Eliminating Sun Glare Disturbance at Signalized Intersections by a Vehicle to Infrastructure Wireless Communication

Final Report

TranLIVE

Qing Li, Ph.D. Candidate

Fengxiang Qiao, Ph.D.

and

Lei Yu, Ph.D., P.E.

May 2016

DISCLAIMER

1. Report No. TranLIVE/TSU/16/04	2. Government Accession No.	Recipient's Catalog No.

4. Title and Subtitle Eliminating Sun Glare Disturbance at Signalized Intersections by a Vehicle to Infrastructure Wireless Communication	5. Report Date May 2016
	6. Performing Organization Code TranLIVE/TSU/16/04
7. Author(s)- Qing Li, Fengxiang Qiao. and Lei Yu	8. Performing Organization Report No. TranLIVE/TSU/16/04
9. Performing Organization Name and Address Innovative Transportation Research Institute Texas Southern University 3100 Cleburne Avenue Houston, TX 77004	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTRT12GUTC17/KLK900-SB-003
12. Sponsoring Agency Name and Address Tier 1 University Transportation Center TranLIVE Office of the Assistant Secretary for Research and Technology U.S. Department of Transportation 1200 New Jersey Avenue, SE; Washington, DC 20590	13. Type of Report and Period Covered Research Report 01/01/12 - 05/31/16 14. Sponsoring Agency Code

15. Supplementary Notes

100% matching fund from Texas Southern University

16. Abstract

Due to sun glare disturbances, drivers may encounter fatal threats on roadways, particularly at signalized intersections. Many studies have attempted to develop applicable solutions, such as avoiding sun positions, road geometric re-directions, and wearing anti-glare glasses. None of these strategies has been able to fully solve the problem. As one of the "Connected Vehicle" practices proposed by U.S. Department of Transportation, Advanced Warning Messages (AWM) are capable of providing wireless information about traffic controls, as a supplement to conventional signs and signals, which could be somehow blocked by obstacles or natural disturbances, such as sun glare. The Drivers' Smart Advisory System (DSAS) is a system that can provide drivers with AWM. This research explores the implications of DSAS messages on driving behaviors under sun glare disturbance using a driving simulator. Statistical analyses were applied to assess: (1) the negative impacts of sun glare, (2) the compensation of the DSAS AWM to sun glare effects, and (3) the improvement in driving performance owing to the DSAS AWM. Four performance indexes were measured: (1) half kinetic energy speed, (2) mean approach speed, (3) brake response time, and (4) braking distance. The effects of the socio-demographic factors of gender, age, educational background, and driving experience were also studied. The analytical results illustrated that the DSAS can compensate for the reduced visibility due to sun glare, and it can improve driving performance to a normal visual situation, particularly for left turns and through movements.

17. Key Words Sun glare disturbance, Warning messages, V2I wireless communication system, Driving behaviors, Driving simulator, Drivers' Smart Advisory System (DSAS), Half kinetic energy.	18. Distribution Statement No restriction. This document is available to the publication through the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161 www.ntis.gov

19. Security Classify (of this report) Unclassified	20. Security Classify (of this page) Unclassified	21. No. of Pages 101	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

DISCLAIMER

NOTICE

ACKNOWLEDGMENT

The authors would like to thank the participants of the driving simulator tests for this research and the graduate research assistants at Texas Southern University (TSU) in providing technical assistants on data analysis. Also the authors would like to express thanks to all personnel who have directly or directly contributed to this project or have provided various assistances.

ABSTRACT

As an innovative advancement of Intelligent Transportation System, the Drivers' Smart Assistance System (DSAS) provides wireless information of traffic control as a supplement to conventional signs and signals, which are sometimes blocked by obstacles (trees and trucks) or nature disturbances (fogs and sun glare). This book specifically evaluates driving performance of the DSAS using sun glare as an example. The system implication was investigated through a driving simulator test.

With sun glare disturbances, drivers may encounter hazard threats on roadways, particularly at a signalized intersection with visional impairment. Many studies have been conducted for applicable solutions, such as avoiding sun positions, road geometric re-directions, wearing anti-glare glasses, etc. However, these strategies cannot fully solve the problem. The DSAS can be specifically designed to provide drivers with wireless warning message of traffic control signal, which has the potential to mitigate sun glare effects at intersections.

During simulator imitation tests, nine scenarios were designed covering three types of traffic movements (left-turn, straight, and right-turn) in the situations with/without a sun glare effect, and with/without the DSAS message. Thirty subjects representing the demographical distribution in Houston, TX, USA were recruited for the test.

Statistical analyses were conducted to: (1) examine the negative impacts of sun glare, (2) evaluate the compensation of the DSAS to sun glare, and (3) assess the implication of the DSAS when there is a sun glare. Four performance measures were conducted including (1) mean approach speed, (2) half kinetic energy speed, (3) brake response time, and (4) brake response distance.

Impacts of social-demographic factors (gender, age, education background, and driving experience) were also scanned. Results show that the DSAS can basically improve driving performance to normal visual situation particularly for brake response time and distance, and mitigate sun glare effects especially for left-turn and through movement.

EXECUTIVE SUMMARY

This research is proposed to test a Vehicle to Infrastructure (V2I) wireless communication system dedicated to eliminate the sun glare disturbance at signalized intersections, which is a Radio Frequency Identification (RFID) based Drivers' Smart Assistant System (DSAS) to provide drivers with the instant signal status of the upcoming signalized intersection. With the DSAS messages on the signal status, the disturbance of sun glare on drivers' visibility of traffic signal can be eliminated, thereby improving safety on roads. The effectiveness of the DSAS could be reflected by drivers' driving behaviors, which were investigated in a driving simulator test.

A research framework was developed for the use of a driving simulator to test drivers' driving performance, while approaching a signalized intersection without and with sun glare disturbance. Besides, the implication of the sun glare and the DSAS message on drivers' driving performance was identified by the driving simulator test.

Thirty test subjects were recruited for the driving simulator test, based on the demographical distributions in Houston, Texas. Each test subject drove around multiple artificial signalized intersections under sun glare disturbance, which convers nine scenarios. The variables of the scenarios include three types of movement (left-turn, straight, and right-turn), without and with a sun glare effect, without and with the DSAS message. Test subjects' driving behaviors were recorded and analyzed, in terms of approaching speed, brake response time, braking distance, which is associated with test subjects' socio-demographic factors as well.

Results show that the implication of the DSAS message in the enhancement of drivers' safety awareness is statistically significant for drivers. However, not all driving behaviors

recorded in the test obtained the same interpretation. Elderly drive slower and require longer time to respond to a hazard, highly educated people drive slower than lowly educated people for right turn, and male drivers drive faster than female on straight movement. Eye track analysis and more complex scenarios are recommended for further studies so as to implement the DSAS on-road tests at a large scale.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background of Research

Visibility plays a crucial role in driving safety. Usually, rain, snow, and fog are typical weather threats of lower visibility. Picture-perfect weather is always favorite for many people to enjoy driving. Or at least, light is always bright, which is our instinctive reaction, no matter if we have obtained enough light to see what we are busy with. However, that is the case for moderate light level, whereas too much light may lead to blind driving. Since the human visual system extrapolates colors from what it detects at just three basic wavelengths, the light from sunlight only appears white to the human eyes (Starr, 2005). When the sunlight becomes more intense, the visibility of objects will be impaired, and low-contrast objects may be rendered invisible. Instead of visible surroundings with the sun light, drivers may find it difficult to perceive the dynamic traffic situations, thereby undertaking higher probability of crashing.

Glare-related crashes have been occurring in anywhere in the world. In Chiba Prefecture, Japan, 10,352 sun glare related incidents had been reported from 2007 to 2011 (Hagita and Mori, 2013). In Great Britain, an average of 36 deaths is attributed to the sun glare at dawn during rush hour, and the glare has been involved in nearly 3,000 traffic incidents every year at risk of blind driving temporarily by the dazzle of the sun light on the windscreen (DTGMH, 2013). Due to the fact that some glare-related crashes may be hidden in a category like excessive speed and glare is not always classified as an official cause of crashes for investigation, the official crash number is nowhere near the real situation. Therefore, sun glare is an essential variable in traffic incidents. Many strategies have been applied to mitigate the sun glare effect, such as wearing polarized sunglasses, avoiding driving in the peak hour of sun glare, not exactly along the direction of east-west, and so on.

Since the directions of sunlight vary by time of day and seasons, any kinds of medial measures would be difficult to implement. Recently, innovative technologies have been introduced to obliterate the visional disturbance of glare by improving the communication between drivers and traffic control signals.

The one that draws public attentions is the Radio Frequency Identification (RFID)-based Driver's Smart Advisory System (DSAS) (Qiao et al., 2013b). The DSAS is able to provide drivers with early warning message on traffic signals, so that drivers can react early to avoid unnecessary waiting for green lights and/or running for red-lights at signalized intersections. The pilot test of such RFID based DSAS was conducted at an intersection with through movement only. Since it was simply a pilot test, its scenario design, data collection, and data analysis were very limited and fundamental.

In order to comprehensively identified drivers' driving performance with and without sun glare disturbances at signalized intersections, it is necessary to conduct further tests and in-depth analysis regarding the impacts of this DSAS message on driver's signal awareness and reactions under more scenarios (e.g. for all three different splits: left, through, and right).

Considering the fact that participants may undertake high risks of collision with other vehicles or pedestrians during the on-road tests, it would be more feasible and safe to conduct a driving simulator test first before large scales on-road tests can be implemented

1.2 Objectives of Research

The goal of this research is to use the driving simulator to test the impacts of Drivers' Smart Advisory System (DSAS) messages on driving performance for vehicles approaching signalized intersections under a sun glare effect.

While the visual destruction caused by a sun glare would affect driving performance during all phases of traffic signals, the occurrence of sun glare during red phase could induce even higher risks of crashes. With regard to this, the studies in this research only focus on the impacts of sun glare during the red phase.

1. To achieve the proposed research goal, the following two objectives are proposed: to develop a research framework for the use of driving simulator to test drivers' driving performance for vehicles approaching a signalized intersection with and without sun glare disturbance;
2. To identify the implication of sun glare and the DSAS message on driving performance.

1.2 Outline of the Study

The report is organized as follows. Chapter 1 introduces the background and objectives of this research. Chapter 2 is the literature review of sun glare, existing strategies and new technologies to mitigate sun glare effects, and driving simulator tests in transportation studies. Chapter 3 describes the design of study and data collection process. Chapter 4 reports the results and analyses. Finally, Chapter 5 provides the conclusions and recommendations.

CHAPTER 2

LITERATURE REVIEW

This chapter summarizes the literature review on sun glare effects and prevention strategies, and new technologies to mitigate sun glare effects effectively. Since driving simulator tests have been chosen, the applications of driving simulators in transportation studies (safety, geometric design, traffic sign design, etc.) are also reviewed. Finally, the conclusions of literature review are summarized.

2.1 Sun Glare Effects and Prevention Strategies

2.1.1 Sun Glare Effects

What is Sun Glare. Sun glare is a type of glare that can be described in many different ways. Bass (2010) defines sun glare as the loss in visual performance or visibility, or the annoyance of discomfort, produced by a luminance in the visual field greater than the luminance to which human eyes are adapted. In the perspective of optics in dictionaries, glare is discomfort produced in an observer by one or more visible sources of light. Also, it is known as disability glare, which is the visual disability caused by visible sources or areas of luminance in an observer's field of view but don't assist in viewing. The Lighting Research Center of Rensselaer Polytechnic Institute defines glare as "a visual sensation caused by excessive and uncontrolled brightness" (Lighting Research Center, 2007). Generally speaking, glare could be considered as the effect occurred either for excessive light or too large luminance range in observers. The brightness sources could be artificial, such as car headlamps at night and camera flash (Figure 1), or could come from the nature such as the sun light (Figure 2).

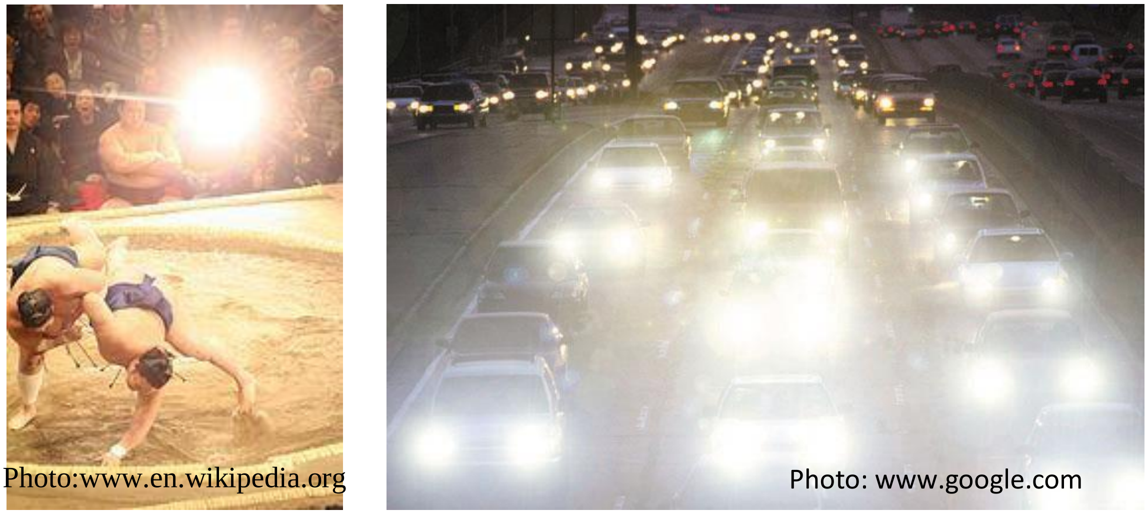


Photo:www.en.wikipedia.org

Photo: www.google.com

(a) (b)

Figure 1. Artificial Glare: (a) Camera Flash during a Sumo Fight; (b) Headlamps at Night.

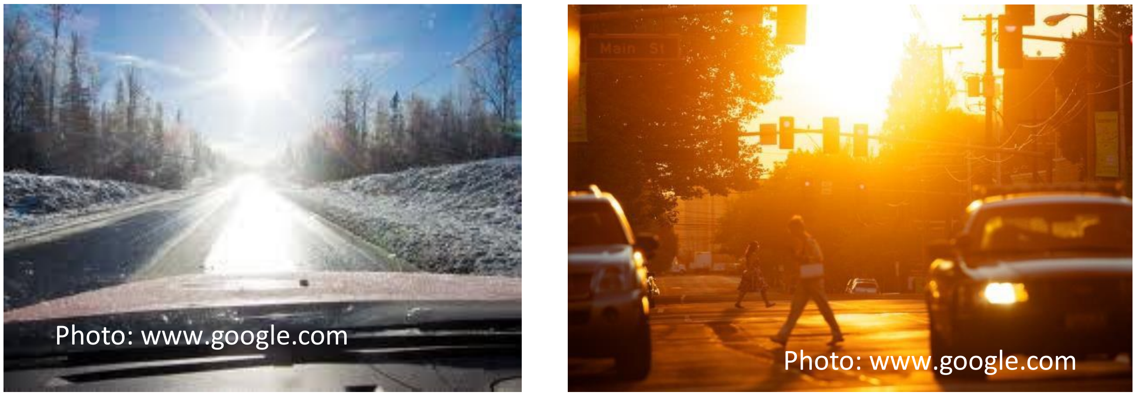


Photo: www.google.com

Photo: www.google.com

(a) (b)

Figure 2. Natural Glare (a) Sun Glare on Highway; (b) Sun Glare at a Signalized Intersection.

In the perspective of human vision, human eye features three different light detecting cells which function in higher (daytime) lighting levels. Each of these cone cells is sensitive to a different range of wavelengths: short wavelengths for blue, medium for green, and long for red (see Figure 3). In daylight photopic conditions, the human eye achieves its peak sensitivity in the yellow-green range, at around 555 nanometers wavelength. The spectrum of the sun's solar radiation is much broader than other light sources, as shown in Figure 3.

