI</td>
<td>0.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>CI</td>
<td>34.7960</td>
<td>0.0482</td>
</tr>
<tr>
<td>OI</td>
<td>0.0211</td>
<td>0.5116</td>
</tr>
<tr>
<td>CSLI</td>
<td>0.0858</td>
<td>0.3531</td>
</tr>
<tr>
<td>SCI</td>
<td>0.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>RI</td>
<td>604.0000</td>
<td>0.0017</td>
</tr>
</tbody>
</table>

### Table 30 ADA-SI I Calculation for Upper College Road Part 3, Sidewalk 3

<table>
<thead>
<tr>
<th>Index</th>
<th>Method 1</th>
<th>Method 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSI</td>
<td>0.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>CI</td>
<td>28.4240</td>
<td>0.0033</td>
</tr>
<tr>
<td>OI</td>
<td>0.0053</td>
<td>0.5873</td>
</tr>
<tr>
<td>CSLI</td>
<td>0.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>SCI</td>
<td>0.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>RI</td>
<td>528.6300</td>
<td>0.0019</td>
</tr>
</tbody>
</table>
Table 31 ADA-SI Calculation for Green Hall Part 1, Sidewalk 4

<table>
<thead>
<tr>
<th>Index</th>
<th>Method 1</th>
<th>Method 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSI</td>
<td>0.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>CI</td>
<td>0.2125</td>
<td>0.6194</td>
</tr>
<tr>
<td>OI</td>
<td>0.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>CSLI</td>
<td>0.0438</td>
<td>0.2713</td>
</tr>
<tr>
<td>SCI</td>
<td>0.1313</td>
<td>0.1206</td>
</tr>
<tr>
<td>RI</td>
<td>588.0400</td>
<td>0.0017</td>
</tr>
</tbody>
</table>

Table 32 ADA-SI Calculation for Green Hall Part 2, Sidewalk 5

<table>
<thead>
<tr>
<th>Index</th>
<th>Method 1</th>
<th>Method 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSI</td>
<td>0.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>CI</td>
<td>2.2441</td>
<td>0.2823</td>
</tr>
<tr>
<td>OI</td>
<td>0.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>CSLI</td>
<td>0.1462</td>
<td>0.0617</td>
</tr>
<tr>
<td>SCI</td>
<td>0.0254</td>
<td>0.6275</td>
</tr>
<tr>
<td>RI</td>
<td>493.0500</td>
<td>0.0020</td>
</tr>
</tbody>
</table>

Regarding the possible range of the indices in method 1, it should be mentioned that the lowest value for the indices in the first method is 0. Since their values depend on the number of violations in sidewalks, there is no boundary for the highest value (infinity). These indices are negative which means that higher indices are the worse the sidewalk.
is. However, in the method 2, the possible range of the indices is from 0 (the lowest) to 1 (the highest). Therefore, the indices of the second method are positive. This means the higher indices are the better the sidewalk is.

4.4.7.2. The Survey’s Results

In the survey, the participants were asked to walk and use a wheelchair on all five sidewalks mentioned in the previous section. In total, 40 individuals participated in this survey. Twenty percent of them were 19 years old or younger. Sixty percent of them were between 20 and 29 years old. Ten percent of them were between 30 and 39 years old and seven percent of them were older adults (more than 60 years old). Fifty-seven percent of the participants were female while forty-three percent were male. Forty-two percent of participants mentioned that they usually use sidewalks more than 6 times per day. Forty-two percent of them usually use sidewalks between 2 to 5 times a day. Fifteen percent of them use the sidewalk once a day. The majority of participants (75%) stated that each of their walks on sidewalks takes 5 to 15 minutes on average. Eight percent of the participants walked for 15-30 minutes per sidewalk trip, and 15% of them reported taking less than 5 minutes per sidewalk trip. The majority of participants (97%) recognized themselves as average physical shape while the rest stated that they are in great physical shape.

The results were analyzed using the ANOVA (with 95% confidence level). We investigated whether the travel modes and sidewalks had an effect on ratings. This test was done for all indices and overall ratings. The results are shown in Table 33. As you can see, the p-values for all indices and overall rating for both travel modes and all
sidewalks are less than 0.05. This means that participants rated the sidewalks attributes significantly different while using different traveling modes (walking and wheelchair) at different sidewalks. Figure 28 illustrates all main effect plots. As you can see, the sidewalk 4 and the sidewalk 5 located in front of the Green Hall are rated higher than the sidewalk 1, sidewalk 2, and sidewalk 3 located in the Upper College Road. Additionally, participants rated higher while they walked rather than while they used wheelchair. For some indices such as CI, OI and overall ratings, there is interaction between sidewalks and travel modes (Figure 29). Considering overall ratings, the sidewalk 5 is the best sidewalk while considering CI ratings the sidewalk 4 is the best. Considering OI, in walking mode the sidewalk 4 and in wheelchair mode sidewalk 5 is the best sidewalk. As a result, all of the sidewalks located in front of the Green Hall have higher ratings compared with the sidewalks located in the Upper College Road.

Table 33 ANOVA Results for Traveling Mode and Sidewalk effects

<table>
<thead>
<tr>
<th>Index</th>
<th>F-Value for Travel mode</th>
<th>P-Value for Travel mode</th>
<th>F-Value for Sidewalks.</th>
<th>P-Value for Sidewalks.</th>
<th>F-Value for Interaction</th>
<th>P-Value for Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSI</td>
<td>17.29</td>
<td>&lt;0.001</td>
<td>5.29</td>
<td>&lt;0.001</td>
<td>0.86</td>
<td>0.491</td>
</tr>
<tr>
<td>CI</td>
<td>120.71</td>
<td>&lt;0.001</td>
<td>37.24</td>
<td>&lt;0.001</td>
<td>9.96</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>OI</td>
<td>43.99</td>
<td>&lt;0.001</td>
<td>59.99</td>
<td>&lt;0.001</td>
<td>4.76</td>
<td>0.001</td>
</tr>
<tr>
<td>CSLI</td>
<td>39.98</td>
<td>&lt;0.001</td>
<td>13.81</td>
<td>&lt;0.001</td>
<td>1.57</td>
<td>0.184</td>
</tr>
<tr>
<td>SCI</td>
<td>29.38</td>
<td>&lt;0.001</td>
<td>8.28</td>
<td>&lt;0.001</td>
<td>0.23</td>
<td>0.920</td>
</tr>
<tr>
<td>RI</td>
<td>15.71</td>
<td>&lt;0.001</td>
<td>10.53</td>
<td>&lt;0.001</td>
<td>1.57</td>
<td>0.184</td>
</tr>
<tr>
<td>Overall</td>
<td>117.46</td>
<td>&lt;0.001</td>
<td>38.37</td>
<td>&lt;0.001</td>
<td>10.86</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
Figure 28 Main Effects Plot
A correlation study between the indices of both methods and the average of participants’ ratings while using travel modes was conducted. Since there was no running slope violation, the correlation study regarding this attribute of sidewalk was not conducted (Table 34). Table 35 reports the correlation results of the cross-slope attribute. Method 1 has a high negative correlation with the ratings while method 2 has a high positive correlation with the ratings for both travel modes. Table 36 illustrates the results of the obstruction attribute, which are similar to the cross-slope results. Using both methods, the indices had high correlations with ratings for both travel modes.
These strong correlations between indices and participants’ perception validates the ability of indices for evaluating the sidewalks.