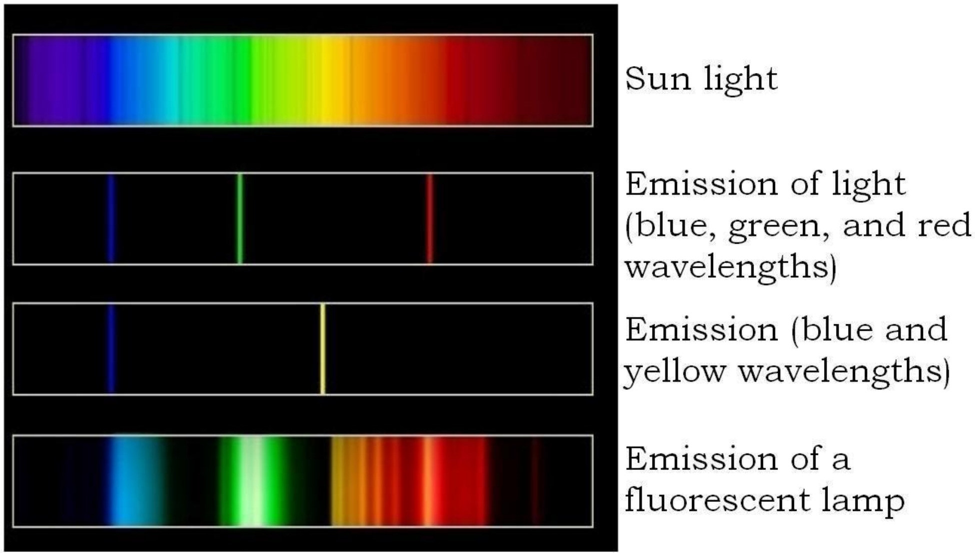


Figure 3. The Spectra of four Different Light Sources (Source: www.illinoislighting.org)

To a human eye, any of the light sources in Figure 3 are the same in white color (Starr, 2005). The higher luminance exposes to human eyes, the more intense white color the eyes can receive. The intense white impairs the visibility of the objects, and low-contrast objects may be rendered invisible. Moreover, sun glare usually reflects from uncontrolled ambient directly or indirectly into the eyes. Thus, human's viewing angles could be fully affected by sun glare disturbances. On roadway system, the invisibility of traffic situations under such a sun glare effect may lead to miserable consequence of sightless driving.

Conditions, Locations, and Time Features of Sun Glare. People enjoy batching in warm sun light at beach, skillfully utilize sun glare in decoration design, or even convert the energy from sun light to electricity by solar panels. Sun glare is a natural phenomena existing in the environment. How can it be concerned with blindness and vehicle crashes?

Hagita and Mori (2013) studied the relationship between the solar position at the crash time and spot using the traffic crash database in Chiba Prefecture, Japan. They found that the traffic incident rate increases when the difference in angel between the sun and vehicle is between about -45 degree and 45 degrees, which is defined as viewing angel (within 90 degree) for sun glare (Figure 4). In Figure 4, the line on the right hand of the vehicle extending straight indicates its travel direction.

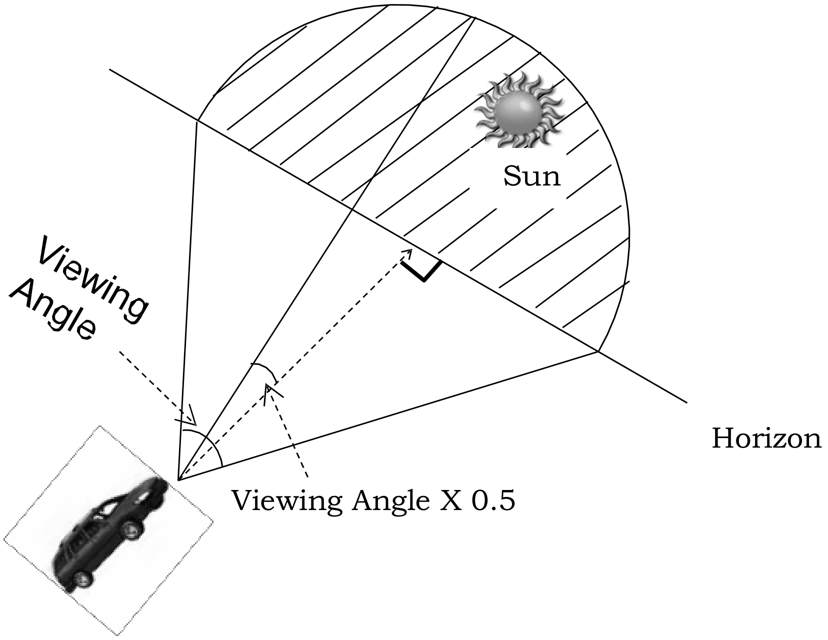


Figure 4. Viewing Angle (Source: Hagita and Mori, 2013)

Mitra (2008) demonstrated that the traffic incident rates at dusk and dawn are higher than the rates at other times, in an analysis of traffic incident data, sunset and sunrise periods, and road travel directions in Arizona.

Also, Hagita and Mori (2013) pointed out that the percentage of incidents occurred during sun rises or sun sets, toward the horizon, are higher in winter than in the other seasons. All intersections are spots, where road users may have high possibility to be blinded by the sun light, as the direction of incident sunlight varies by time of day and season. Likewise, the sun glare is especially acute in the early fall and early spring, when the sun rises almost exactly East and sets almost exactly West. On the streets that are laid out in an East-West pattern, there could be higher possibility of crashes occurred in the morning and afternoon commutes, as drivers are more likely to driving directly into the sun.

Consequence of Sun Glare Effects. The effects of sun glare could vary. Typically, like the definition of glare, visibility could be impaired and temporary visual performance could be destructed to its initial state. Observers may experience annoying or painful sensation. Even worse, when the sun glare effects take place unexpectedly during a driving trip on crowded highways, signalized intersections or work zones, the consequences could be miserable. For instance, pedestrians and bicycles are quite often involved in the traffic incident at signalized intersections, especially for the right turning vehicles (Hagita and Mori, 2013).

At most signalized intersections, right-turn on red is allowed. Meanwhile, pedestrians and cyclists are allowed to cross the street as well. That may bring about conflicts between right-turn vehicles and crossing pedestrians/cyclists. On the other hand, the detection of signals at intersections is sometimes a heavier workload for drivers, while the objects of pedestrians and cyclists are rather smaller. The attention from drivers to those objects may tend to be lower than in a normal visual situation for right turn.

Another explanation for high frequency of crashes at intersections is the immediate effects of glare. Raney and Simmons et al. (1999b) found that the immediate presence of glare may lower drivers' ability of detecting pedestrians and other targets appearing in mirrors. The immediate effects of glare may be extended to a significant drop in driving behaviors, including the increased lane-position variability, the reduced speed on curves, and the increased steering variability. This impairment effects require time to recover to a pre-established level of visual function after exposure to glare, and may bring drivers to either hesitate to drive through or run the red-light unconsciously.

2.1.2 Existing Sun Glare Prevention Strategies

Many handy strategies to prevent sun glare from becoming a hazard have been utilized in the daily life, which are summarized as following (Waldron, 2013):

- Wear sunglasses with polarized lenses, or wear eyeglasses with an anti-reflective coating. Scratched eyeglasses or contact lenses make the glare worse.
- Heed the speed limit, particularly driving into the sunrise on the way into work or the sunset on the way home.
- Slow down for longer time and more space to react.
- Increase the following distance to leading vehicle beyond the recommended safe distances to allow three or more seconds between vehicles.
- Turn headlights on for oncoming motorists, who are driving toward the sun.
- Clean the windshield outside and inside. A cracked or dirty windshield can magnify glare.
- Use the visor as much as possible, but remember that visors can also block the vision.
- Consider alternative routes to minimize east/west driving whenever possible. Use north/south streets until finding an east/west road with lots of trees or taller buildings.
- Avoid driving in the period of sunrise or sunset.

- Don’t use high-gloss products on the dashboard, which can contribute to extra glare.
- Leave extra time for the trip to avoid rushes.
- Conduct regular eye exams or surgery for more sensitive to the sunlight.
- Avoid driving right after eye exams or surgery

2.1.3 Issues of Existing Strategies

In principle, the strategies mentioned above are able to mitigate sun glare effects to some extent, but not as effective as expected in practice. First, requiring drivers to carry out all of these strategies all the time is not feasible. The presence of sun glare varies by time and season, whereas routine must be conducted regularly. Shift travel time for important appointments or tasks is not always possible. Shift route for the same destination is not always available either. Second, wearing polarized sunglasses is the most popular strategy currently. But, drivers need to keep their sunglasses always around them in the car in order to prevent the distraction of looking for them while driving. Last, leaving extra headway and space with other vehicles, and driving slowly are always associated with safety, but not every driver can strictly follow this. Overall, most of the strategies quite rely on educating for better driving habits, which is the hardest part to be changed. It requires a long term education program.

As a fact of these, even though the strategies in section 2.1.2 have already been advised to the public, many sun-glare-related crashes still occur around the world. What’s more, pedestrians and cyclists are often involved in the sun glare related crashes. As has been stated in Chapter 1, though the number of crash doesn’t account for a significant portion, the recorded crash number is not capable of reflecting completely the real situation.

2.1.4 Sun Glare Related Incidents

Many research results verified that a number of crashes have been attributed to sun glare effects. For instance, Choi and Singh (2005) analyzed the General Estimates System (GES) 2000-2003 crash database for the impacts of glare, and proved that the crash involvement of sun glare exposed to drivers was more frequent, as compared to those crashes without visional destructions during sunrises. The similar research was conducted by Hagita and Mori (2013), who pointed out that the solar position is a variable for the traffic incident rates. When the sun light exposes to the first vehicle's concerned viewing angle, their line of sight can be hindered.

This visual disturbance gives rise to the higher involvement of pedestrians and bicyclists in crashes at signalized intersection. This could be a safety threat particularly when they are driving through a signalized intersection, and when the green light is turning from green to yellow and then red. What's more, most of drivers slowdown in fog, but not in glare for a nice clear day. Even under such unclear vision, they are far more attentive to road conditions like snow, rain, sleet or high winds (Waldron, 2013). They tend not to consider sun glare as risky as other terrible weather conditions that may cause.

2.2 New Technologies to Mitigate Sun Glare Effects

Conventionally, drivers are able to perceive traffic signals only when they are close to the signal controllers without any visual disturbances in between. When sun glare is in effect, drivers' perception time could be extended and their response time could be longer than usual. Meanwhile, their driving performance could become erratic, in terms of steering, braking, and acceleration, which are the threats of safety on roads.

To mitigate the sun glare effect or similar threats, some new technologies have been proposed including the communication tools such as WiFi, blue tooth, RFID, ZigBee, and even smart phone (Qiao et al., 2013c). The predominant idea is to equip an “electronic eye” and/or an “electronic ear” for drivers through developing a dedicated wireless communication system, including the vehicle-to-infrastructure (V2I) at work zones (Qiao et al., 2016a; Rahman et al., 2015; Qiao et al., 2016b; Qiao et al., 2014; Li et al., 2013), STOP sign intersections (Li et al., 2016a; Li et al., 2016b), and vehicle-to-vehicle (V2V) communications along local street (Li et al., 2016c). The purpose is to provide alternative way to deliver real-time traffic control information to drivers effectively. The real-time traffic control information may improve drivers’ driving behaviors, which are subject to individual socio-demographic factors as well (Li et al., 2015a; Li et al., 2015 b; Qiao et al., 2016c). Besides, the V2I system has been considered as a strategy to reduce vehicle emissions (Li et al., 2015c; Li et al., 2014;).

Wu et al. (2010) developed an advanced driving alert system (ADAS), which contains Stationary ADAS (based on roadside infrastructure such as Changeable Message Signs - CMS) and In-Vehicle ADAS (driven by advanced communication technology such as Vehicle Infrastructure Integration - VII). Simulator tests were applied to evaluate the system, in which traffic signal status (TSS) information was used for energy and emission reductions. The TSS aims at alerting drivers to slow down for the upcoming intersection, so that they are able to prevent unnecessary cruise or acceleration. In this way, drivers may avoid the dilemma of red-light-running.

Schultz and Talbot (2009) developed an Advance Warning Signals (AWS), which provides advance warning about an approaching intersection or an impending signal change. With the AWS systems, speeds can be managed to reduce in the time right before the onset of the yellow interval (Schultz and Talbot, 2009).

Singh et al. (2012) proposed an Intelligent Traffic Lights using Radio Frequency Identification (RFID). The system provides quality of service to emergency vehicles, improves the accuracy of Automatic Traffic Light Violation Detection system, and assists to trace out stolen vehicles. The RFID in this system is applied to recognize the emergency vehicles.

Qi et al. (2009) investigated the application of the VII technology to prevent crash from happening in various hard conditions. The three VII-based driver warning systems include: 1) Rural Highway Driver Warning System (RHDWS) designed to prevent runoff road (ROR) collisions in curvy rural highways. With the system, three types of warnings about lane departure, curve ahead, and speed limits, are provided, so that drivers are able to gain time to adjust their driving behaviors responding to the oncoming unexpected road conditions. 2) Highway Lane Change Warning System (HLCWS) designed to prevent the collisions associated with lane changes. 3) Work Zone Driver Warning System (WZDWS) designed to prevent the collisions occurred at work zones, which consists of an in-vehicle driver warning subsystem and a real-time Dynamic Message Sign (DMS) subsystem.

These types of advanced driving alert systems, even though will definitely enhance the safety and efficiency, are still in the stage of lab testing. The specific impacts on driving behaviors and environments, as well as the tools for dedicated short range communications (DSRC) between vehicles and infrastructures are still in developing. Therefore, there are many rooms in this area regarding the hardware/software designs, and the impacts on driving behaviors.

Kotchasarn (2009) reported an RFID based vehicular communication system, which is an in-vehicle alert system to provide drivers a timely warning message about unexpected traffic jams caused by a crash or similar other incidents on the roads, at an effective non-line-of-sight (NLOS) distance.

2.3 RFID Based Drivers' Smart Advisory System

2.3.1 System Mechanism

Qiao et al. (2013b) employed the RFID to have developed a Smart Warning System (SWS) or called Drivers' Smart Advisory System (DSAS), which is a V2I wireless communication system to inform drivers timely about traffic guidance and warning messages. Pilot tests of this system have been conducted at un-signalized intersections with stop sign (Qiao et al., 2013a), work zones (Qiao et al., 2014), and signalized intersections with a sun glare effect (Qiao et al., 2013b), respectively. The on-road pilot tests results are all promising.

The RFID system consists of one or more tags (emitters), a reader (receiver), a GPS, computer processing software, and a database. Figure 5 shows the components of the RFID system (Source: Qiao et al., 2009).

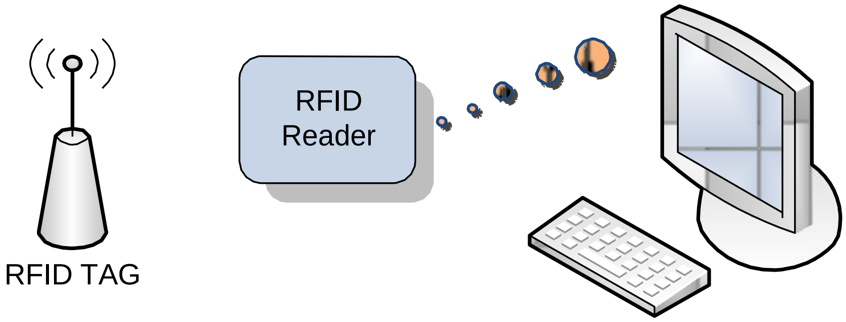


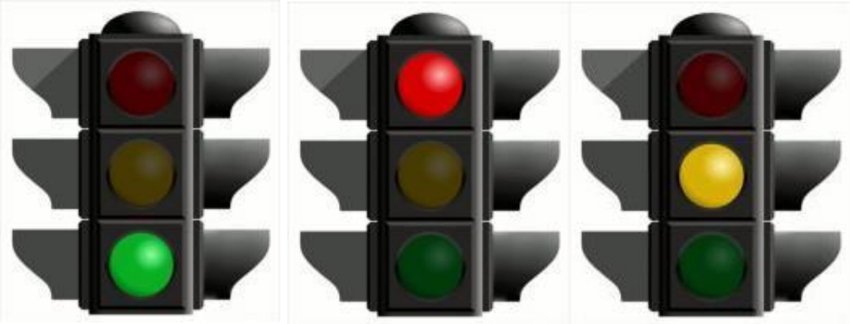
Figure 5. Components of the RFID System (Source: Qiao et al., 2009)

The RFID reader could be installed inside a vehicle, which receives signals emitted from the tags attached to the relevant infrastructure (stop sign, traffic signal, traffic sign, etc.) within a certain detection range (Qiao et al., 2012b).

2.3.2 System Hardware

The hardware system of RFID based communication to mitigate sun glare disturbance at intersection is similar to other RFID based system. The tags are wired to a post nearby the traffic lights. The signals from the tags can be detected by the receiver (the readers) inside the vehicles. In the meantime, the GPS unit reports the geographical locations of the vehicles. The on-board computer checks if the tag signal(s) are approaching based on all information received. If the tag ID is a valid one through a search from the pre-set inventory database, proper voice prompts and visual warning message can be provided to drivers.

At an approach to an intersection, multiple tags could be involved with different ID configurations. As is shown in Figure 6, tag one represents the green signal; tag two represents the red signal, and tag three represents the yellow signal.



(a) Tag one (b) Tag two (c) Tag three

Figure 6. The Tag Configuration of a Typical RFID Based Traffic Signal System

Once the RFID reader receives the tag information, the computer inside the vehicles can process the information and display the corresponding signals on the screen. Figure 7 is the interface of the displaying system.

Figure 7. Interface of the On-board DSAS

2.3.3 System Software

The Visual Basic (VB) programming tool is used to develop the RFID based DSAS at signalized intersections. The Microsoft Communications Control, Microsoft Data Access Object, Microsoft MapPoint and Microsoft Winsock Control are major components of the software system.

The system software was developed in Visual Basic 6.0 environment and is compatible with other Microsoft Windows desktop application. The Microsoft Winsock Control is used to communicate with RFID receiver through Ethernet. The RFID receiver transmits information to on-board processing computer every second. As soon as the signal from a tag is detected and verified, the system will trigger visual display and voice prompts to drivers.

2.3.4 On-Road Pilot Tests

The RFID sets from a company called Tagsense were used for tests, while the reader was installed inside the vehicle (Figure 8).

Figure 8. The RFID Receiver is Inside a Vehicle, however the Antenna of which can be Placed Inside or Outside the Vehicle, Depending on the Connection Availability.

The pilot test of this system was conducted by selecting 10 test subjects. The major purpose of this test is to evaluate the communication system and identify whether this system is feasible in practice, as well as receiving feedbacks from test drivers.

In the pilot test, each driver drove through a designated route shown in Figure 9 for 20 runs under a normal situation (no any in-vehicle warning of traffic signals) when facing to the sunsets. In this way drivers experienced almost all signal phases (red, green, and yellow). The test was conducted during the sunset, from 5pm to 7pm, when the sun glare effect was significant for drivers approaching a signalized intersection.

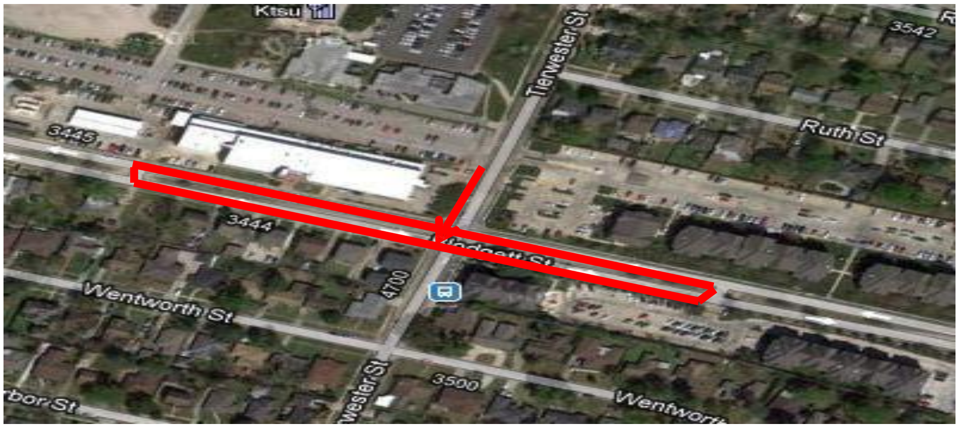


Figure 9. The Test Route for DSAS, where the Red Arrow Indicates the Target Intersection that the DSAS Message Provided Warning Message for. In this Test Field, the Westbound Vehicles (from right to left) were Normally Facing to Sunset Glares during 5pm and 7pm in Sunny days in the Fall Season.

After the 20 normal runs, the drivers were required to drive another 20 runs following the same routes with the advisory messages provided. The messages included “Red Ahead”, “Green Ahead”, and “Yellow Ahead”. A posterior survey was conducted to drivers on their actual feelings about the warning messages. The primary findings from the pilot tests were illustrated as follows. (Qiao *et al.*, 2013b).

(1) When approaching the intersection on green phase, vehicles drove smoother and even more aggressively with the advisory messages were provided.

(2) When approaching the intersection on red phase, vehicles’ approach speeds were slower when the advisory messages were provided.

(3) With the advisory messages, vehicles performed much less excessive acceleration rates.

(4) The posterior survey shows that 90% of participants agree that the system can enhance safety in intersections areas. 100% of participants agreed that the application of the system can improve their awareness of the traffic signals.

2.3.5 Further Work after the Pilot Tests

The concept of the DSAS advisory messages by Qiao *et al*. (2013b) is innovative and the on-road pilot test is promising. However, several further steps still need to be proceeded before large scale on-road tests can be conducted for practical implementations.

More Performance Measures Should be Covered: Besides testing the impacts on the changes of speed and acceleration rates, there should be a need to test the impacts of such advisory system on drivers' more driving performances, and even on safety measures and vehicle emissions.

More Scenarios should be Included: The pilot tests only considered through movement with 10 subjects. More scenarios such as all turning movements (left turn, through movement, and right turn) should be considered. In this case, the test field should be even broader covering larger areas.

Safety Issues should be Addressed: During the test stage, it is too risky to conduct comprehensive tests with multiple scenarios on real road. Instead, driving simulator tests could be more feasible.

More Types of Data should be Retrieved and Analyzed: The data that can be retrieved from real-road tests could be subject to the availability of equipment and costs. In order to easily retrieve more information (such as instant brake information, steeling movement information, and even eye tracking information), it would be more convinced to use a driving simulator for part of the pilot tests.

2.4 Driving Simulator Tests in Transportation Studies

Though almost everyone drives on daily bases, driving is still one of the most complex and dangerous things as well. It requires a full range of sensory, perceptual, cognitive, and motor functions, all of which can be affected by a wide range of individual stressors and experience levels. To study such complex driving behaviors, a driving simulator is a rather ideal option. Transportation experimental studies can be always conducted with on-road tests, however using a simulator is safer and more cost effective (Donald *et al.* 2011).

2.4.1 Features of Driving Simulator

A driving simulator can provide objective and repeatable measures of driver performance, such as speeds, acceleration, and braking; and allows complete control of the driving environment such as traffic flow, weather, and roadway designs. It can be easily administrated in a laboratory setting for the ideal experimental environment, even for hazardous situations like work zones and signalized intersections with sun glare disturbance.

For the controlling of vehicles, the comparability of the driver's situation awareness can be assessed by studying their behavioral changes on roads and in specific situations associated with heightened levels of visual search. For instance, if an experienced driver is aware of a situation that is likely to present difficulties from other road users, he or she may search for the roadway changes (Crundall & Underwood, 1998; Underwood *et al.* 2003). Those behaviors can be recorded and measured by simulator tests.

Table 1 lists the benefit and cost considerations when selecting a driving simulator (Source: Keith *et al*., 2005). Though the costs for on-road and high-fidelity simulation studies are also high, the high –fidelity simulation could provide more high benefits for the studies, in terms of driver behaviors, highway geometrics, traffic conditions, and experimental conditions. It is no doubt that on-road study can provide very high degree of realism. However, participants may encounter medium risky in the on-road studies, while the risk to them in simulation studies are very low. For a feasible reason, safety shall be always considered as the top priority.

Table 1. Benefit and Cost Considerations when Selecting a Driving Simulator (Source: Keith et al., 2005)

Benefits/Costs	**Low-Fidelity Simulation**	**High-Fidelity Simulation**	**On-the-Road Studies**
Ability to study relevant driver behaviors	Medium-High	High	Medium
Ability to study range of highway geometrics	High	High	Medium
Ability to study range of traffic conditions	Medium	High	Medium
Control over experimental conditions	Medium-High	High	Medium
Degree of realism	Medium	Medium-High	Very High
Relative cost	Medium	High	High
Risk to driver	Very Low	Very Low	Low-Medium

2.4.2 Using Driving Simulator for Safety and Roadway Design

Driving simulators are often used for safety tests and to assist in the design of roadways as it is much simpler and cheaper to reject a design element in a driving simulator than to rebuild a road or tunnel to fix design errors. Results of experiments can be easily used to model drivers' behaviors, and analyze potential safety threats.

Qi et al. (2009) proposed three VII-based driver warning systems (RHDWS, HLCWS and WXDWS), which is specifically designed for the hard road conditions, such as runoff roads, work zones, and highway with heavy traffic volume. In practice, safety is undoubtedly an essential issue in on-road tests for such hard road conditions. Drivers may be exposed to actual driving hazards, such as high probability of collision. In this case, the impacts of the three systems on driver’s driving behaviors were tested in driving simulation experiments. Types of roads and traffic conditions were designed in the scenarios. All aspects of the driving environment were fully controlled. The complex driver’s behaviors in response to the driver warning systems were assessed.

2.4.3 Using Driving Simulator for Traffic Sign Tests

The driving simulator is an available tool for sign testing and evaluation. There have been many studies that use a driving simulator to conduct sign tests, such as the open road tolling signing study by Benda et al. (2009), the freeway guide sign design study by Upchurch et al. (2002), the driver comprehension of traffic information on graphical congestion display panels study by Richards et al. (2004), the guide signing for two-lane exit study by Upchurch et al. (2005), the colors for traffic control devices at transponder-controlled tollbooth lanes study by Golembiewski et al. (2006), the logo sign design study for major traffic generator by Qiao et al. (2007b), the guide sign design study for exits along highways by Qiao et al. (2007a), and the congestion pricing guide sign test by Qiao, et al. (2012a).

2.5 Summary of Literature Review

Based on the literature review above, the following conclusions can be summarized.

(1) Sun glare negatively affects drivers' driving performance as it impairs human's visibility of objects like pedestrians, vehicles around them, and even their routes. Drivers' visual performance may be temporarily destructed to its initial state. Even worse, drivers may feel annoying or painful sensation, and may find it difficult to drive and continue their trips. Consequently, they may undertake higher possibility of crash on roads. Therefore, the sun glare is a threat of road users' safety definitely.

(2) Existing sun glare prevention strategies are not really reliable, and they cannot fully help to diminish traffic crashes. There are still a number of sun glare related crashes happening around the world. The presence of sun glare varies by time and season, and most of the existing strategies tend to change drivers' habits for safety purpose. However, improving driving habits is a long term education program.

(3) New technologies enable to develop the V2I communication systems to deliver real time signal information to drivers in alternative ways. RFID technology provides one of the ways to deliver critical alert warning messages to drivers for the compensation of lower visibility on the roads. Particularly, the promising results of DSAS message has been drawn attentions from the literatures.

(4) Since the on-road tests of the DSAS message could induce safety and other issues, the driving simulator test is a feasible and ideal option. In a driving simulation study,

almost all driving environment could be controlled and many driver's driving performances are recordable and measureable. What's more, driving simulator test is the safest and the most cost effective option among similar studies.

CHAPTER 3

DESIGN OF THE STUDY

In chapter one, the objectives of the research are determined as to develop a research framework to test drivers' driving performance at signalized intersections with sun glare using a driving simulator, and to identify the implication of sun glare and the DSAS message on driving performance. This chapter focuses on the plan to address these objectives, and describe how the tests were conducted.

3.1 Identify the Appropriate Framework to Test Implications of DSAS in Simulator

This section intends to identify an appropriate framework to simulate the sun glare effect as well as the impacts of the DSAS message at signalized intersections, which should be feasible and affordable to implement. The implications of the DSAS message on drivers' driving performance should be studied with statistical comparisons of the test data.

The developed framework consists of an applicable procedure with six working steps as are illustrated in Figure 10.

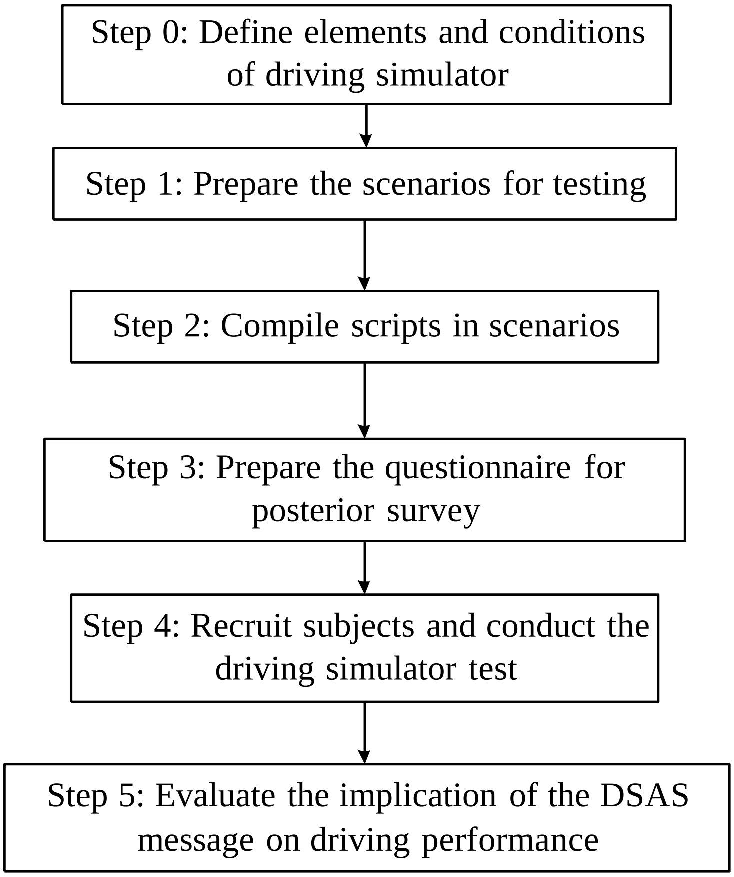


Figure 10. The Proposed Test Framework to Analyze the Implication of DSAS Messages in a Driving Simulator

Step 0: *Define elements and conditions of driving simulator*

In this initial step, all elements and conditions in a driving simulator tests should be pre-defined, including weather specifications, posted speed limit(s), lane change regulations (if any), type of intersections, type of roadway(s), and how the sun glare effect should be imitated. The design of the driving simulator experiment should also be briefed for reliable results, including the number of subjects and the criteria of recruitment.

Step 1: *Prepare the scenarios for testing*

In this step, the audio messages, the artificial setting of sun glare, the configuration of scenarios, and the sequential signal configurations at a target intersection should be particularly designed. The scenarios designed for the driving simulator test should include different directional splits (left turn, through movement, and right turn), where the sun glare effect takes place and the DSAS messages are provided. Each scenario will be named with a unique code.