Table 34 Correlation study Between RSI and Individuals Rating

<table>
<thead>
<tr>
<th>Side</th>
<th>RSI1</th>
<th>RSI2</th>
<th>Walking</th>
<th>Wheelchair</th>
<th>RSI1-Wheelchair</th>
<th>RSI2-Wheelchair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side 1</td>
<td>0</td>
<td>1</td>
<td>2.80</td>
<td>2.40</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Side 2</td>
<td>0</td>
<td>1</td>
<td>2.55</td>
<td>2.25</td>
<td>RSI1-Walking</td>
<td>RSI2-Walking</td>
</tr>
<tr>
<td>Side 3</td>
<td>0</td>
<td>1</td>
<td>2.70</td>
<td>2.25</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Side 4</td>
<td>0</td>
<td>1</td>
<td>3.00</td>
<td>2.90</td>
<td>RSI1-RSI2</td>
<td></td>
</tr>
<tr>
<td>Side 5</td>
<td>0</td>
<td>1</td>
<td>2.85</td>
<td>2.65</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

Table 35 Correlation study Between CI and Individuals Rating

<table>
<thead>
<tr>
<th>Locations</th>
<th>CI-1</th>
<th>CI-2</th>
<th>Walking</th>
<th>Wheelchair</th>
<th>CI1-Wheelchair</th>
<th>CI1-Walking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side 1</td>
<td>26.2400</td>
<td>0.0819</td>
<td>2.65</td>
<td>1.65</td>
<td>-0.9923</td>
<td>-0.9457</td>
</tr>
<tr>
<td>Side 2</td>
<td>34.7960</td>
<td>0.0482</td>
<td>2.40</td>
<td>1.10</td>
<td>CI2-Wheelchair</td>
<td>CI2-Walking</td>
</tr>
<tr>
<td>Side 3</td>
<td>28.4240</td>
<td>0.0033</td>
<td>2.40</td>
<td>1.35</td>
<td>0.9087</td>
<td>0.9186</td>
</tr>
<tr>
<td>Side 4</td>
<td>0.2125</td>
<td>0.6194</td>
<td>3.00</td>
<td>2.80</td>
<td>CI1-CI2</td>
<td></td>
</tr>
<tr>
<td>Side 5</td>
<td>2.2441</td>
<td>0.2823</td>
<td>2.85</td>
<td>2.55</td>
<td></td>
<td>-0.88</td>
</tr>
</tbody>
</table>
Table 36 Correlation study Between OI and Individuals Rating

<table>
<thead>
<tr>
<th>Locations</th>
<th>OI-1</th>
<th>OI-2</th>
<th>Walking</th>
<th>Wheelchair</th>
<th>OI1-Wheelchair</th>
<th>OI1-Walking</th>
<th>OI2-Wheelchair</th>
<th>OI2-Walking</th>
<th>OI1- OI2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side 1</td>
<td>0.0050</td>
<td>0.4994</td>
<td>2.15</td>
<td>1.45</td>
<td>-0.7162</td>
<td>-0.6671</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side 2</td>
<td>0.0211</td>
<td>0.5116</td>
<td>2.05</td>
<td>1.25</td>
<td>OI2-Wheelchair</td>
<td>OI2-Walking</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side 3</td>
<td>0.0053</td>
<td>0.5873</td>
<td>2.00</td>
<td>1.35</td>
<td>0.9851</td>
<td>0.9605</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side 4</td>
<td>0.0000</td>
<td>1.0000</td>
<td>3.00</td>
<td>2.85</td>
<td>OI1- OI2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side 5</td>
<td>0.0000</td>
<td>1.0000</td>
<td>2.80</td>
<td>2.75</td>
<td>-0.69</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Regarding the roughness, both methods have small correlations with ratings for both travelling mode (Table 37). These ratings correlated positively with method 2 and negatively with method 1. Regarding the changes in surface level, the indices have a small correlation with both travel modes. Same as the roughness index, the ratings correlated positively with method 2 and negatively with method 1 (Table 38). Finally, the indices of the surface condition attribute have a moderate correlation with ratings for both travel modes (Table 39). Similar to the changes in surface level, the ratings positively correlated with method 2 and negatively correlated with method 1. These weak and medium correlations can be due to the interactive relationship which these attributes might have. More data collection in sidewalks with various conditions would be needed to validate these indices. These small and medium correlations can be due to the interactive relationship which these attributes might have. More data collection in sidewalks with various conditions would be needed to validate these indices.
### Table 37 Correlation study Between RI and Individuals Rating

<table>
<thead>
<tr>
<th>Locations</th>
<th>RI1</th>
<th>RI2</th>
<th>Walking</th>
<th>Wheelchair</th>
<th>RI1-Wheelchair</th>
<th>RI1-Walking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side 1</td>
<td>488.0200</td>
<td>0.0020</td>
<td>2.35</td>
<td>1.85</td>
<td>-0.0453</td>
<td>-0.2863</td>
</tr>
<tr>
<td>Side 2</td>
<td>604.0000</td>
<td>0.0017</td>
<td>2.55</td>
<td>2.10</td>
<td>R12-Wheelchair</td>
<td>R12-Walking</td>
</tr>
<tr>
<td>Side 3</td>
<td>528.6300</td>
<td>0.0019</td>
<td>2.60</td>
<td>2.10</td>
<td>0.0490</td>
<td>0.3001</td>
</tr>
<tr>
<td>Side 4</td>
<td>588.0400</td>
<td>0.0017</td>
<td>2.85</td>
<td>2.60</td>
<td>R11-R12</td>
<td></td>
</tr>
<tr>
<td>Side 5</td>
<td>493.0500</td>
<td>0.0020</td>
<td>2.80</td>
<td>2.80</td>
<td>-0.99</td>
<td></td>
</tr>
</tbody>
</table>