The various audio messages can be composed by using relevant technical tools such as the one on the website of AT&T Natural Voice ™ (NV, http://www2.research.att.com/~ttsweb/tts/demo.php), which provides high-quality conversions of texts to audio message for specified language(s). The text messages that should be converted to audio in this research include the instructional message about directional splits, and the warning messages about the signal status at intersections. The way how drivers normally sense the static traffic signs and traffic signals should be considered in the determination of the length and content of the audio messages. The artificial sun glare can be simulated by projecting an image of sun glare onto the traffic signal areas on the screen of the driving simulator.

Mandated design and recommendations in relevant standards and guidelines should be strictly followed, so as to well design the layout of signalized intersections, the placement of control signs and signals, and the distance between signalized intersections.

Step 2: *Compile scripts in scenarios*

In this step, computer scripts for various scenes in scenarios will be compiled, which may incorporate with the DSAS messages and the traffic signal timing. These scripts should be carefully checked and debugged in the driving simulator before formal tests can be started.

Step 3: *Prepare the questionnaire for posterior survey*

A posterior questionnaire should be prepared for the subjects, who are recruited to participate in the driving simulator test. The questionnaire is proposed to investigate how subjects feel about the application of the DSAS messages during their tests. The answers could be used to partially evaluate the subjects' understanding of the warning messages and the applicability of the DSAS messages in each scenario, and to improve the DSAS audio messages if needed.

Step 4: *Recruit subjects and conduct the driving simulator test*

The recruitment of subjects will be launched right before the implementation of the driving simulator test. A short training should be provided individually right before the formal test, so that the subject will be able to be familiar with both the simulation environment and the vehicle in scenarios. Each subject will be required to complete all scenarios in one test. The questionnaire prepared in Step 3 will be provided to them after the test for their subjective feelings.

Step 5: *Evaluate the implication of the DSAS message in driving performance*

The implications of the DSAS messages will be evaluated by measuring subjects' specific driving performance such as speeds and braking reactions. Statistic tests will be conducted to examine the significant difference in their driving performance. All possible variables that may affect subjects' driving performance measures in the application of the DSAS audio messages will be assessed in the statistic tests as well.

3.2 Develop Suitable Scenarios and Conduct Tests in a Driving Simulator

3.2.1 Scenario Design

The design of scenarios considers three factors: (a) with sun glare (S) or without ($\bar{S}$); (b) with the DSAS audio message (D) or without ($\bar{D}$), and (c) directional splits: left turn (L), through movement (T), and right turn (R).

This creates a pool of 2 x 2 x 3 = 12 scenario base. Logically the DSAS message is only applied when a sun glare effect takes place in a scenario. Therefore, the three scenarios for the situations of no sun glare with DSAS message for the three directional splits are eliminated from the pool. Thus, nine scenarios remain for the test: (1) no sun glare no DSAS for left turn ($\overline{SD}L$), (2) with sun glare no DSAS for left turn ($S\bar{D}L$), (3) with sun glare with DSAS for left turn (SDL), (4) no sun glare no DSAS for through movement ($\overline{SD}T$), (5) with sun glare no DSAS for through movement ($S\bar{D}T$), (6) with sun glare and DSAS for through movement (SDT), (7) no sun no glare no DSAS for right turn ($\overline{SD}R$), (8) with sun glare no DSAS for right turn ($S\bar{D}R$), and (9) with sun glare with DSAS for right turn (SDR). The unique codes for all scenarios are listed in Table 2.

Table 2. Unique Scenario Codes for Simulator Tests at Signalized Intersections

Scenario Number	**Sun Glare (S, $\overline{S}$)**	**DSAS (D, $\overline{D}$)**	**Directional Split (L, T, R)**	**Scenario Code**
1	No	No	Left	$\overline{SD}L$
2	Yes	No		$S\overline{D}L$
3	Yes	Yes		SDL
4	No	No	Through	$\overline{SD}T$
5	Yes	No		$S\overline{D}T$
6	Yes	Yes		SDT
7	No	No	Right	$\overline{SD}R$
8	Yes	No		$S\overline{D}R$
9	Yes	Yes		SDR

The nine test scenarios with unique codes are embedded into a 10 km long track with ten signalized intersections involved. The layout of the test route on track is illustrated in Figure 11, including three left turns, three right turns, and three through movements with and without the DSAS messages, and with and without the sun glare effect.

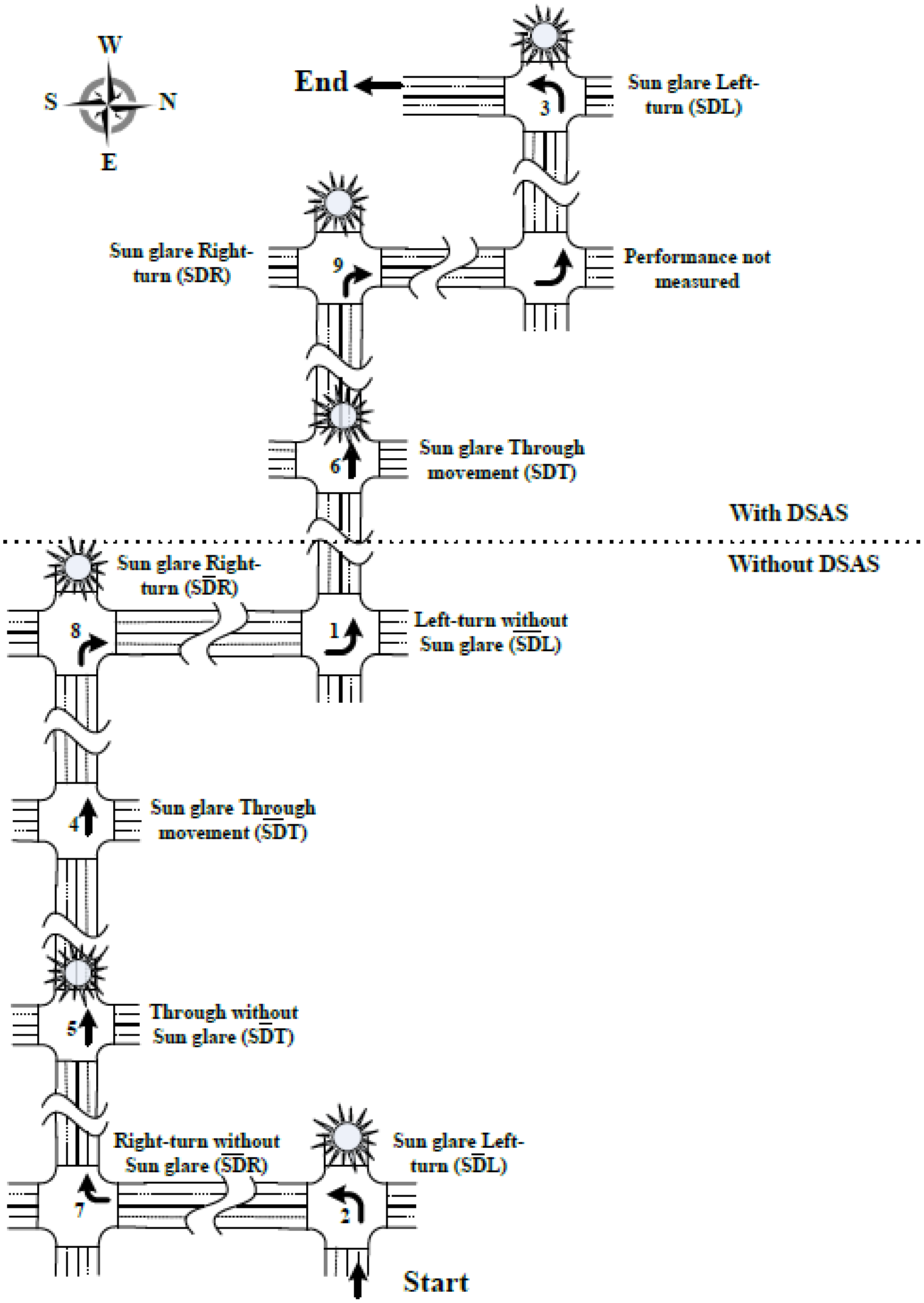


Figure 11. The Layout of Test Routes on the Track, Including three Left, three Right and three Through Movements with and without the DSAS Message

In Figure 11, the number at each intersection indicates the unique code with corresponding scenario. Along the track in Figure 11, each subject was required to depart from the "Start" point and follow the predefined voice messages to make left turn, right turn, or through movement at each intersection. The movement directions at all intersections are indicated as arrows.

The first six intersections beneath the dash line in Figure 11 represent all scenarios "without DSAS" (*i.e.* for scenarios 2, 7, 5, 4, 8, and 1), where the subjects were instructed to make two left-turns, two right-turns and two through movements with and without sun glare disturbance at intersections, respectively.

Starting from the seventh intersection (marked as scenario 6) above the dash line in Figure 11, all scenarios (6, 9, and 3) are within the category of "with DSAS" while sun glare is in effect. Subjects' driving performance at the no-code intersection that is located after scenarios 9, is not measured. No sun glare effect is allocated at this intersection, while drivers can relax their eyes for a while after two continuous scenarios (6 and 9) with sun glare disturbances. Another reason why this intersection is neither set with sun glare nor measured is that, the sun glare always appears from the west direction of the entire track (the upper part of Figure 11), while the driving direction towards this intersection is to the north (*i.e.* the right side of Figure 11).

During the test, each subject was the only driver on the track. Except visional disturbance of sun glare, no other weather conditions were involved in the simulation environment.

3.2.2 Determination of Locations to Provide Audio Messages

There are two types of audio messages designed to alert drivers. The first type is the lane preparation message to guide drivers for suitable lane change if needed. For example, if a driver was instructed to turn left, he/she should change to or stay at the left lane. The distance that drivers receive this type of message and complete the entire action is named as the "Lane Preparation Distance" D_{lp} as indicated in Figure 12. The second type of audio message is about the status of signal at the signalized intersection provided by the DSAS audio messages. The distance between the locations, where the second type of audio message is delivered and the stop line is marked at an intersection, is named as the "Signal Message Distance" D_{sm}, which is also illustrated in Figure 12.

It is assumed that drivers complete their lane change preparation before the audio signal light messages are provided. Their driving performance responding to the audio message during traveling within the "Signal Message Distance" should be studied.

In Figure 12, the lane change message "Please turn left / turn right / go straight" Lasted for 1.0 second long. With the posted speed limit of 72 km/h (45 mi/h, or 20 m/s), a vehicle can drive for a distance of $D_a = 1.0\ s\ x\ 20 \frac{m}{s} = 20\ m$ in one second

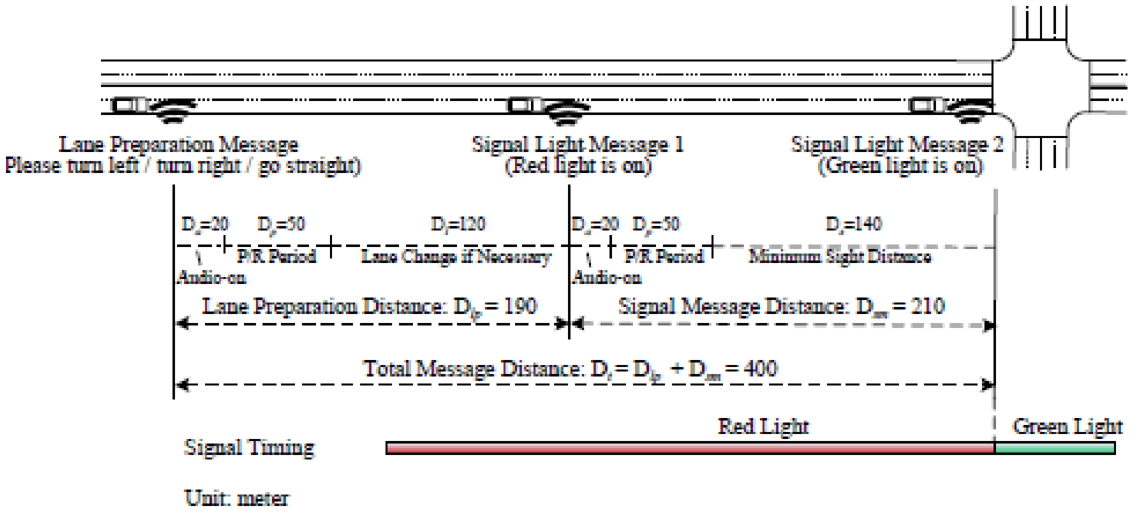


Figure 12. Illustration of Lane Prepare Distance and the Signal Message Distance, where the Lane Preparation Period Happens before Audio Signal Light Messages are Provided to Drivers so that the Tests were Focused on Impacts of Audio Signal Light Message only.

Once the audio message for lane change is broadcasted completely, drivers need a certain time to perceive and react, and travel for a distance of D_p. Based on the review by Chang *et al*. (1985), the perception-reaction time is 1.9 seconds for the 85th percentile time and 2.5 seconds as the 95th percentile time. In this study, 2.5 second is chosen as the perception-reaction time. The distance of D_p traveled during this period is then calculated as: $D_p = 2.5\ s\ x\ 20 \frac{m}{s} = 50\ m$.

The lane change distance of D_r in Figure 12 is the time for vehicles to make necessary lane change. Toledo and Zohar (2005) summarized from literatures that lane changing durations are on an average of 5 seconds to 6 seconds. If 6 seconds are used with the posted speed of 20 m/s, the lane change distance is 6 s x 20 m/s = 120 m.

Therefore, the total lane preparation distance D_{lp} is D_{lp} = D_a + D_p + D_l = 20 m + 50 m + 120 m = 190 m.

For the “Signal Message Distance” D_{sm} period, the signal light audio message “red Light is On” is provided after vehicles complete their proper light changes. This audio message lasted for 1.0 secong also, resulting in an audio-on distance of $D_a = 1.0\ s\ x\ 20\ m/s = 20\ m$. The perception-reaction distance of D_p is also 50 meters (2.5 s times 20 m/s) as was calculated for the lane change message.

The minimum sight distance of D_s for signal visibility can be found from Table 4D-2 (Minimum Sight Distance for Signal Visibility) of the Manual on Uniform Traffic Control Devices (MUTCD, 2009). Under the posted speed limit of 72 km/h (20 m/s), the minimum sight distance D_s is found as: D_s = 140 m.

So the total message distance of D_{sm} can be calculated as: D_{sm} = D_a + D_p + D_s = 20 m + 50 m + 140 m = 210 m.

The total message distance is then: D_t = D_{lp} + D_{sm} = 190 m + 210 m = 400 m.

This means the first type of audio message on lane preparation should be provided to drivers at 400 meters away from the stop line. Similarly, the audio message of signal light from the DSAS should be provided when vehicles are 210 meters (D_{sm}) away from the stop line.

Since the minimum sight distance ($\mathrm{D_s} = 140$ m) for signal visibility is considered in the total length of the signal message distance of D_{sm} (210 meters), drivers should be able to clearly see the traffic light (green, yellow, or red). This means in no less than 140 meters away, drivers should be able to sense the signal of traffic lights, from either their eye visions (if no sun glare), or the DSAS audio message (if sun glare presents).

However, drivers may find themselves into high risk if there is a sun glare but no DSAS audio message(s) provided.

When vehicles reach the stop line, the traffic signal is triggered to change from *Red* to *Green*. Meanwhile, if the DSAS message is in use, an audio message "Green Light Is On" is provided to drivers. This change of signal is simply for the smooth movement of test vehicle between two consecutive intersections along the test track.

3.2.3 Apparatus

The study was carried out on a fixed-base driving simulator Drive Safety DS-600c in the campus of Texas Southern University. The main elements of the driving simulator include a full-width automobile cab and a 180 degree wraparound screen (3 meters height and 2.5 meters radius), on which displays a fully integrated, immersive driving simulation scene (see Figure 13.)

Figure 13. The Driving Simulator Drive Safety DS-600C for the Test

With the driving simulator, subjects are able to drive on a virtual track that simulates the movement on a real road in terms of audio, visual, and dynamic effects. Besides, the driving simulator can record much more complex behavioral responses, including preparatory behaviors (slowing in anticipation of hazard, changing lane position to avoid a potential hazard) as well as emergency maneuvers to avoid the actual hazard (Underwood *et al*., 2011). For the scenarios with sun glare, an artificial sun glare was generated by projecting a sun glare image onto the signal lights over the screen of the driving simulator through a dedicated overhead projector (Figure13).

3.2.4 Participants

Totally thirty subjects were recruited for the in-simulation test. The recruitment was based on Houston's demographics from 2010 census database. The proportion of subjects regarding gender, age, and education background was adjusted for the legal driving age in U.S., and a number of subjects were round into integer numbers. As is shown in Table 3, fifteen male and fifteen female subjects participated in the tests. They are above eighteen years old with valid C class drive licenses. Twenty-one subjects had obtained high school and associated degrees, while nine had obtained bachelor's degree or higher. All subjects have self-reported that they have normal or corrected-to-normal visions, and don't have any problem with hearing.

Table 3. Gender, Age and Education Distribution of the Subjects for Simulator Tests

Subject	**Gender**		**Education Background**			
	Male	Female	<65	65 +	High school and Associate Degree	Bachelor's degree or higher
Houston 2010 Census data	49.9%	50.1%	91.5%	8.5%	74%	26%
Adjusted Distribution			29%	9%	70%	30%
Subjects in test	**15**	**15**	**27**	**3**	**21**	**9**
Total	**30**		**30**			

3.2.5 Test Procedure

The driving simulator test was conducted during June of 2013 with thirty participants. Valid drive identification and insurance documents were carefully checked and their relevant personal information such as age, gender, education background, and driving experiences were noted down. Test instructions were provided individually to each participant, who then went through a warm-up training procedure before the formal test. A waiting area separated from the room with the driving simulator was allocated to host subjects in queue, so that there were no cross influences between subjects who were waiting outside and the subjects who was conducting the tests. During the tests, the subject followed the instructions and drove along the designed track in Figure 11 to go through all nine scenarios in Table 2 within the ten intersections. Artificial sun glare was provided at intersections in need. Each test lasted for about 10 minutes long and the posterior questionnaire survey was conducted after each test.

3.3 Data Collection and Determination of Performance Measures of Driving Behaviors

3.3.1 Data Collection and Processing Tools

Raw data from the driving simulator test were collected at a frequency of 60 Hz. This means 60 records were stored for each second during the test. The recorded information includes: (a) vehicle’s geo-location (x, y, and z coordinates), (b) speed in m/s, and (b) drivers’ break responses indicating braking levels with a decimal number ranging from 0.0 to 1.0, with 0.0 being the minimum (no brake) and 1.0 the maximum (full brake).

The collected data were processed through a self-developed program in the computer language MATLAB. Statistical analysis was conducted in the MS Excel based *t*-test. The *t*-test was based on the relevant mean values over all subjects for each parameter. Socio-demographic factors such as gender, education background, driving experience, and age, were variables of the statistical tests as well. Statistical significant difference was accepted at $p < 0.05$.

3.3.2. Measures of Driving Performance

Based on the designed scenarios in Table 2 and the test procedure, driving behaviors can be compared under three visual situations: (1) no-glare no DSAS $\left(\overline{SD}\right)$, (2) with glare but no DSAS $(S\overline{D})$, and (3) with sun glare with DSAS (SD). The levels of workload resulted from the DSAS advisory message were self-reported by subjects through the posterior questionnaire survey.

Five performance measures are addressed in quantifying subjects' driving behaviors with the three visual situations ($\overline{SD}$, $S\overline{D}$, and SD) to evaluate the safety and applicability of the DSAS messages.

(1) Mean approach speed,

(2) Speed reduction process with the attenuation of kinetic energy,

(3) Brake distance to the stop line,

(4) Brake response time, and

(5) Effect of socio-demographic factors on travel maneuvers.

The mean approach speeds and speed reduction process toward an intersection should be directly impacted by the visibility (or more accurately: sensibility) of traffic lights. It is expected that subjects would decelerate on diverse ways in relation to their different levels of perceptions to the traffic light. For the less visible traffic signal, subjects should tend to drive slowly. The reduction in speed for turning movements is assumed to be one of immediate effects of glare (Ranney *et al*., 1999b; Hagita and Mori, 2013). Meanwhile, the location of half attenuation of kinetic energy is studied as well during the speed reduction process.

The brake distance is measured from where the brake action is applied after the audio/visional message of traffic light is provided, to the stop line at an intersection. Accordingly, the brake response time is measured between the moment the DSAS message is provided, and the moment the drivers start to apply brake.

Drivers may not immediately decelerate while receiving message on traffic lights. Their decisions depend on the instant speeds at that time and the individual driving behaviors. Sun glare as well as the audio message would conceptually affect the brake distance and brake response time.

Socio-demographic factors, including gender, education background, driving experiences, are also important variables to determine the mean speed, distance for half kinetic energy attenuation, brake distance, and brake response time. All these test results are reported and discussed in Chapter 4.

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter, the results of the driving simulator tests are presented, which include the impacts of the DSAS messages on approach speeds, speed decreasing process with attenuation of kinetic energy, brake distance, brake response time, and the effects of socio-demographic factors on the application of the DSAS messages under sun glare disturbances. Meanwhile, those impacts, the applicability of the DSAS messages, the erratic phenomenon observed during the tests, and drivers' feelings from questionnaire survey are discussed.

4.1 Impacts on Mean Approach Speeds

Table 4 lists the mean approach speeds towards target signalized intersections for three directional splits (left, through and right) under three visual situations ($\overline{SD}$, $S\overline{D}$, and SD), as well as the t-test results identifying the significant differences caused by sun glare and DSAS audio messages.

Table 4 contains two portions. In the first portion, the mean speeds for three directional splits are listed under three visual situations: (1) normal situation – no sun glare no DSAS message ($\overline{SD}$), (2) sun glare disturbances with no DSAS messages ($S\overline{D}$), and (3) sun glare disturbances with DSAS messages (SD).

Table 4. Mean Approach Speeds on Three Directional Splits (Left, Through, and Right), and t-test Results of the Impacts of Sun Glare and DSAS Messages on Mean Speeds.

Visual Situations	**Mean Speed (km/h)**		
	Left	**Through**	**Right**
$\overline{SD}$	50.12± 17.52	50.82 ± 18.30	47.08 ± 13.52
$S\overline{D}$	48.77 ± 12.23	54.69 ± 14.57	52.47 ± 14.32
SD	53.54 ± 12.23	49.40 ± 15.29	51.28 ± 13.90
***t*-Test 1: On the impacts of sun glare** $\overline{SD}$ (no sun glare no DSAS) *vs* $S\overline{D}$ (with sun glare no DSAS)			
t(426)	0.92	4.73	4.00
p-two tail	0.36	3.08E-06	7.34E-05
Significant	No	**Yes**	**Yes**
***t*-Test 2: On the compensation of DSAS** $\overline{SD}$ (no sun glare no DSAS) *vs* SD (sun glare with DSAS)			
t (426)	2.16	0.87	1.65
p-two tail	0.03	0.39	1.6E-03
significant	**Yes, but close**	No	Yes
***t*-Test 3: On the impacts of DSAS** $S\overline{D}$ (sun glare without DSAS) *vs* SD (sun glare with DSAS)			
t (426)	3.59	3.66	0.87
p-two tail	3.72E-04	2.79E-04	0.38
significant	**Yes**	**Yes**	No

The second portion presents t-test results on: (1) the impacts of sun glare ($\overline{SD}\ vs\ SD$), (2) the improvement of DSAS message ($\overline{SD}\ vs\ SD$), and (3) the impacts of DSAS ($S\overline{D}\ vs\ SD$). These are cross analyzed and discussed in Sections 4.1.1. through 4.1.4.

4.1.1 Mean Speeds Under a Normal Visual Situation

The row for visual situation $\overline{SD}$ in Table 4 displays that, the mean speeds with neither sun glare nor DSAS messages for left turn (50.12 ± 17.52km/h) and through movement (50.82± 18.30 km/h) are quite close to each other, while the mean speed for right turn is relatively slower (47.08± 13.52 km/h). This is probably because right turn vehicles need more attentions to prepare for turnings with relatively smaller radius. Participants in the tests reported that they were habitually trying to slow down and watching out the traffic coming from left side of the oncoming intersection, and then turn right even on red.

4.1.2 Impacts of Sun Glare on Mean Approach Speeds

The row for visual situation of $S\overline{D}$ in Table 4 lists the mean approach speeds with sun glare disturbance but no DSAS message. Compared with a normal visual situation, the mean approach speed for left turn reduces slightly to 48.77 ± 12.23 km/h ($t(426)=0.92$ and p-two tail=0.36, see the portion of t-test 1 in Table 4). However, the mean approach speeds for through movement and right turn increase significantly to 54.69 ± 14.57 km/h ($t(426)=4.73$ and p-two tail=3.08E-06) and 52.47 ± 14.32 km/h ($t(426)=4.00$ and p-two tail=7.34E-05), respectively.

Usually, less visibility should lead to lower driving speeds (U.S. Department of Transportation, 2013). Thus, the decrease in mean speed for left turn is understandable, but the change is not significant. Nevertheless, the mean speeds for through movement and right turn adversely increase in the case of sun glare disturbance. The increase in speeds for through movement could be explained by that some subjects could not be aware of approaching a signalized intersection due to the sun glare destruction. A worse consequence could be that they would run the red-light. The posterior questionnaire survey tells that, approximately 47% of subjects (14 out of 30 subjects) committed signal violation unconsciously on through movements.

Moreover, subjects were allowed to make a right turn on red. It is more likely that they are inclined to complete the stop procedure as quickly as possible, even though there are unconformable visual disturbances of sun glare. Most subjects felt that, the sun glare effect destructed their visibility to an uncomfortable level, as is reported in the questionnaire survey.

4.1.3 Compensation of DSAS Messages on Mean Speeds

The portion of *t*-test 2 in Table 4 shows the comparison results of the mean speeds under the visual situations of SD (sun glare with DSAS) and $\overline{SD}$ (no sun glare no DSAS), which examines the impacts of DSAS messages on mean approach speeds for three directional splits. Only the mean speed for through movement (49.40± 15.29 km/h) performs apparently similar to the normal situation ($\overline{SD}$) (t(426) = 0.87 and *p*-two tail = 0.39 as are listed in the portion for *t*-test 2).

Though there is significant difference in mean speeds for left turn (*t*(426) = 2.16 and *p*-two tail = 0.03), the *p* value of 0.03 is quite close to the confidence point of 0.05. This implies that the DSAS messages affect subjects' driving speeds, but not exactly to a normal level.

For the right turn, the speeds deviate from their normal visual situation ($\overline{SD}$) relatively (t(426) = 1.65 and *p*-two tail = 1.6E-03). Subjects performed high speed for right turn on red obviously. Therefore, with the DSAS messages, the mean speed for through movement and left turn are compensated completely and partially to a normal visual situation, respectively. The impacts of DSAS message on the speeds for right turn are, however, somehow not significant.

4.1.4 Impacts of DSAS Messages on Mean Speeds

The portion of *t*-test 3 in Table 4 compares the mean speeds between SD (sun glare with DSAS) and $S\overline{D}$ (sun glare without DSAS). The statistical test results show that there are significant differences in the mean speeds for left turn and through movement for the application of the DSAS messages (for left: *t*(426) = 3.59 and *p*-two tail = 3.72 E-04; for through: *t*(426) = 3.66, and *p*-two tail = 2.79 E-04), whereas no apparent difference is found for right turn (*t*(426) = 0.87 and *p*-two tail = 0.38). With the DSAS messages, subjects drove significantly slower for through movement and faster for left turn. For the right turn, they drove slower as well, but the difference is not significant.

In another word, for left-turn by comparing between $S\overline{D}$ and SD, drivers performed higher speed approaching an intersection, even though they knew the upcoming signal light is red through the DSAS audio messages. Whether the higher speed is attributed to their high confidences will be further examined by analyzing the speed decreasing process in Section 4.2.

In addition, the DSAS messages slowed down the mean speeds significantly for through movement, and relatively for right turn. There was no signal violation recorded for through movement vehicles, which is different from the situation of $S\overline{D}$. Though the difference in the mean speeds is not significant for right turn, the slower speeds and zero violation recorded implicate the improvement of safety awareness.

4.2 Impacts on Mean Speed Decreasing Process

In a normal situation with no visual destruction on traffic signal, subjects are supposed to gradually decelerate and stop at the stop line of each intersection during red signal phase. At the beginning of this period, drivers would sense the signal in advance. If the signal is red, the drivers should apply the brake pedal to decelerate. During this process, the vehicle's kinetics energy (E) as well as speed should be dynamically attenuated to zero when reaching the stop line. Figure 14 illustrates how the dynamic speeds reduce in related to the attenuation of vehicle's kinetic energy during red signal phase.

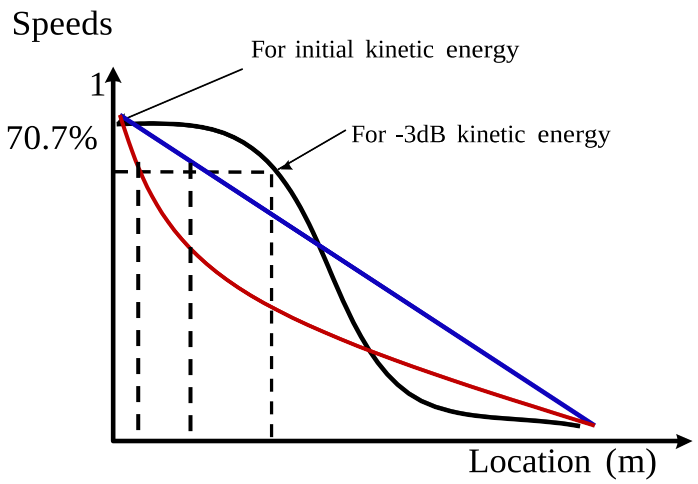


Figure 14. Dynamic Speed Reduction Corresponding to the Attenuation of Kinetic Energy when Vehicles Approaching a Stop Line during Red Signal Phase.

In Figure 14, while the vehicle's speed reduces with the attenuation of the kinetic energy (E) of the vehicle, the way of speed reduction is actually different from the way of kinetic energy attenuation. The process of the energy attenuation could be illustrated in three patterns with different slopes, indicated by blue line, red line and black line. In either event, the -3dB point indicates the speed at the half energy. To some extent, the corresponding distances for the -3dB points could be an obvious indication of how quickly the vehicle decelerated or how hard the brake was conducted. The -3dB point is calculated as follows:

The kinetic energy is a function of driving speed (v) with a relationship defined in Equation (1):

$$E = \frac{1}{2}\, m\, v^2 \tag{1}$$

Where, E is the kinetics energy, m is the weight of the vehicle, and v is the speed.

Let E_0 represent the initial kinetic energy when drivers comprehended the message of a red traffic signal (either from signal light or from other sources like the DSAS audio warning), and v_0 is the initial speed. After drivers have applied the brake pedals accordingly, the vehicle's initial kinetic energy E_0 should be attenuated to E_t at time *t* with an energy reduction ratio α ($0 \le \alpha \le 1$), *i.e*.

$$E_t = \alpha \cdot E_o \tag{2}$$

then,

$$\frac{1}{2}\, m v_t^2 = \alpha \cdot \frac{1}{2}\, m v_0^2 \tag{3}$$

So,

$$\frac{v_t}{v_0} = \sqrt{\alpha} \tag{4}$$

This means, if the kinetic energy decreases to its α times, the speed should decrease to its $\sqrt{\alpha}$ times.

In physics and engineering practices, such energy attenuation, as well as the resulted reduction of sped, are normally depicted by the measurement of decibel (dB), which is a logarithmic unit to express the ration between two values of a physical quantity, often power, energy, r intensity. The number of decibels is ten times the logarithm to base 10 of the ratio of the two power quantities. A decibel is one tenth of a bel, a seldom-used unit named in honor of Alexander Graham Bell (IEEE, 2000).