### Table 38 Correlation study Between CSLI and Individuals Rating

<table>
<thead>
<tr>
<th>Locations</th>
<th>CSLI1</th>
<th>CSLI2</th>
<th>Walking</th>
<th>Wheelchair</th>
<th>CSLI 1-Wheelchair</th>
<th>CSLI 1-Walking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side 1</td>
<td>0.0688</td>
<td>0.1275</td>
<td>2.35</td>
<td>1.60</td>
<td>-0.2400</td>
<td>-0.0482</td>
</tr>
<tr>
<td>Side 2</td>
<td>0.0858</td>
<td>0.3531</td>
<td>2.25</td>
<td>1.65</td>
<td>CSLI 2-Wheelchair</td>
<td>CSLI 2-Walking</td>
</tr>
<tr>
<td>Side 3</td>
<td>0.0000</td>
<td>1.0000</td>
<td>2.50</td>
<td>1.80</td>
<td>0.2989</td>
<td>0.1148</td>
</tr>
<tr>
<td>Side 4</td>
<td>0.0438</td>
<td>0.2713</td>
<td>2.90</td>
<td>2.60</td>
<td>CSLI1- CSLI12</td>
<td></td>
</tr>
<tr>
<td>Side 5</td>
<td>0.1462</td>
<td>0.0617</td>
<td>2.65</td>
<td>2.40</td>
<td>-0.80</td>
<td></td>
</tr>
</tbody>
</table>
Table 39 Correlation study Between SCI and Individuals Rating

<table>
<thead>
<tr>
<th>Location</th>
<th>SCI 1</th>
<th>SCI 2</th>
<th>Walking</th>
<th>Wheelchair</th>
<th>CI1-Wheelchair</th>
<th>CI1-Walking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side 1</td>
<td>0.0063</td>
<td>0.6563</td>
<td>2.20</td>
<td>1.60</td>
<td>-0.6156</td>
<td>-0.7413</td>
</tr>
<tr>
<td>Side 2</td>
<td>0.0000</td>
<td>1.0000</td>
<td>2.40</td>
<td>2.00</td>
<td>CI2-Wheelchair</td>
<td>CI2-Walking</td>
</tr>
<tr>
<td>Side 3</td>
<td>0.0000</td>
<td>1.0000</td>
<td>2.60</td>
<td>2.05</td>
<td>0.4320</td>
<td>0.5483</td>
</tr>
<tr>
<td>Side 4</td>
<td>0.1313</td>
<td>0.1206</td>
<td>2.85</td>
<td>2.35</td>
<td>SCI 1-SCI2</td>
<td></td>
</tr>
<tr>
<td>Side 5</td>
<td>0.0254</td>
<td>0.6275</td>
<td>2.65</td>
<td>2.30</td>
<td>-0.92</td>
<td></td>
</tr>
</tbody>
</table>

A regression analysis was conducted to investigate the correlation between overall ratings and the indices. The different combinations of the indices were considered using the best subset method in Minitab software. In Minitab, the best model was chosen based on $R^2$, $R^2$-adjusted, $R^2$-predicted, Mallows $C_p$, and square root of Mean Square Error. As you can see in Table 40, the best model includes all indices except the RSI.

The best regression equation is calculated (Equation 23). The regression statistics and ANOVA results are shown in Table 41 and Table 42. The regression model and all attributes except RI have a p-value less than 0.05. According to the model summary, 74.26% of the variability of overall ratings is explained with this model.
Table 40 The Best Subset Results

<table>
<thead>
<tr>
<th>Var.</th>
<th>R-Sq (adj)</th>
<th>RSq (pred)</th>
<th>Mallows Cₚ</th>
<th>S</th>
<th>CI</th>
<th>RSI</th>
<th>RI</th>
<th>OI</th>
<th>CSLI</th>
<th>SCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60.4</td>
<td>60.2</td>
<td>59.6</td>
<td>105.4</td>
<td>0.50</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>55.6</td>
<td>55.4</td>
<td>54.8</td>
<td>140.9</td>
<td>0.53</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>69.0</td>
<td>68.7</td>
<td>67.9</td>
<td>43.6</td>
<td>0.44</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>68.6</td>
<td>68.2</td>
<td>67.3</td>
<td>46.7</td>
<td>0.45</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>73.3</td>
<td>72.9</td>
<td>71.8</td>
<td>13.5</td>
<td>0.41</td>
<td>X</td>
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Overall Rating = -0.116 + 0.1386 SCI + 0.1773 CSLI + 0.2811 OI + 0.0993 RI + 0.3726 CI \quad (23)

Table 41 ANOVA Results for the Regression Model

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Table 42 Regression Statistics Results

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5. DISCUSSION AND CONCLUSION

Since the mid 90s, significant efforts and resources have been expended to manually measure and evaluate sidewalks for ADA compliance in Rhode Island. An automated system could save thousands of hours spent crawling on hands and knees to measure the running slope, cross-slope and other attributes of sidewalks. This study identified an automated system to accelerate the current sidewalk measurement process at RIDOT while maintaining measurement integrity. After a comprehensive online search and attendance of multiple exhibitions, an automated system, The CS8900 Walking Profiler was selected. This system which was produced by SSI Inc. was selected as the best fit for RIDOT needs, as established through consultation with RIDOT officials. The quality, accuracy and reliability of the data generated by the automated system was evaluated using a five-step approach. Using the verified manual and automated methods, different sidewalks were assessed and the results were compared. After conducting various comparison tests, it was determined that the automated
measurements agree well with the manual measurement results. By using the automated method, RIDOT could save at least $534,000 in labor cost in five years and decrease the surveying time by at least by 60%. This study also provides recommendations to the RIDOT authorities about sidewalk indices to evaluate ADA compliance and safety of sidewalks based on the automated data the system provided. The automated system and the developed sidewalk indices will allow a faster and easier process for sidewalk evaluation and assessment, leading to enhanced sidewalk quality, and improved safety and accessibility for sidewalks users for years to come. In future studies, the indices and their correlations with subjects’ perceptions should be tested on more sidewalks. The addition of more sidewalks could allow an integrated index to be developed that encompasses all sidewalk attribute into one definitive index.
ACKNOWLEDGEMENT

The authors would like to acknowledge The Rhode Island Department of Transportation and the University of Rhode Island Transportation Center for their support and guidance throughout this research project. Moreover, the authors wish to thank undergraduate students Robyn Johnson, and Ulices Ortiz for their help in conducting the field studies.