Then,

$$10\lg\frac{E_i}{E_0} = 20\lg\frac{v_i}{v_0} = 20\lg\sqrt{\alpha} \qquad (5)$$

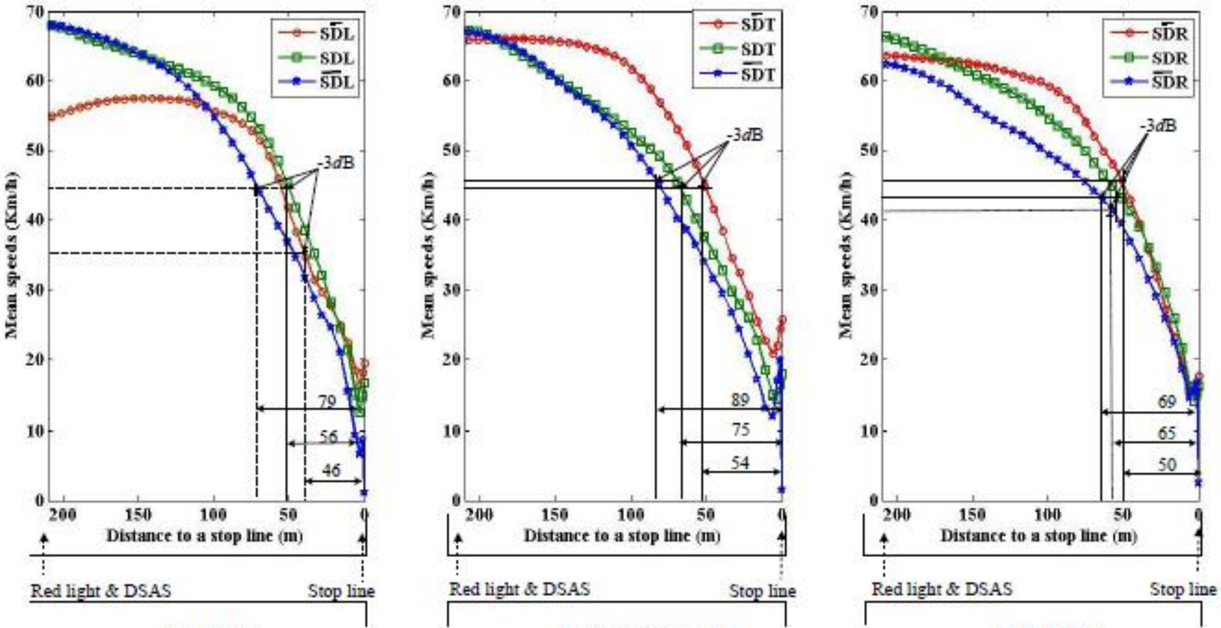
The result from Equation (5) is in the unit of dB, which is used for a wide variety of measurements in science and engineering, most prominently in acoustics, electronics, and control theory. The attenuation of energy, while it is hard to describe the entire attenuation process, is normally measured at the time (or location) of its half energy status, *i.e.* when $\alpha=\frac{1}{2}$. This is known as the Half Power Point (Van Valkenburg, 2008). In the case of the research in this study, the decibel value is

$$20\lg\sqrt{\alpha} = 20 \cdot (-0.5) \cdot \lg(2) = -3 \text{ (dB)} \qquad (6)$$

This means, a change in energy by a factor of 1/2 (or to the half energy) approximately corresponds to a -3 dB change of decibel measurement.

In the case of this study, the speed at 210 meters away from an intersection is considered as the initial speed (vo) with initial kinetics energy (E_o). At the point of −3dB, the initial kinetics energy (E_o) attenuates to its 50% (α=1/2), while the initial speed (v_o) reduces to its 70.7% or $\frac{1}{\sqrt{2}}$.

Figure 15 displays the mean speed reducing profiles. The blue lines in Figure 15 indicates the mean speed in a normal visual situation ($\overline{SD}$), green line in the situation with sun glare with DSAS message (SD), and red line in the situation under sun glare disturbance without DSAS messages ($S\overline{D}$). In Figure 15, the distances for the speeds of v_{-3dB}, to the stop line are all pointed out for all three directional split. Recall that, the DSAS messages were provided to subjects at about 210 meters towards to the stop line. With the all considerations in section 3.2.2, the drivers should be able to maneuver their vehicles at about 140 meters heading to the stop line.



(a) Left-turn (b) Through movement (c) Right-turn

Figure 15. Mean approach speed profile and distances at 70.0% of original speeds to a stop line at a signalized intersection on (a) Left-turn, (b) Through movement, and (c) Right-turn.

From the test results under a normal visual situation, vehicles' mean kinetic energy attenuated to its half (at the speeds of $v{-}3\text{dB}$) ($\overline{SD}$) at about 70 to 90 meters away to the stop line (left 79 meters, through 89 meters, and right 69 meters).

With the visual disturbance of sun glare ($S\bar{D}$), such half energy distances are shortened to 46 meters for left turn, 54 meters for through movement, and 50 meters for right turn. It implies that less visibility caused by sun glare disturbance may lead to shorter half-attenuation distance, as the drivers may have difficulties in recognizing the red light signal when compared with normal visual situations. On the other hand, it is noticed that the red line in Figure 15 (a) indicates a relative lower speed at the distance of 210 meters than other lines, which could be interpreted by the design of scenario. All subjects started with the 2nd scenario (see Figure 11) represented by the red line in the driving test. The buffer distance is probably not sufficient to speed up to 72 km/h before they approached the intersection.

Surprisingly, with the DSAS message in the situation of SD indicated with green lines in Figure 15, the speeds decrease continuously without hard braking, unlike the situation of $S\bar{D}$ represented by red lines. What's more, the distances at the speed of $v_{-3\text{dB}}$ become quite close to the one in a normal situation ($\overline{SD}$) for through movement and right turn (89 m for through and 69 m for right) as are in Figure 15 (b) and (c).

For left turn however, the DSAS messages does not improve such distance significantly, but still ten meters longer distance was observed (56 m of SDL vs 46 m of $S\bar{D}L$) in Figure6 (a).

Overall, with the DSAS message, the speeds (green lines) decrease more smoothly and the distances at the speed of $v{-}3\text{dB}$ to the stop line become longer. This further implies that with the DSAS message provided, the subjects normally decelerated earlier so as to smoothly approach the intersection with confidence, even though their visibilities were destructed by a sun glare effect. Furthermore, the DSAS message did draw drivers' attentions to the traffic situation, rather than distracted them. Meanwhile, the smooth deceleration profile validates that drivers performed higher speeds for left turn with confidence under the situation of SD, which is mentioned in second 4.1.1.

4.3 Impacts on Mean Brake Distance

During the simulator tests, once the subjects stepped on the brake pedal, the levels of braking (ranging from 0.0 to 1.0) were recorded immediately. The correspondent geo-locations at the braking level of greater than 0.0 were utilized to calculate the brake distances to the target intersection.

Figure 16 displays the mean brake distances for all subjects under different visual situations. The *x*-axis is mean brake distance in meters and the three visual situations are ticked on the y-axis: $\overline{SD}$ (no-glare no DSAS message), S$\bar{D}$ (with glare no DSAS message), and SD (with sun glare with DSAS message).

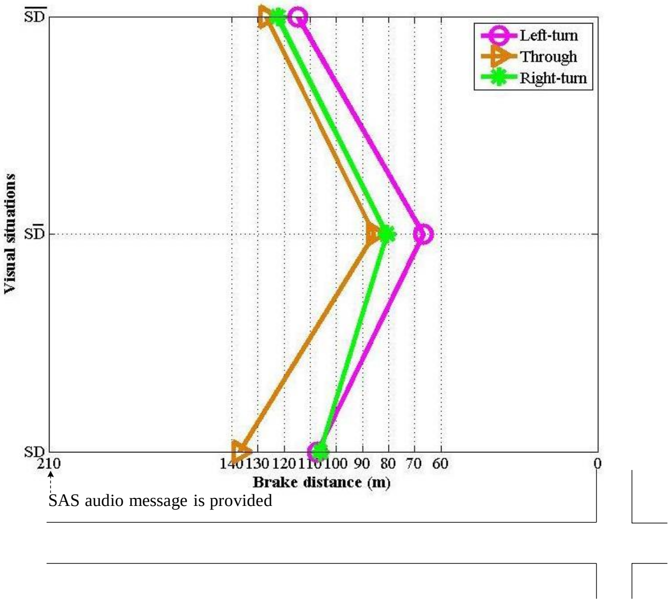


Figure 16. Mean brake distance toward the stop line on three travel splits under three visual situations.

4.3.1 Impacts of Sun Glare on Brake Distance

Figure 16 shows that the brake distances to the stop line for all directional splits are very close to each other in a normal situation ($S\bar{\bar{\bar{\bar{D}}}}$) (with detailed data in Table 5), all at the locations of approximate 120 meters towards the stop line. However, this distance reduces to around 80 meters for through movement and right turn under a sun glare effect ($S\bar{D}$). For left turn, the distance becomes even shorter by about 68 meters.

Table 5. Brake distance to a stop line at a signalized intersection (Unit: meter)

Travel Splits		**Brake Distance**		
		$\overline{SD}$	$S\bar{D}$	SD
Left-turn	Mean	114.69	66.55	107.28
	Std	38.94	50.77	53.74
Through	Mean	126.62	85.43	136.81
	Std	43.59	26.09	47.49
Right-turn	Mean	122.38	80.52	106.19
	Std	44.54	48.67	59.98

These differences are all significant (left: $t(58) = 4.121$, and $p = 1.213E\text{-}04$; through: $t(58) = 4.56$,*and* $p = 2.718E\text{-}05$; and right: $t(58) = 3.48$ and $p = 9.718E\text{-}04$) (see Table 6), which imply that sun glare seriously destructs subjects' visibility.

Table 6. t-test Results for Mean Brake Distance to a Stop Line at a Signalized Intersection.

Splits	$\overline{SD}\ vs\ S\bar{D}$		$\overline{SD}\ vs\ SD$		$S\bar{D}\ vs\ SD$	
	t(58)	*p* two-tail	*t*(58)	*p* two-tail	*t*(58)	*p* two-tail
Left	4.12	**1.21E-04***	0.61	0.54	3.02	**3.70E-03***
Through	4.56	**2.72E-05***	0.87	0.39	5.29	**1.96E-06***
Right	3.48	**9.72E-04***	1.19	0.24	1.82	0.07

*Significant

4.3.2 Compensation of DSAS Message on Brake Distance

With the DSAS messages under a sun glare effect (SD), the brake distance increases to about 110 meters for left and right turns (see Figure 16 and Table 5). For through movement, the brake distance becomes longer (136.81 meters), which is even longer than the required distance of 120 meters for lane change. What's more, there is no significant difference in the brake distance when comparing the situation SD and the normal visual situation of $\overline{\text{SD}}$. This implies that the DSAS message is able to compensate the negative impacts of sun glare destruction to a normal visual level, in terms of the brake distance.

4.3.3 Impacts of DSAS Message on Brake Distance

The comparison of the situation of $\overline{\text{SD}}$ and SD shows that with the DSAS messages, the brake distances are extended from 66.55 meters to 107.28 meters (for left turn), from 136.81 meters to 85.43 meters (for through movement), and from 106.19 meters to 80.52 meters (for right turn). Their differences are significant for left turn (*t*(58) = 3.02 and *p* = 3.7E-03) and through movement (*t*(58)= 5.29 and *p*= 1.96E-06).

Though the difference for right turn isn't significant (*t*(58)=1.82 and *p*=0.07), the *p*-value of 0.07 is quite close to the confident threshold of 0.05. Thus, the DSAS messages may affect subjects' brake distance for right turn as well, but not to the significant level.

4.4 Impacts on Mean Brake Response Time

The time, over which the subjects spend to perceive a given red signal (either through observe the traffic signal lights, or through the perception of the DSAS audio message, which is provided at about 210 meters away from the stop line) before braking, is considered as brake response time. The brake response times under different visual situations for three directional splits are plotted in Figure 17.

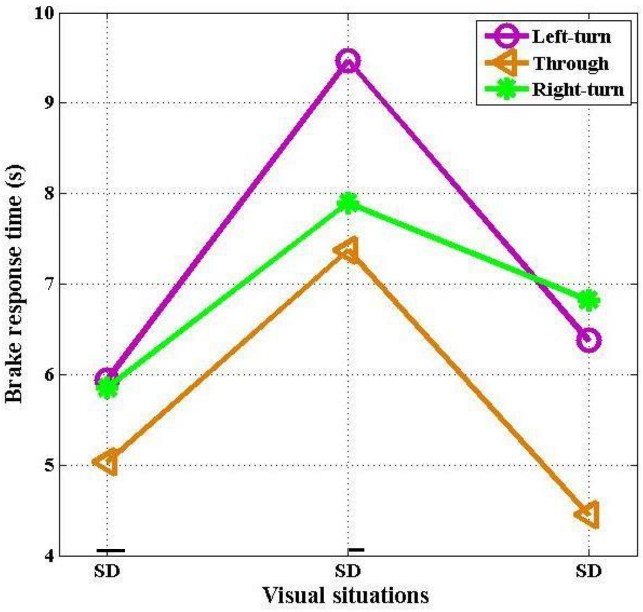


Figure 15. Mean Brake Response Time for Red-light on three Directional Splits Corresponding to Different Visual Situations.

In Figure 17, the *x*-axis indicates three visual situations, while the *y*-axis presents brake response time in seconds. Similar to Figure 16, when sun glare and DSAS are both absent (in the situation of $\overline{SD}$, the brake response times for all directional splits are very close to each other (about 5-6 seconds). In the visual situation of $S\bar{D}$ (with sun glare but no DSAS message), the brake response times are extended to longer than 7 seconds.

Interestingly, the brake response times are back to 6+ seconds for left and right turns in the situation of SD (with DSAS under sun glare). For through movement, the brake response time is further shortened to 4+ seconds. Table 7 lists each specific brake response time.

Table 7. Brake Response Time to the Given Signal Red-Light at the Intersection (Unit: second).

Splits		**Brake Response Time**		
		$\boldsymbol{\overline{SD}}$	$\boldsymbol{S\overline{D}}$	$\boldsymbol{SD}$
Left-turn	Mean	5.94	9.47	6.37
	Std	3.94	3.41	4.38
Through	Mean	5.03	7.37	4.44
	Std	3.13	2.19	3.19
Right-turn	Mean	5.85	7.90	6.82
	Std	3.61	3.63	4.94

Table 8 shows the *t*-test results of the brake response time among the three different visual situations.

Table 8. t-test Results for Brake Response Time.

Splits	$\boldsymbol{\overline{SD}\ vs\ S\overline{D}}$		$\boldsymbol{\overline{SD}\ vs\ SD}$		$\boldsymbol{S\overline{D}\ vs\ SD}$	
	t(58)	*p* two-tail	*t*(58)	*p* two-tail	*t*(58)	*p* two-tail
Left	3.77	**3.82E-04***	0.41	0.68	3.05	**0.34E-02***
Through	3.37	**1.35E-03***	0.87	0.39	4.15	**1.10E-04***
Right	2.19	**3.26E-02***	0.72	0.48	0.96	0.34

***significant**

4.4.1 Impacts of Sun Glare on Brake Response Time

Regardless of the DSAS messages, there are significant differences between the situations of $\overline{\overline{\overline{S}}}\overline{D}$ and $S\overline{D}$ for all three directional splits in Table 8 (left: *t*(58)=3.77 and *p* =3.82E-04; through: *t*(58)=3.37 and *p*=1.35E-03; right: t(58)=2.19 and *p* = 3.26E-02). This phenomenon could be logically interpreted by that, the sun glare disturbance destructs subjects' awareness of the upcoming red-light, and eventually delays their response times to brake.

4.4.2 Compensation of DSAS Messages on Brake Response Time

Noticeably, no obvious differences in brake response time are found between the situations of $\overline{S}\overline{D}$ and SD for all directional splits in Table 8 (left: *t*(58)=0.41and *p*= 0.68; through: *t*(58)=0.87 and *p* = 0.39; right: *t*(58)=0.72 and *p* = 0.48). This indicates that under a sun glare situation, subjects' brake response time could be compensated to a normal visual situation with the aids of DSAS messages.