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APPENDICES

APPENDIX 1 - SURVEY SAMPLE FOR TEXT DRIVING PROJECT

Hands-on & Hands-free Texting During Driving  

Sanaz Motamedi  
Kevin Shepherd  
University of Rhode Island

Questionnaire

Participant ID:
Gender: Female □ Male □
Age:______________________
Driving Habits:
How many years have you held your driver’s license? ....................
On average, how many miles do you drive per year? ....................
Driving style:
Which option below would you consider your driving style?
Defensive □ Normal □ Aggressive □
Speed limit:
What is your usual speed while driving?
Below the speed limit □ Exactly the speed limit □ About 5-10 mph above speed limit □ More than 10 mph over speed limit □
Car:
What is your personal vehicle’s year, make and model?______________________
Does your vehicle have an integrated hands-free option installed? Yes □ No □
Cellphone:
What type of smartphone do you use? Android □ iOS □ Others .................
Texting Habits:
How frequently do you text or send e-mails from your phone while driving?
Never □ Once in a while □ Often □ Frequently □ Always □
Which texting method do you typically use to read and send texts/e-mails while driving?
Hands-On □ Hands-Free □ Both □
How would you say texting while driving affects your driving performance?
Very Negative Impact □ Negative Impact □ No Difference □ Positive Impact □ Very Positive Impact □
Traffic Survey:
Have you ever had your license revoked or suspended? Any moving violations? Have you involved the use of a smartphone on-road? If so, please provide context.

Thank you for your cooperation & participation!
APPENDIX 2- CONSENT FORM FOR TEXT DRIVING PROJECT

Consent Form

The University of Rhode Island
Department of Mechanical, Industrial and System Engineering
Address: 203 Wales Hall, 92 Upper College Road, Kingston, RI 02881 USA
Title of Project: Is hands-free texting a better alternative to hands-on texting while driving?

CONSENT FORM FOR RESEARCH

You have been invited to take part in a research project described below. The researcher will explain the project to you in detail. You should feel free to ask questions. If you have any questions later, Professor Jay Wang, the person mainly responsible for this study, (401) 874-5195, will discuss them with you. You must be at least 18 years old, have a valid driver's license, and a smartphone to be in this research project.

Description of the project:
This research project is to study the impact of different forms of texting (hands-on and hands-free) while driving and how it affects your driving performance.

What will be done:
If you decide to take part in this study, you will first complete a brief questionnaire. Then you will sit in the driver's seat of a stationary vehicle and make responses (hands-free or Hands-on) to the text messages which you will receive. This experiment takes about 45 min.

Risks or discomfort:
There are no risks or discomforts that might reasonably be expected to happen.

Benefits of this study:
The participants might become more aware of how texting influences their driving performance, and the researchers may learn more about how different methods of communication affect driving performance.

Confidentiality:
Your part in this study is confidential. None of the information will identify you by name. All records will be treated with care to maintain the confidentiality of the subjects. The data pertaining to subjects and their answers will be stored in the principal investigator's laptop with secure lock and kept in locked office which located in room 103M, Gibbeth Hall, URI and will be accessible only to researcher.

Decision to quit at any time:
The decision to take part in this study is up to you. You do not have to participate. If you decide to take part in the study, you may quit at any time. Whatever you decide will in no way penalize you. If you wish to quit, simply inform the investigator Sara Motamed with phone: 4014061730 of your decision.
Rights and Complaints:
If you are not satisfied with the way this study is performed, you may discuss your complaints with Professor Jay Wang or with Sanaz Motamed (Phone: 4014061730), anonymously, if you choose. In addition, if you have questions about your rights as a research participant, you may contact the office of the Vice President for Research and Economic development, 70 Lower College Road, Suite 2, University of Rhode Island, Kingston, Rhode Island, telephone: (401) 874-4328.

You have read the Consent Form. Your questions have been answered. Your signature on this form means that you understand the information and you agree to participate in this study.

Signature of Participant __________________________ Signature of Researcher __________________________

Typed/printed Name __________________________ Typed/printed name __________________________

Date __________________ Date __________________

Please sign both consent forms, keeping one for yourself
APPENDIX 3- SAMPLE OF QUESTIONNAIRE 1 FOR OLDER ADULT DRIVING PROJECT

Assessment of Driving Questionnaire

1. Please indicate your:
   - Age: □ Younger than 60 years old  □ 61-70 years old  □ 71-80 years old  □ More than 90 years old
   - Gender: □ Female  □ Male

2. How many years have you had your driver’s license?
   □ 1-20 years  □ 21-30 years  □ 31-40 years  □ 41-50 years
   □ 51-60 years  □ Over 60 years

3. How often do you drive?
   □ More than once a day  □ Once a day  □ Thrice a week  □ Twice a week
   □ Once a week  □ Twice a month  □ Once a month  □ Other

4. How long does your drive usually take in average?
   □ Less than 15 minutes  □ 15-30 minutes  □ 0.5-1 hour  □ 1-1.5 hours
   □ 1.5-2 hours  □ Over 2 hours  □ Other (please specify)

5. Please check any type of health concern you have (choose none if there isn’t any).
   □ Memory  □ Vision  □ Hearing  □ Muscle weakness or paralysis
   □ Speaking  □ Balance  □ Pain  □ Heart conditions  □ Bones or joints
   □ Breathing  □ None  □ Other (please specify)

6. Please choose the condition(s) which you were at fault in a crash or near crash experience.
   □ Driving approaching an intersection  □ Driving on highways or high-speed roads
   □ Driving at night  □ Driving in heavy traffic
   □ Driving in rainy weather  □ Driving in foggy weather
   □ Driving in snowy weather  □ Driving on unfamiliar roads
   □ Passing another vehicle  □ Making left turn
   □ Changing lanes  □ Merging into Traffic
   □ None  □ Other (please specify)