4.4.3 Impacts of DSAS Message on Brake Response Time

On the other hand, there are significant differences between the visual situations of SD and $S\overline{D}$ for left turn and through movement in Table 8 (left: t(58) = 3.05 and p = 3.4E-03; through: (t(58) = 4.15 and p =1.10E-04). These visible differences could further confirm that the DSAS message is able to improve the visibility and shorten subjects' brake response time. However, subtle difference is spotted for right turn (*t*(58)=0.96 and

$p = 0.34$; SD: 6.82 s; $\overline{SD}$: 7.90 s). This could be possibly explained by the right turn on red policy and the fact that more attentions are normally required to prepare for right turn.

4.5 Effect of Socio-Demographic Factors on Travel Maneuvers with DSAS Messages

It is hypothesized that when the DSAS message is provided, drivers' driving performance might be more or less subject to their individual socio-demographic factors. The study is extended to take the socio-demographic factors into account, including subjects' gender, education, driving experience, and age. The subjects are divided into two groups across all the socio-demographic factors, as described below:

- Gender: male and female
- Education: final degree is bachelor degree or above, and final degree is high school or below
- Driving experience: less than three years, and three years and above
- Age: younger than 65, and 65plus.

The significance levels of the impacts of socio-demographic factors are examined by *t*-tests on three indexes: mean approach speed, mean brake distance, and brake response time (see Table 9).

Table 9. t-test Results with Socio-Demographic Factors in the Situation of **SD**

Splits	**Gender**		**Education**		**Driving Experience**		**Age (<65 and 65+)**	
	t	***p***	***t***	***p***	***t***	***p***	***t***	***p***
Mean Approach Speed								
SDL	1.31	0.20	0.70	0.49	0.12	0.9	5.83	**2.88E-06***
SDT	2.35	**0.03***[1]	1.50	0.15	0.73	0.47	3.42	**1.96E-03***
SDR	1.92	0.07	3.03	**0.01***[2]	0.10	0.92	3.53	**1.44E-03***
Mean Brake Distance								
SDL	0.56	0.58	0.91	0.37	0.51	0.61	1.09	0.28
SDT	1.43	0.16	1.01	0.32	0.54	0.59	1.66	0.11
SDR	0.17	0.87	1.10	0.28	0.49	0.64	0.12	0.90
Mean Brake Response Time								
SDL	0.17	0.87	1.54	0.13	0.51	0.61	6.08	**1.48E-06***[3]
SDT	0.44	0.66	1.45	0.16	0.54	0.59	0.73	0.47
SDR	0.71	0.48	1.40	0.17	0.49	0.63	2.72	**0.01***[3]

*****[1] Significant difference between males (52.85± 9.30) and female (45.96± 6.50).

*****[2] Significant difference between highly educated people (44.93±7.10) and lowly educated people (54.01 ± 7.72).

*****[3] Significant difference between seniors (left: 11.55± 8.33, right: 9.23± 9.59) and the young (left: 5.58±2.99, right: 6.45±4.03)

***** Significant

4.5.1 Socio-demographic Impacts on Mean Approach Speeds

Table 9 shows that the examined socio-demographic factors affect the mean approach speeds rarely under the situation of SD (sun glare with DSAS messages)

For Gender. For the impacts of gender with the DSAS messages, male drove obviously faster than female for through movement ($t(28) = 2.35$ and $p = 0.03$). According to Nauert (2011), male is more likely to drive aggressively than female counterpart, which may be considered as a possible reason for the higher approach speeds conducted by male.

For Education Background. Highly educated subjects drove apparently slower than the ones received lower level of education, particularly for right-turn ($t(28)=3.03$ and $p=.01$). This is consistent with Dearton's (2003) findings that, highly educated drivers are often associated with better health and functional ability. Higher educated people are more likely to drive carefully and slower than poorly educated ones.

For Driving Experience. It is expected that drivers with less driving experience might find it difficult to manage their speeds when approaching a signalized intersection with sun glare. Surprisingly in Table 9, there are no significant differences in the mean speeds caused by driving experience. This means that driving experience is not a variable in the mean approach speeds with DSAS messages for all directional split (left, through, and right turns).

For Age. The ‘slowing effect’ is reflected in the elderly’ driving speeds as well. They performed significantly slower speeds for all directional splits (left: *t*(28) =5.83 and *p*=2.88E-06; through: *t*(28) = 3.42 and *p* = 1.96E-03; and right: *t*(28) =3.53 and *p*=1.44E-03) (see Table 9). The mean approach speeds by age groups for are shown in Table 10.

Table 10. Mean Approach Speeds by Age Groups (Unit: seconds)

Splits	**Seniors (65+)**	**Young (<65)**
Left	36.34±3.75	56.18±6.58
Through	37.67±6.20	51.21±7.51
Right	39.39±5.42	53.11±7.42

Dukic, T., & Broberg, T. (2012) mentioned that older drivers pay more attentions to lines and markings on the road to position themselves in traffic, while younger drives attend more to dynamic objects such as other cars that appear to represent potential threats. During the driving simulator test in this study, each subject was the only driver on the road, which means the attention to the dynamic objects for the young could be ignored, but the attention to the lines and marking on the road for the elder could be rather heavy workload, which may lead to slower speeds for elderly drivers.

From another standpoint, the seniors’ slower speeds are just the implication of safety. As a whole, older drivers’ slower driving speeds and longer response time (as will be discussed in section 4.5.3) are in line with the previous studies that elderly drivers have the tendency to be more careful and to monitor their responses more thoroughly than younger drivers (Botwinick, 1966).

4.5.2 Socio-demographic Impacts on Mean Brake Distance

For the mean brake distance in Table 8, there are no significant differences found for all the examined socio-demographic factors, regardless of drivers' gender, education background, driving experiences, and age. This is an interesting result meaning that all subjects start to brake at the similar distance, no matter what socio-demographic factors are concerned with.

4.5.3 Socio-demographic Impact on Mean Brake Response Time

Regarding the mean brake response time, the significant differences appear only at age comparison between young and elderly drivers for left turn and right turn. Salthouse (2000) found that the elderly have longer response times than young individuals on cognitive performance tasks that place demands on attentional and visual processing abilities, which phenomenon is named 'slowing effect' (Verhaeghen & Cerella, 2002). Therefore, seniors' slower response times are convinced.

In addition, for left turn, age has significant impacts on the brake response time ($t(28)= 6.08$ and $p = 1.48E\text{-}06$). The elderly drove significantly slower than the young. In fact, many research found that there is high possibility of crash by elderly drivers who intend to turn left at an intersection (*e.g.* Chandraratna & Stamatiadis, 2003; Gelau, 2009; Mayhew *et al.* 2006), which is valid for countries travelling in the right traffic lane. From their research, it could be learnt that elder drivers usually find it the most difficult to make left turn, comparing with the other directional splits, thereby spending longer time on their maneuver.

4.6 Drivers' Feeling from Questionnaire Survey

All subjects filled out the questionnaire form right after their driving simulator tests to report their feelings about the application of DSAS messages.

Though 53% of the subjects felt that the DSAS audio message may raise workload during their driving, all of them accept such reasonable work load. All subjects evaluated the disturbance of the sun glare effect with the highest score of 5 (uncomfortable level).

According to the survey, about 70% of subjects paid more attentions to the DSAS audio messages, while the rests to the conventional traffic signs. They reported that they didn't know there would be audio instructions available, and they followed the traffic signs habitually. All of them felt that, when the DSAS message was providing, they are able to be aware of the traffic situation better under the sun glare disturbance.

Further, they all think that the DSAS message can really increase their defensive driving awareness and enhance the safety of pedestrians at an intersection with visual disturbance. All of them agree that the combination of the DSAS audio message and the control signs is a feasible and applicable solution to enhance drivers' as well as pedestrians' safety. Lastly, three subjects suggested that the audio message can be louder.

In sum, all subjects highly valued the application of the DSAS audio message. With the DSAS audio message, they feel that are able to more safely drive through a signalized intersection under a sun glare effect.

4.7 Summary of Test Results

Table 10 summarizes the statistical significance of difference in subject's driving performance, in terms of mean approach speeds, brake distance, and brake response time under three visual situations $\overline{\mathrm{SD}}$, S$\overline{\mathrm{D}}$ and SD. Owing to the sun glare visual destruction (S$\overline{\mathrm{D}}$), subjects' mean approach speeds deviate from the one they perform in a normal situation ($\overline{\mathrm{SD}}$) without a sun glare effect. Their deviation points are concluded as follows (see Table 11):

1. Subjects drove faster for through movement and right turn;
2. Subjects braked in a shorter distance to the stop line for the all directional splits;
3. Subjects responded slower to the status of red-light for all three directional splits;
4. Sun glare slightly affects the driving speed for left turn. The approach speed for left turn is slower than usual, but not at a significant level.

In Table 11 it is seen that, sun glare has significant negative impacts on almost all measurement indexes for almost all directions. These are reflected in almost all rows for "With Sun Glare but no DSAS Message" with significant test results as "Yes". The only exception is for left turn mean approach speed. This is probably because that left turn has longer turning curve, and the drivers should all know that the sun glare effect would soon be disappeared shortly when vehicles are on their turning curves.

Table 11. Summary of Significance of Impacts of Sun Glare and DSAS Messages for three Directional Splits (Left, Through, and Right).

Measures	**Comparison**	**Visual Situations**	**Splits**	**Change**	**Significant**
With Sun glare but no DSAS Message	$\overline{SD}\ vs\ S\overline{D}$	Mean speeds	Left	Decrease	No
			Through	Increase	**Yes**
			Right	Increase	
		Brake distance	Left	Decrease	
			Through	Decrease	
			Right	Decrease	
		Brake response time	Left	Increase	
			Through	Increase	
			Right	Increase	
With Sun Glare and DSAS Message	$\overline{SD}\ vs\ SD$	Mean speeds	Left	Increase	**Yes**
			Through	Decrease	No
			Right	Increase	**Yes**
		Brake response time	Left	Increase	No
			Through	Decrease	
			Right	Increase	

		Brake distance	Left	Decrease	
			Through	Increase	
			Right	Decrease	
	$S\overline{D}\ vs\ SD$	Mean speeds	Left	Increase	**Yes**
			Through	Decrease	
			Right	Decrease	No
		Brake distance	Left	Increase	**Yes**
			Through	Increase	
			Right	Increase	No
		Brake response time	Left	Decrease	**Yes**
			Through	Decrease	
			Right	Decrease	No

When the DSAS audio message was provided under the sun glare situation of SD, subjects seldom performed differently from in the normal visual situation of $\overline{SD}$. With the DSAS messages, they drove faster to approach the intersection for turning movement, but slowly as usual for through movement. This phenomenon is explained by that they performed high speeds with confidence.

Further comparison between the situation of with (SD) and without ($S\overline{D}$) the DSAS messages shows that, the application of the DSAS message doesn't improve subjects' driving performance significantly for right turn, but well for left turn and through movement. The defect of the DSAS messages for right turn was interpreted by the policy of right-turn on red and more attention required for right turn.

Socio-demographic factors analyses involve the impacts of the DSAS message on subjects’ driving performance. It is found that subjects’ individual gender, education and driving experience don’t influence their brake distance to the stop line at an intersection at all, but few differences present in their response time and approach speeds. Age is an essential independent variable in determining significant differences. The differences attributed to their gender, education level and age are summarized as follows:

1. Male drove faster than female when approaching an intersection with the DSAS audio message, but only the difference for through movement appears remarkable;
2. Higher educated people drove slower than low educated ones, especially for right turn;
3. Seniors drove evidently slower than younger for all directional splits;
4. Seniors spent longer time to respond to the red light for left and right turns.

Table 12 lists the summary of *t*-test results with the socio-demographic factors in the application of the DSAS message.

Table 12. Summary of t-test Results with the Socio-demographic Factors in the Application of the DSAS Message.

Socio-	**Left**	**Through**	**Right**

demographic Factors	Change	Significant	Change	Significant	Change	Significant
Approach speeds						
Male-Female	Decrease	No	Decrease	**Yes**	Decrease	No
HS-Bachelor	Decrease	No	Decrease	No	Decrease	**Yes**
Seniors-younger	Increase	**Yes**	Increase	**Yes**	Increase	**Yes**
Brake response time						
Seniors - Younger	Decrease	**Yes**	Increase	No	Decrease	No

Reasons for the differences listed in Table 11 are varied. For instance, male is usually associated with aggressive driving; less attention is required for through movement than the other direction splits; highly educated people concern more about their better health and functional ability than lowly ones. Additionally, 'slowing effect' usually takes place by elderly drivers. Elderly drivers require more attention to make turning movement, especially for left turn.

Moreover, the results of questionnaire survey show that all subjects felt that the introduction the DSAS audio messages are applicable and feasible to enhance drivers' as well as pedestrians' safety.

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Literature reviews were conducted on sun glare effects, the protection strategies, and new technologies proposed to mitigate sun glare's effects on roads. The pilot test with the RFID based DSAS message was reviewed as well. Based on these, a research framework for simulator tests was developed to further study the implication of sun glare and the DSAS message in driving performance approaching signalized intersections.

A total of nine scenarios are designed for three different levels of visual situation, ($\overline{SD}$, $S\overline{D}$, and SD) in three directional splits (left, through and right). Five performance measures are addressed, namely mean approach speeds, speeds reduction process with attenuation of kinetic energy, brake distance to the stop line, brake response time for red-light signal, and effects of socio-demographic factors (gender, education, driving experience, and age) on travel maneuvers. Statistic t-tests were conducted among the performance measures to investigate the significant levels of differences caused by the sun glare effect and the DSAS messages.

Analytical results show that, there are statistically significant differences caused by sun glare and the DSAS message in approach speeds, speed reducing profile with the attenuation of kinetic energy, brake response distance, and brake response time. A sun glare effect can obviously destruct drivers' visibility of the upcoming traffic signal, though the significant impairment does not appear at the mean approach speeds for left turn.

When the DSAS messages are provided, the performance measures have been completely or patricianly improved to a normal situation (no sun glare disturbance) for different directional splits, especially regarding the brake response time and brake distance. Though the mean approach speeds in the situation of SD (with sun glare and DSAS message) for left and right turns are higher than in a normal situation, the smoother speeds reducing profile and the slower speeds for through movement tell that drivers were aware of their high speeds. In other words, they performed high speeds with confidence. Besides, the differences caused by the DSAS message in the performance measures are statically significant for left turn and through movement. The policy of right-turn on red and more attention required for right turn are considered in the insignificant difference for right turn.

In addition, no significant difference caused by individual socio-demographic factors is found in mean brake distance when the DSAS messages are provided, but few differences shown on mean approach speeds and mean brake response time. Though there are significant differences caused by gender for through movement and by education level for right turn regarding the mean approach speed, the p-values are quite close to the confident point of 0.05. To a certain extent, the differences could be ignored. Moreover, age is a determinative variable in the application of the DSAS message. The elderly performed slower approach speeds and longer response time for the red-light signal than the youth, which are consistent with the previous studies that the elderly tend to be more aware of their responses than the youth (Botwinick, 1966). That is just the implication of safety. Thus, those are positive statistically significant differences.

In all, the DSAS message is able to improve the smoothness of speeds profile, without excessive deceleration, and compensate the negative effects of sun glare back to a normal situation for all directional splits. The DSAS message is applicable for all types of drivers, particularly beneficial for the elderly, who have longer response times than the young on cognitive performance tasks.

It is recommended continuing test the implication of the DSAS message with even more scenarios such as different types of DSAS message, different signal phase settings (green, yellow, and "green to yellow" and "red to green" when vehicles are approaching the intersections, etc.). More variables could be monitored during the tests such as drivers' eye tracking information, the steering movements, etc. Implications of the DSAS message on safety indexes should also be tested in driving simulators.

APPENDIX A

QUESTIONNAIRE SURVEY FORM

1. Do you feel that the audio instruction/warnings raise more workload for motorists?
   Yes/No
   If yes, can you accept it?
   Yes/No

2. Which warnings have you paid more attention to during the test?
   1) DSAS Audio message
   2) Traffic signs

3. Do you feel that you know the signal status better during the test with the DSAS message?
   Yes/No

4. Do you think the DSAS message is able to increase drivers' defensive driving awareness?
   Yes/No

5. Do you think that the DSAS message can really increase the safety at the signalized intersections with visual disturbance of sun glare?
   Yes/No

6. Do you think it is a good idea to apply the DSAS message at signalized intersections with sun glare effect to improve the safety of pedestrians and motorists?
   Yes/No

7. Do you have advices to improve the DSAS audio message?

REFERENCES

Bass, M. (2010). *Handbook of Optics: Volume III – Vision and Vision Optics, Third Edition.* McGraw-Hill Professional: New York, Chicago, San Francisco, Lisbon, London, Madrid, Mexico City, Milan, New Delhi, San Juan, Seoul, Singapore, Sydney, Toronto. ISBN: 9780071498913

Benda, J., Hochmuth, J., Kowshik, R., Medgyesy, L. (2009). Open Road Tolling Signing Studies. In *TRB 88th 30 Annual Meeting Compendium of Papers CD-ROM. Transportation 31 Research Board*, Washington D.C.

Botwinick, J. (1966). Cautiousness in advanced age. *Journal of Gerontology*, Vol. 21, Issue 3. 347-353.

Chandraratna, S., & Stamatiadis, N. (2003). Problem driving maneuvers of elderly drivers. *Transportation Research Record*, 1843, 89–95.

Chang, M.-S., Messer, C. J., & Santiago, A. J. (1985). Timing Traffic Signal Change Intervals Based on Driver Behavior. Transportation Research Record: *The Journal of Transportation Research Board*, 1027, 20-30.

Choi, E.-H., and Singh, S. (2005). Statistical assessment of the glare issue – human and natural elements. In *Proceedings of the Federal Committee on Statistical Methodology workshop*. Retrieved from the Federal Committee on Statistical Methodology Website: http://www.fcsm.gov/05papers/Choi_Singh_IVA.pdf.

Crundall, D. & Underwood, G. (1998). Effects of Experience and Processing Demands on Visual Information Acquisition in Drivers. *Ergonomics*, 41, 448-458.

Deaton, Angus. (2003). *Health, Income, and Inequality*. Retrieved from the National Bureau of Economic Research website: http://www.nber.org/reporter/spring03/health.html.

Department for Transport: Great Minster House (DTGMH). (2013). *Road Accidents Great Britain 2012*.

Dukic, T., & Broberg, T. (2012). Older drivers' visual search behavior at intersections. *Transportation Research Part F: Traffic Psychology and Behaviour*, 15, 462-470.

F.Qiao, Q. Li, and L. Yu. (2016b). Performance Measures of Smartphone Warning Messages in Work Zones and Intersections. *Proceedings of the 23rd Intelligent Transportation Society (ITS) World Congress*, Melbourne, Australia, 10-14 October 2016.Paper #: AM-TP0062.

Fisher, D. L., Rizzo, M., Caird, J. K., Lee, J. D. (2011). *Driving Simulation for Engineering, Medicine, and Psychology*. CRC press, Taylor & Francis Group.ISBN 978-1-4200-6100-0.

G. Wu, K. Boriboonsomsin, W.-B. Zhang, M. Li, and M. Barth. (2010). Energy and Emission Benefit Comparison of Stationary and In-Vehicle Advanced Driving Alert Systems. Transportation Research Record*: Journal of the Transportation Research Board*, vol. 2189, no. 1, pp. 98-106,

Gelau, C. (2009). Elderly drivers' needs for support at intersections. In M. W. Greenlee (Ed.), *New issues in experimental and applied psychology: A festschrift for alf zimmer*. Lengerich, Germany: Pabst-Science-Publishers.

Golembiewski, G., Katz, B., Knoblauch, R., Rousseau, G. (2006). Determining Colors for Traffic Control Devices at Transponder-Controlled Tollbooth Lanes with a Sign Simulator. Transportation Research Record: *the Journal of the Transportation Research Board* (Impact Factor: 0.44). 01/2006; DOI:10.3141/1973-08.

Hagita, K. & Mori, K. (2013). The effect of sun glare on traffic accidents in Chiba prefecture, Japan. In *Proceedings of the Eastern Asia Society for Transportation Studies*, Vol.9, 2013. ISSN: 1881-1132.

IEEE Standard 100 Dictionary of IEEE Standards Terms. (2000). Seventh Edition, The Institute of Electrical and Electronics Engineering, New York, 2000; ISBN 0-7381-2601-2; page 288

Illinois coalition for responsible outdoor lighting. (2011, January). *The color of lights: more than meets the eye*. Retrieved from the Illinoislighting website: http://www.illinoislighting.org/lightcolor.html.

Keith, K., Trentacoste, M., Depue, L., Granda, T., Huckaby, E., Ibarguen, B., Kantowitz, B., Lum, W., Wilson, T. (2005). *Roadway Human Factors and Behavioral Safety in Europe*. Chapter 3 - Driving Simulators: Roadway Design and Visualization. U.S. Department of Transportation.

Kotchasarn, C. (2009). RFID Assisted Vehicular Communication Systems. cicsyn, pp.166-171, *2009 First International Conference on Computational Intelligence, Communication Systems and Networks*.

Li, Q., F. Qiao, and L. Yu (2014). Impacts of Vehicles to Infrastructure Communication Technologies on Vehicle Emissions. Proceedings of *the International Conference on*

Environmental Science and Technology, American Academy of Sciences, Houston, TX, June 9-13, 2014.

Li, Q., F. Qiao, and L. Yu. (2015a). Fuzzy lane-changing models with socio- demographics and Vehicle-to-Infrastructure system based on a simulator test. *Journal of Ergonomics*. http://dx.doi.org/10.4172/2165-7556.1000144. ISSN:2165-7556 JER, an open access journal. Volume 5 • Issue 4 • 1000144.

Li, Q., F. Qiao, and L. Yu. (2015c). Implications of Wireless Communication System for Traffic Operations on Vehicle Emissions. *Proceedings of the 107th Air & Waste Management Association (AWMA),* June 22-25, 2015. Raleigh, North Carolina, USA.

Li, Q., F. Qiao, L. Yu. (2015b). Socio-demographic impacts on lane-changing response time and distance in work zone with drivers' smart advisory system, *Journal of Traffic and Transportation Engineering (English Edition*), Volume 2, number 5, October 2015. Elsevier Publishing. http://dx.doi.org/10.1016/j.jtte.2015.08.003.

Li, Q., F. Qiao, X. Wang, and L. Yu (2013). Impacts of P2V Wireless Communication on Safety and Environment in Work Zones through Driving Simulator Tests (paper # 26-179). Proceedings of *the 26th Annual Conference of the International Chinese Transportation Professionals Association (ICTPA),* Tampa, Florida, May 24-26, 2013.

Li, Q., F. Qiao, X. Wang, and L. Yu. (2015). Measures of Performance when Drivers Approaching STOP Sign Intersections with the Presence of Drivers Smart Advisory System. Proceedings of the *28th Annual Conference of the International Chinese*

Transportation Professionals Association (ICTPA), May 14 ~ 16, 2015, Los Angeles, USA.

Li, Q., F. Qiao, X. Wang, and L. Yu. (2016a) Drivers Smart Advisory System Improves Driving Performance at STOP Sign Intersections. *Journal of Traffic and Transportation Engineering (English Edition).* In Press

Li, Q., F. Qiao, Y. Qiao, and L. Yu. (2016c). Implications of Smartphone Messages on Driving Performance along Local Streets. *Proceedings of the 11th Asia Pacific Transportation Development Conference and 29th ICTPA Annual Conference - Bridging the East and West: Theories and Practices of Transportation in the Asia Pacific*. May 27-29, 2016. Hsinchu, Taiwan. Paper #: 81.

Lighting Research Center. (2007, February). *Light Pollution*. Retrieved from the Lighting Research Center website: http://www.lrc.rpi.edu/programs/nlpip/lightinganswers/lightpollution/glare.asp

Mayhew, D. R., Simpson, H., & Ferguson, S. A. (2006). Collisions involving senior drivers: High-risk conditions and locations. *Traffic Injury Prevention*, 7, 117–124.

Mitra, S. (2008): Investigating Impacts of Sun Glare on Transportation Safety, *TRB 2008 Annual Meeting CD-ROM*, 08-2184

Nauert, R. (2011, October 18). *Aggressive Drivers Identify with Their Car*. Retrieved from the Psychcentral website: http://psychcentral.com/news/2011/10/18/aggressive-drivers-identify-with-their-car/30443.html.

Qi, Y., Chen, X., Yang, L., Wang, B. and Yu, L. (2009). Vehicle Infrastructure Integration (VII) Based Road-Condition Warning System for Highway Collision Prevention. *Research Report SWUTC*/09/476660-00043-1

Qiao, F., Yu, L., Zhang, R., Chen, Z., and Fatholahzadeh, R. (2009), *RFID Applications in Transportation Operation and Intelligent Transportation Systems* (*ITS*), Texas Southern University, Research Report for the Southwest Region University Transportation Center (SWUTC), Report number: SWUTC/09/476660-00044-1, June 2009, (57 pages). http://swutc.tamu.edu/publications/technicalreports/476660-00044-1.pdf. Date accessed: June 8, 2014.

Qiao, F., Jia, J. Yu, L. Li, Q. and Zai, D. (2014) Radio Frequency Identification-Based Drivers' Smart Assistance System to Enhance Safety and Reduce Emissions in Work Zone. Publication in Transportation Research Record*: Journal of Transportation Research Board series*, Washington, DC, January 12-16, 2014. In print

Qiao, F., Jia, J., & Yu, L.(2013b). RFID based road assisting application in traffic lights safety improvement. *Proceedings of the 13th World Conference on Transport Research (WCTR)*, Rio Grado, Brazil, July 15-18, 2013.

Qiao, F., Korzhova, P., and Yu, L. (2012a). Testing Drivers' Understanding of Pricing Signs Using Driving Simulator. *Presentation and publication in proceedings of the 91st TRB Annual Meeting*, Washington DC, January 22-26, 2012. TRB 12-0438

Qiao, F., Liu, X. and Yu, L. (2007a). Using Driving Simulator for Advance Placement of Guide Sign Design for Exits along Highways, *Proceedings of the Driving Simulator Conference (DSC) 2007 North America in Iowa City*, Iowa, September 12-14, 2007.

Qiao, F., Q. Li, and L. Yu. (2014). Testing Impacts of Work Zone X2V Communication System on Safety and Air Quality in Driving Simulator, Proceedings of *the 21st ITS World Congress, Detroit, USA*, September 7-11, 2014. Pp. TS64.

Qiao, F., R. Rahman, Q. Li, and L. Yu. (2016a) Identifying demographical effects on speed patterns in work zones using smartphone based audio warning message system. *Journal of Ergonomics*. 6: 153. doi:10.4172/2165-7556.1000153.

Qiao, F., Rahman, R., Q. Li, and L. Yu. (2016). Identifying Suitable Warning Message from Smartphone App to Enhance Safety around Work Zone Activity Area. *Proceedings of the 2016 World Conference on Transport Research*, July 10-16, 2016. Shanghai, China.

Qiao, F., Wang, H., Liu, X. and Yu, L. (2007b). Using Driving Simulator for Logo and Symbol Design at Interchanges for Major Traffic Generator, *Proceedings of the Driving Simulator Conference (DSC) 2007 North America in Iowa City*, Iowa, September 12-14, 2007.

Qiao, F., Wang, J., Wang, X., Jia, J. and Yu, L. (2012b). A RFID Based e-STOP Sign and Its Impacts to Vehicle Emissions. Presented and Published in *Proceedings of The 15th International IEEE Conference on Intelligent Transportation Systems – ITSC 2012*. Anchorage, Alaska, USA. September 16-19, 2012.

Qiao, F., Wang, X., Qiao, Y., and Yu, L. (2013c). Developing Wireless Warning System To Enhance The Workers Safety In Work Zone Area. *Proceedings of the 13th World Conference on Transport Research (WCTR)*, Rio Grado, Brazil, July 15-18, 2013.

Qiao, F., Wang, X., Yu, L. and Jia, J. (2013a). Using RFID to Improve Drivers Awareness of STOP Sign at Unsignalized Intersections. Publication in *the proceedings of the 92nd Transportation Research Board Annual Meeting, Transportation Research Board of the National Academies*, Washington, DC, Jan 2013.

Rahman, R., F. Qiao, Q. Li, L. Yu, and P.-H. Kuo (2015). Smart Phone Based Forward Collision Warning Message in Work Zones to Enhance Safety and Reduce Emissions. Proceedings of the *94th Transportation Research Board Annual Meeting*, National Academy of Sciences, Washington, DC, January 11-15, 2015.

Ranney, T.A., Simmons, L.A., & Masalonis, A.J. (1999b). The immediate effects of glare and electrochromic glare-reducing mirrors in simulated truck driving. *Human Factors* (in press)

Richards, A., McDonald, M., Fisher, G., Brackstone, M. (2004). Investigation of Driver Comprehension of Traffic Information on Graphical Congestion Display Panels using a Driving Simulator. *European Journal of Transport and Infrastructure Research*, 4 (2004), pp. 417–435

Salthouse. T.A. (2000). Aging and measures of processing speed. *Biological Psychology*, 54, 35-54.

Schultz, G. G., and E. Talbot. (2009). Advance Warning Signals: Long-term Monitoring Results. In *Transportation Research Record: Journal of the Transportation Research Board, Transportation Research Board of the National Academies*, Washington, DC, in press.

Singh, H., Kumar, K., Kaur, H. (2012). Intelligent Traffic Lights Based on RFID. *International Journal of Computing & Business Research*, Proceedings of I- Society.

Starr, Cecie. (2005). *Biology: Concepts and Applications*. Thomson Brooks/cole, ISBN 0-534-46226-X.

Toledo, T., D. Zohar. (2007). Modeling the duration of lane changes. In *Proceedings of the 2007 Annual Meeting*. CD-ROM. Transportation Research Board, Washington, D.C., January 2007.

U.S. Department of Transportation (USDOT) (2013, October 22). *2009 Edition Chapter 4D. Traffic Control Signal Features.* Retrieved from the Department of Transportation Website: http://mutcd.fhwa.dot.gov/htm/2009/part4/part4d.htm.

Underwood, G., Chapman, P., Brocklehurst, N., Underwood, J., & Crundall, D. (2003). Visual attention while driving: sequences of eye fixations made by experienced and novice drivers. *Ergonomics,* 46(6), 629-646

Underwood, G., Grundall, D., & Chapman. P. (2011). Driving simulator validation with hazard perception. *Transportation Research Part F*, 14, 435-446.

Upchurch, J., Fisher, D. L., Carpenter, C., Dutta, A. (2002) Freeway Guide Sign Design for the Central Artery Tunnel Using a Driving Simulator. *Transportation Research*

Board Annual Meeting CD-ROM (Committee A3A02 - Traffic Control Devices), *TRB, National Research Council*, Washington, D.C.

Upchurch, J., Fisher, D. L., Waraich, B. (2005). Guide Signing for Two-Lane Exits with an Option Lane: A Human Factors Evaluation. *Transportation Research Board Annual Meeting CD-ROM, TRB, National Research Council*, Washington, D.C.

Van Valkenburg, M. E. (2008). *Network Analysis* (*3rd edition ed.*). ISBN 0-13-611095-9. Retrieved 2008-06-22.

Verhaeghen, P., Steitz, D.W., Sliwinski, M. J., & Cerella. J. (2003). Aging and dual-task performance: A metal-analysis. *Psychology and Aging*, 18, 443-460.

Waldron, K. (2013). *Sun Glare Can be Deadly for Drivers*. Retrieved from the New Jersey 101.5 website: http://nj1015.com/sun-glare-can-be-deadly-for-drivers/.