7. Choose and rank the top 3 conditions that you like to avoid when driving.
   □ Driving approaching an intersection (Rank#......)
   □ Driving at night (Rank#......)
   □ Driving in rainy weather (Rank#......)
   □ Driving in snowy weather (Rank#......)
   □ Passing another vehicle (Rank#......)
   □ Changing lanes (Rank#......)
   □ Making left turn (Rank#......)
   □ Driving in heavy traffic (Rank#......)
   □ Driving in foggy weather (Rank#......)
   □ Driving on highways (Rank#......)
   □ Driving on unfamiliar roads (Rank#......)
   □ Merging into Traffic (Rank#......)
   □ Other (please specify)
Assessment of Driving Questionnaire

Note: Likert Scale in this survey stands for:
1 = not challenging  2 = somewhat challenging  3 = challenging
4 = very challenging  5 = extremely challenging

8. Please rate the level of challenge that you experience while driving when approaching an intersection WITH traffic lights.
   □ 1  □ 2  □ 3  □ 4  □ 5

9. Please rate the level of challenge that you experience while driving when approaching an intersection WITHOUT traffic lights.
   □ 1  □ 2  □ 3  □ 4  □ 5

10. Please rate the level of challenge that you experience while making left turns that is NOT controlled by a traffic light.
    □ 1  □ 2  □ 3  □ 4  □ 5

11. Please rate the level of challenge that you experience while making left turns that is controlled by a traffic light.
    □ 1  □ 2  □ 3  □ 4  □ 5

12. Please rate the level of challenge that you experience while driving on highways or high-speed roads that familiar with.
    □ 1  □ 2  □ 3  □ 4  □ 5

13. Please rate the level of challenge that you experience while driving on highways or high-speed roads that unfamiliar with.
    □ 1  □ 2  □ 3  □ 4  □ 5

14. Please rate the level of challenge that you experience while changing lanes on a three- or four-lane divided highway.
    □ 1  □ 2  □ 3  □ 4  □ 5
Assessment of Driving Questionnaire

Note: Likert Scale in this survey stands for:

1 = not challenging  
2 = somewhat challenging  
3 = challenging  
4 = very challenging  
5 = extremely challenging

15. Please rate the level of challenge that you experience while passing another vehicle on a three- or four-lane divided highway.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

16. Please rate the level of challenge that you experience while passing another vehicle on two-lane undivided highway.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

17. Please rate the level of challenge that you experience while driving in heavy traffic.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

18. Please rate the level of challenge that you experience while driving at night on lighted urban roads.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

19. Please rate the level of challenge that you experience while driving at night on unlighted urban roads.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

20. Please rate the level of challenge that you experience while driving at night on lighted rural roads.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

21. Please rate the level of challenge that you experience while driving at night on unlighted rural roads.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

22. Please rate the level of challenge that you experience while driving in light rain.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

23. Please rate the level of challenge that you experience while driving in light snow.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

24. Please rate the level of challenge that you experience while driving in light fog.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Assessment of Driving Questionnaire

Note: Likert Scale in this survey stands for:
1 = not challenging 2 = somewhat challenging 3 = challenging
4 = very challenging 5 = extremely challenging

25. Please rate the level of challenge that you experience while driving in heavy rain.
   □ 1 □ 2 □ 3 □ 4 □ 5

26. Please rate the level of challenge that you experience while driving in heavy snow.
   □ 1 □ 2 □ 3 □ 4 □ 5

27. Please rate the level of challenge that you experience while driving in heavy fog.
   □ 1 □ 2 □ 3 □ 4 □ 5

Thank you!

If you are interested in participating in this study please leave your contact information.

Name: __________________________ Email: __________________________

Phone: (_____)_________ _______

Address: __________________________ __________________________
          (Street)           (City)        (State)       (Zip code)
Senior Mobility Questionnaire

Please indicate your:

- Age: □ Younger than 60 years old □ 61-70 years old □ 71-80 years old □ 81-90 years old □ More than 90 years old
- Gender: □ Female □ Male

1. How many years have you had your driver’s license?
   □ 1-20 years □ 21-30 years □ 31-40 years □ 41-50 years
   □ 51-60 years □ Over 60 years

2. How often do you drive?
   □ More than once a day □ Once a day □ Twice a week □ Thrice a week
   □ Once a week □ Twice a month □ Once a month □ Other ………………

3. How long does your drive usually take in average?
   □ Less than 15 minutes □ 15-30 minutes □ 0.5-1 hour □ 1-1.5 hour
   □ 1.5-2 hours □ Over 2 hours □ Other (please specify) ……………………..

4. Please check any type of health concern you have (choose none if there isn’t any).
   □ Memory □ Vision □ Hearing □ Muscle weakness or paralysis
   □ Speaking □ Balance □ Pain □ Heart conditions □ Bones or joints
   □ Breathing □ None □ Other (please specify) ……………………………

5. Please choose the condition(s) which you were at fault in a crash or near crash experience.
   □ Driving approaching an intersection □ Driving on highways or high-speed roads
   □ Driving at night □ Driving in heavy traffic
   □ Driving in rainy weather □ Driving in foggy weather
   □ Driving in snowy weather □ Driving on unfamiliar roads
   □ Passing another vehicle □ Making left turn
   □ Changing lanes □ Merging into Traffic
   □ None □ Other (please specify) ………………………………………
Senior Mobility Questionnaire

Section One: Advanced Driving Assistant System

Note: Likert Scale in this survey stands for:

1 = not likely  2 = somewhat likely  3 = likely  4 = very likely
5 = extremely likely

Technology System: Automatic Windshield Wipers

1. Do you think this system is **helpful**?

☐ 1  ☐ 2  ☐ 3  ☐ 4  ☐ 5

2. Do you think this system is **easy to use**?

☐ 1  ☐ 2  ☐ 3  ☐ 4  ☐ 5

3. Do you think this system is **distracting or annoying**?

☐ 1  ☐ 2  ☐ 3  ☐ 4  ☐ 5

4. Do you think this system is a **necessity** for safe driving?

☐ 1  ☐ 2  ☐ 3  ☐ 4  ☐ 5

5. Would you **use** this system?

☐ 1  ☐ 2  ☐ 3  ☐ 4  ☐ 5
Senior Mobility Questionnaire

Section One: Advanced Driving Assistant System

Note: Likert Scale in this survey stands for:

1 = not likely  2 = somewhat likely  3 = likely  4 = very likely  5 = extremely likely

---

Technology System: LED Camera

1. Do you think this system is helpful?
   \[ \square 1 \quad \square 2 \quad \square 3 \quad \square 4 \quad \square 5 \]

2. Do you think this system is easy to use?
   \[ \square 1 \quad \square 2 \quad \square 3 \quad \square 4 \quad \square 5 \]

3. Do you think this system is distracting or annoying?
   \[ \square 1 \quad \square 2 \quad \square 3 \quad \square 4 \quad \square 5 \]

4. Do you think this system is a necessity for safe driving?
   \[ \square 1 \quad \square 2 \quad \square 3 \quad \square 4 \quad \square 5 \]

5. Would you use this system?
   \[ \square 1 \quad \square 2 \quad \square 3 \quad \square 4 \quad \square 5 \]
Senior Mobility Questionnaire

Section One: Advanced Driving Assistant System

Note: Likert Scale in this survey stands for:

1 = not likely  2 = somewhat likely  3 = likely  4 = very likely  5 = extremely likely

Technology System: Adaptive Cruise Control

1. Do you think this system is helpful?
   □ 1   □ 2   □ 3   □ 4   □ 5

2. Do you think this system is easy to use?
   □ 1   □ 2   □ 3   □ 4   □ 5

3. Do you think this system is distracting or annoying?
   □ 1   □ 2   □ 3   □ 4   □ 5

4. Do you think this system is a necessity for safe driving?
   □ 1   □ 2   □ 3   □ 4   □ 5

5. Would you use this system?
   □ 1   □ 2   □ 3   □ 4   □ 5
Senior Mobility Questionnaire

Section One: Advanced Driving Assistant System

Note: Likert Scale in this survey stands for:

1 = not likely  2 = somewhat likely  3 = likely  4 = very likely  
5 = extremely likely

Technology System: Lane Departure System Warning System

1. Do you think this system is **helpful**?
   
   □ 1  □ 2  □ 3  □ 4  □ 5

2. Do you think this system is **easy to use**?
   
   □ 1  □ 2  □ 3  □ 4  □ 5

3. Do you think this system is **distracting or annoying**?
   
   □ 1  □ 2  □ 3  □ 4  □ 5

4. Do you think this system is a **necessity for safe driving**?
   
   □ 1  □ 2  □ 3  □ 4  □ 5

5. Would you **use** this system?
   
   □ 1  □ 2  □ 3  □ 4  □ 5
Senior Mobility Questionnaire

Section One: Advanced Driving Assistant System

Note: Likert Scale in this survey stands for:

1 = not likely  2 = somewhat likely  3 = likely  4 = very likely  5 = extremely likely

Technology System: 3D Pedestrian Warning system

1. Do you think this system is helpful?
   □ 1  □ 2  □ 3  □ 4  □ 5

2. Do you think this system is easy to use?
   □ 1  □ 2  □ 3  □ 4  □ 5

3. Do you think this system is distracting or annoying?
   □ 1  □ 2  □ 3  □ 4  □ 5

4. Do you think this system is a necessity for safe driving?
   □ 1  □ 2  □ 3  □ 4  □ 5

5. Would you use this system?
   □ 1  □ 2  □ 3  □ 4  □ 5
Senior Mobility Questionnaire

Section One: Advanced Driving Assistant System

Note: Likert Scale in this survey stands for:

1 = not likely 2 = somewhat likely 3 = likely 4 = very likely 5 = extremely likely

Technology System: Bosch Side View Assist

1. Do you think this system is helpful?
   ☐ 1  ☐ 2  ☐ 3  ☐ 4  ☐ 5

2. Do you think this system is easy to use?
   ☐ 1  ☐ 2  ☐ 3  ☐ 4  ☐ 5

3. Do you think this system is distracting or annoying?
   ☐ 1  ☐ 2  ☐ 3  ☐ 4  ☐ 5

4. Do you think this system is a necessity for safe driving?
   ☐ 1  ☐ 2  ☐ 3  ☐ 4  ☐ 5

5. Would you use this system?
   ☐ 1  ☐ 2  ☐ 3  ☐ 4  ☐ 5
Senior Mobility Questionnaire

Are you interested in trying these systems and services with us? If so, please provide your contact information. We will contact you soon.

Name: ___________________________ Phone Number: ___________________________

Email: ___________________________
APPENDIX 5- CONSENT FORM FOR OLDER ADULT DRIVING PROJECT

Consent Form

The University of Rhode Island
Department of Mechanical, Industrial and System Engineering
Address: 203 Wales Hall, 92 Upper College Road, Kingston, RI 02881 USA
Title of Project: Is hands-free texting a better alternative to hands-on texting while driving?

CONSENT FORM FOR RESEARCH

You have been invited to take part in a research project described below. The researcher will explain the project to you in detail. You should feel free to ask questions. If you have more questions later, Professor Jay Wang, the person mainly responsible for this study, (401) 874-5195, will discuss them with you. You must be at least 18 years old, have a valid driver’s license, and a smartphone to be in this research project.

Description of the project:
The objective of this research is to identify the principal factors associated with elder driver driving accidents and fatalities, assessing the age-related effects and mental workload on driving performance and develop means to effectively assess elder drivers’ driving.

What will be done:
If you decide to take part in this study, you will first complete a brief questionnaire. Then you will sit in the driver’s seat of a stationary vehicle and drive. This experiment takes about one hour.

Risks or discomfort:
There are no risks or discomforts that might reasonably be expected to happen.

Benefits of this study:
The participants gain a better understanding of effects of age on driving performance. The researchers identify critical factors to the increased elder driver driving accidents and develop a system to assess elder driver driving abilities.

Confidentiality:
Your part in this study is confidential. None of the information will identify you by name. All records will be treated with care to maintain the confidentiality of the subjects. The data pertaining to subjects and their answers will be stored in the principal
investigator's laptop with secure lock and kept in locked office which located in room 103M, Gilbreth Hall, URI and will be accessible only to researcher.

**Decision to quit at any time:**
The decision to take part in this study is up to you. You do not have to participate. If you decide to take part in the study, you may quit at any time. Whatever you decide will in no way penalize you. If you wish to quit, simply inform the investigator Sanaz Motamedi with phone: 4014061730 of your decision.

**Rights and Complaints:**
If you are not satisfied with the way this study is performed, you may discuss your complaints with Professor Jay Wang or with Sanaz Motamedi (Phone: 4014061730), anonymously, if you choose. In addition, if you have questions about your rights as a research participant, you may contact the office of the Vice President for Research and Economic Development, 70 Lower College Road, Suite 2, University of Rhode Island, Kingston, Rhode Island, telephone: (401) 874-4328.

You have read the Consent Form. Your questions have been answered. Your signature on this form means that you understand the information and you agree to participate in this study.

__________________________________________
Signature of Participant

__________________________________________
Signature of Researcher

__________________________________________
Typed/printed Name

__________________________________________
Typed/printed name

__________________________________________
Date

__________________________________________
Date

*Please sign both consent forms, keeping one for yourself*
APPENDIX 6- INTERSECTION INSPECTION FORM

RIDOT INTERSECTION ACCESSIBILITY INSPECTION FORM INSTRUCTIONS

1. Complete one Intersection Accessibility Inspection Form for each wheelchair ramp.

2. Select a Typical Ramp Type from the ramps shown on page 1 and fill out the applicable information on the form. If the ramp does not match one of the Typical Ramp Types, provide a sketch in the Detailed Sketch on page 2 and provide the applicable measurements. Not all information is applicable for each ramp type. If information does not apply, indicate with a “NA”, “-----” or other appropriate mark.

3. Use Ramp Type D only when 1 ramp connects to 2 crosswalks.

4. Each ramp at the intersection shall be given a Ramp ID #. Number the ramps in sequential order going clockwise around the intersection starting with north. Show the Ramp ID number on the Overall Intersection Sketch on page 2.

5. Provide an overall sketch of the intersection in the Overall Intersection Sketch block provided on page 2. The sketch shall indicate major and minor street names, arrow indicating approximate north, and wheelchair ramp locations with Ramp ID numbers.

6. Show all of the pushbutton locations, signal head locations and signal head orientation from Section 4 on the Overall Intersection Sketch on page 2.

7. Show approximate location of all obstructions from Section 5 on the Detailed Sketch on page 2. Use the number associated with the obstruction in Section 5 to identify the obstruction.

8. The Detailed Sketch on page 2 is to be used to show a non-typical ramp, the obstructions that are listed in Section 5 and the orientation of all additional photographs. The Detailed Sketch does not need to be completed if none of these apply.

9. All slopes must be measured in percent slope. The slope of each element shall be measured in three (3) locations. Record the steepest slope on the form.

10. All dimensions must be measured in feet and inches. Record the smallest dimension on the form.

11. “Left Side” and “Right Side” shall be determined as if facing the ramp from the street.

12. The pushbutton height (Question 58) shall be measured from the sidewalk surface to the center of the pushbutton.

13. Photos must be taken at the following locations:
   a) From the sidewalk approach looking towards the ramp (both directions). Include the pedestrian pushbutton (if present) in the photo.
   b) Standing on the detectable warning surface looking towards opposite ramp across the street (in the case of Ramp Type C, take pictures of both opposite ramps).
   c) When in doubt over an answer to any question or to clarify an unusual condition.

14. Do not include the curb in the measurement for sidewalk width.

List of Common Ramp and Sidewalk Obstructions including but not limited to:

- Manhole Cover
- Utility Pole
- Fire Hydrant
- Traffic Signal Pole
- Bus Shelter
- Catch Basin Grate
- Guy Wire
- Traffic Controller Cabinet
- Traffic/Guide Sign
- Light Standards/Poles
- Mailbox
- Fences
- Private Sign
- Benches
- Tree/Tree Branches

- SEE DETAILS ON REVERSE SIDE-
RIDOT Intersection Accessibility Inspection Form

<table>
<thead>
<tr>
<th>Traffic Signal ID #</th>
<th>Intersection ID #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp Type:</td>
<td>Ramp ID #</td>
</tr>
</tbody>
</table>

**Section 1: Ramps**

1. Detectable Warning Surface (DWS) Present: Y / N
2. Does the DWS Color contrast with the sidewalk?: Y / N
3. Note defects with the DWS (Circle all that apply): Tom Peeling Domes Missing Other:

4. Ramp Material: __________________________
5. Does the DWS extend the full width of the ramp opening?: Y / N
6. Is the DWS at least 2’ wide?: Y / N

8. If no on 7, provide sketch on detailed sketch (Fig 2) the typical ramp detail (Fig 3) for Ramp B circle location of DWS:

**NOTE:** The numbers in the following fields correspond to the typical ramp details on Fig 1. Fill in the applicable field for each ramp type. All elements shall be measured three times in the directions indicated. The slope reported below shall be the steepest slope measured on the element. All slopes shall be measured with a 2-foot "smart level". If the direction of the roadway slope for 16 and 17 differs from the sketch, please indicate on the detailed sketch (Fig 2).

<table>
<thead>
<tr>
<th>10 ft in</th>
<th>15 ft in</th>
<th>18 ft in</th>
<th>20 ft in</th>
<th>22 ft in</th>
</tr>
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<tbody>
<tr>
<td>14 ft in</td>
<td>15 ft in</td>
<td>15 ft</td>
<td>16 ft</td>
<td>16 ft</td>
</tr>
<tr>
<td>8%</td>
<td>14%</td>
<td>18%</td>
<td>20%</td>
<td>22%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>10 ft in</th>
<th>15 ft in</th>
<th>19 ft in</th>
<th>20 ft in</th>
<th>22 ft in</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 ft</td>
<td>19 ft</td>
<td>19 ft</td>
<td>20 ft</td>
<td>22 ft</td>
</tr>
<tr>
<td>5%</td>
<td>10%</td>
<td>10%</td>
<td>12%</td>
<td>12%</td>
</tr>
</tbody>
</table>

35a. Measured height of lip:
35b. If more than 1/4", is the lip less than 1/2" and beveled at 1/2": Y / N / NA

37. Is there curb across the opening?: Y / N
38. If yes, Curb Material: Concrete Granite Asphalt

39. Additional Comments:

**Section 2: Sidewalks**

- This section pertains to the sidewalk adjacent to the wheelchair ramp. Measurements and observations shall be taken within 6’ of the ramp (approximately one sidewalk pane).

40. Is there sidewalk connecting to the either side of the ramp?: Y / N

41. Sidewalk Material: Asphalt Concrete Brick Other: __________________________

See NOTE in Section 1 above:
42. ft in | 43. % | 44. %

45. Sidewalk Material: Asphalt Concrete Brick Other: __________________________

See NOTE in Section 1 above:
46. ft in | 47. % | 48. %

49. Additional Comments:

-3-

150
Traffic Signal ID #: ___________________
Intersection ID #: ___________________

Ramp Type: ___________________ Ramp ID: ___________________

Section 3: Crosswalk
50. Is the crosswalk at least 6’ wide (See Detail shown in the instructions)? Y / N / NA
50a. Measured width: ______________ ft in
51. Is a 4” x 4” clear space at the bottom of the ramp completely within the crosswalk lines? Y / N / NA
(Crosswalk lines are not included in the clear space - see Ramp Type Details on Page 1)
51a. Measured clear space ______________ ft in by ______________ ft in
52. Is the cross slope (grade perpendicular to direction of travel) within the clear space 2.0% or less? % Y / N
52a. Is the running slope (grade in the direction of travel) within the clear space 5% or less? % Y / N
53. Is the bottom of the wheelchair ramp located 4” from the edge of travel lane (edge line stripe)? Y / N No Edge Line
54. Is there a median/pedestrian refuge? Y / N
54a. If yes, prepare separate Intersection Accessibility Inspection Form for each refuge ramp.
55. What is the crosswalk material? Same as roadway Other (Indicate): ___________________
56. Additional Comments: ___________________

Section 4: Pedestrian Signals
57. Number of pedestrian pushbuttons present on pole: 1 2 NONE (Circle One) Button 1 Button 2
57a. Is pushbutton diameter at least 2 inches? Y / N Y / N
57b. Measured diameter of pushbutton: ______________ in ______________ in
58a. Is the pushbutton height between 42”-48”? Y / N Y / N
58b. Measured height of pushbutton: ______________ in ______________ in
59. Is the pushbutton location within the area shown on the Detail in the Instructions? Y / N
59a. If No, is the pushbutton location within 10 ft of the edge of curb or edge of pavement? Y / N Y / N
60. Measured distance of pushbutton from the face of curb: ______________ ft in ______________ ft in
61. Does the pushbutton activate the WALK signal? Y / N Y / N
61a. If NO, explain issue:
62. Is the force required to activate the pushbutton 5 lbs or less? Y / N Y / N
62a. Measured force required to activate pushbutton: ______________ lbs
63. Is a 30” x 48” level, clear space provided in front of the pushbutton location (i.e., free of obstacles and slope less than 2.0% in all directions) (See Detail in the Instructions)? Y / N Y / N
63a. Measured clear space provided in front of pushbutton: ______________ in x ______________ in ______________ in x ______________ in
64. Is the pushbutton vibrotactile? Y / N Y / N
65. Does the pushbutton contrast visually with the mounting or housing? Y / N Y / N
66. Does the pushbutton vibrate at the beginning of the WALK phase? Y / N Y / N
67. Is a tactile arrow present on the pushbutton? Y / N Y / N
68. Does the tactile arrow point parallel to the crosswalk to be used? Y / N / NA Y / N / NA
69. Does the tactile arrow contrast visually with the mounting or housing? Y / N / NA Y / N / NA
70. Is an instruction plaque present? Y / N Y / N
71. Is the street name present on the instruction plaque? Y / N / NA Y / N / NA
72. Is an arrow present on the instruction plaque? Y / N / NA Y / N / NA
73. Does the arrow point parallel to the crosswalk to be used? Y / N / NA Y / N / NA
74. Is an audible locator tone present? Y / N Y / N
75. Does the audible locator tone sound only when the Don’t Walk and Flashing Don’t Walk are active? Y / N / NA Y / N / NA
76. Does the locator tone repeat at 1 second intervals? Y / N / NA Y / N / NA
77. Is there at least one signal head per pedestrian crossing? Y / N Y / N

77a. Does the signal head on the opposite side of the crossing point towards the ramp? Please sketch the orientation of signal heads on the Overall intersection sketch on page 2.
CONSENT FORM FOR SIDEWALK ASSESSMENT PROJECT

The University of Rhode Island
Department of Mechanical, Industrial and System Engineering
Address: 203 Wales Hall, 92 Upper College Road, Kingston, RI 02881 USA
Title of Project: Is hands-free texting a better alternative to hands-on texting while driving?

CONSENT FORM FOR RESEARCH

You have been invited to take part in a research project described below. The researcher will explain the project to you in detail. You should feel free to ask questions. If you have more questions later, Professor Jey Wang, the person mainly responsible for this study, (401) 874-5195, will discuss them with you. You must be at least 18 years old, have a valid driver’s license, and a smartphone to be in this research project.

Description of the project:
The objective of this research is to learn the safety and ADA compliance on RI sidewalks and its impact on drivers and sidewalk users.

What will be done:
If you decide to take part in this study, you will be interviewed and surveyed briefly regarding the quality and safety of sidewalks.

Risks or discomfort:
There are no risks or discomforts that might reasonably be expected to happen.

Benefits of this study:
The participants gain a better understanding of safety of sidewalk. The researchers will receive first hand information from users’ point of view.

Confidentiality:
Your part in this study is confidential. None of the information will identify you by name. All records will be treated with care to maintain the confidentiality of the subjects. The data pertaining to subjects and their answers will be stored in the principal investigator's laptop with secure lock and kept in locked office which located in room 103M, Gilbreth Hall, URI and will be accessible only to researchers.

The University of Rhode Island is an equal opportunity employer committed to the principles of affirmative action.
in no way penalize you. If you wish to quit, simply inform the investigator Sanaz Motamed with phone: 401-406-1730 of your decision.

Rights and Complaints:
If you are not satisfied with the way this study is performed, you may discuss your complaints with Professor Jay Wang or with Sanaz Motamed (Phone: 401-406-1730), anonymously, if you choose. In addition, if you have questions about your rights as a research participant, you may contact the office of the Vice President for Research and Economic development, 70 Lower College Road, Suite 2, University of Rhode Island, Kingston, Rhode Island, telephone: (401) 874-4328.

You have read the Consent Form. Your questions have been answered. Your signature on this form means that you understand the information and you agree to participate in this study.

Signature of Participant ____________________________ Signature of Researcher ____________________________

Typed/printed Name ____________________________ Typed/printed name ____________________________

Date ____________________________ Date ____________________________

*Please sign both consent forms, keeping one for yourself*